AN-2011 LM3423 Boost 2 Layer Evaluation Board

1 Introduction

This evaluation board showcases the LM3423 NFET controller used with a boost current regulator. It is designed to drive 9 to 12 LEDs at a maximum average LED current of 700mA from a DC input voltage of 10 to 26V.

The evaluation board showcases most features of the LM3423 including PWM dimming, overvoltage protection and input under-voltage lockout. It also has a connector footprint (J7) which can mate with an external LED load board allowing for the LEDs to be mounted close to the driver. Alternatively, the LED+ and LED- banana jacks can be used to connect the LED load.

The boost circuit can be easily redesigned for different specifications by changing only a few components (see the Alternate Designs section found at the end of this application note). Note that design modifications can change the system efficiency. See the *LM3421/21Q1/21Q0 LM3423/23Q1/23Q0 N-Ch Controllers for Constant Current LED Drivers* (SNVS574) data sheet for a comprehensive explanation of the device and application information.

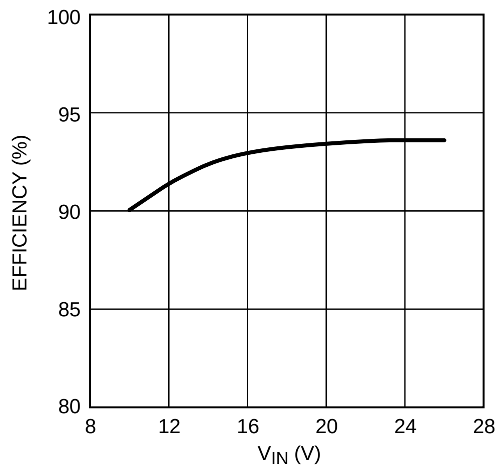

Figure 1. Efficiency with 9 Series LEDS AT 700mA

2 Schematic

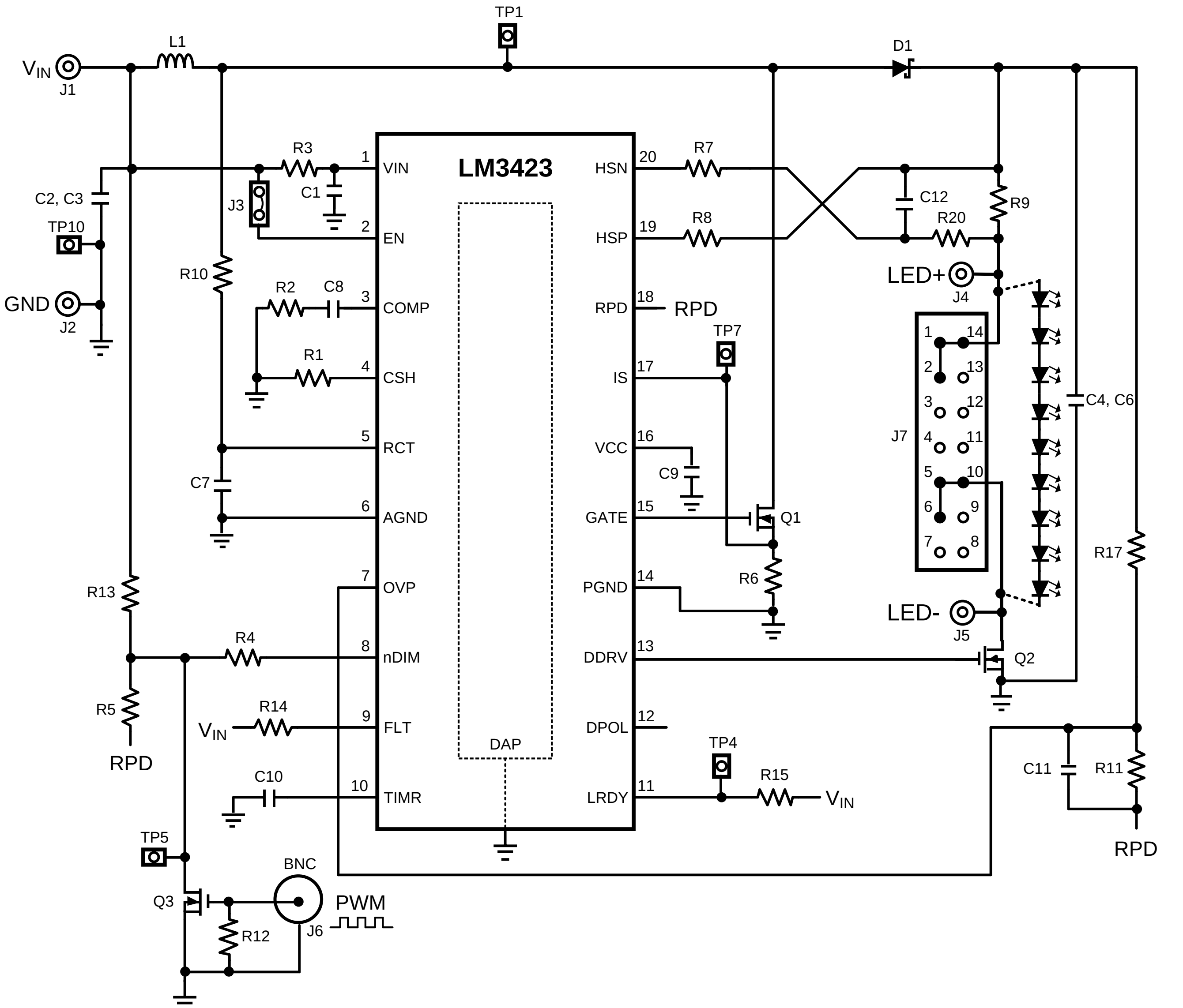

Figure 2. Board Schematic

3 Pin Descriptions

LM3423	LM3421	Name	Description	Function
1	1	V_{IN}	Input Voltage	Bypass with 100 nF capacitor to AGND as close to the device as possible in the circuit board layout.
2	2	EN	Enable	Connect to AGND for zero current shutdown or apply > 2.4V to enable device.
3	3	COMP	Compensation	Connect a capacitor to AGND to set the compensation.
4	4	CSH	Current Sense High	Connect a resistor to AGND to set the signal current. For analog dimming, connect a controlled current source or a potentiometer to AGND as detailed in the *Analog Dimming* section.
5	5	RCT	Resistor Capacitor Timing	External RC network sets the predictive “off-time” and thus the switching frequency.
6	6	AGND	Analog Ground	Connect to PGND through the DAP copper pad to provide ground return for CSH, COMP, RCT, and TIMR.
7	7	OVP	Over-Voltage Protection	Connect to a resistor divider from V_O to program output over-voltage lockout (OVLO). Turn-off threshold is 1.24V and hysteresis for turn-on is provided by 23 µA current source.
8	8	nDIM	Dimming Input / Under-Voltage Protection	Connect a PWM signal for dimming as detailed in the *PWM Dimming* section and/or a resistor divider from V_{IN} to program input under-voltage lockout (UVLO). Turn-on threshold is 1.24V and hysteresis for turn-off is provided by 23 µA current source.
9	-	FLT	Fault Flag	Connect to pull-up resistor from VIN and N-channel MosFET open drain output is high when a fault condition is latched by the timer.
10	-	TIMR	Fault Timer	Connect a capacitor to AGND to set the time delay before a sensed fault condition is latched.
11	-	LRDY	LED Ready Flag	Connect to pull-up resistor from VIN and N-channel MosFET open drain output pulls down when the LED current is not in regulation.
12	-	DPOL	Dim Polarity	Connect to AGND if dimming with a series P-channel MosFET or leave open when dimming with series N-channel MosFET.
13	9	DDRV	Dim Gate Drive Output	Connect to the gate of the dimming MosFET.
14	10	PGND	Power Ground	Connect to AGND through the DAP copper pad to provide ground return for GATE and DDRV.
15	11	GATE	Main Gate Drive Output	Connect to the gate of the main switching MosFET.
16	12	V_{CC}	Internal Regulator Output	Bypass with 2.2 µF–3.3 µF ceramic capacitor to PGND.
17	13	IS	Main Switch Current Sense	Connect to the drain of the main N-channel MosFET switch for R_{DS-ON} sensing or to a sense resistor installed in the source of the same device.
18	14	RPD	Resistor Pull Down	Connect the low side of all external resistor dividers (V_{IN} UVLO, OVP) to implement “zero-current” shutdown.
19	15	HSP	LED Current Sense Positive	Connect through a series resistor to the positive side of the LED current sense resistor.
20	16	HSN	LED Current Sense Negative	Connect through a series resistor to the negative side of the LED current sense resistor.
DAP (21)	DAP (17)	DAP	Thermal PAD on bottom of IC	Star ground, connecting AGND and PGND.

4 Bill of Materials

Qty	Part ID	Part Value	Manufacturer	Part Number
2	C1, C12	0.1 µF X7R 10% 50V	TDK	C1608X5R1H104K
2	C2, C8	1.0 µF X7R 10% 50V	MURATA	GRM21BR71H105KA12L KA01L
1	C3	100 µF 20% 50V	PANASONIC	EEV-FK1H101GP
1	C4	0.1 µF X7R 10% 100V	TDK	C2012X7R2A104M
1	C5	DNP		
4	C6	10 µF X7R 10% 50V (4 installed for a total of 40 µF)	TDK	C5750X7R1H106
1	C7	1000 pF X5R 5% 100V	MURATA	C2012X5R2E102K
1	C9	2.2 µF X7R 10% 16V	MURATA	GRM21BR71C225KA01L
1	C10	10 nF X7R 10% 50V	PANASONIC	ECJ2VB1H103 KA12L
1	C11	47 pF COG/NPO 5% 50V	PANASONIC	ECJ2VG1H470 KA01L
1	D1	Schottky 100V 7A	VISHAY	6CWQ10FNPBF
4	J1, J2, J4, J5	banana jack	KEYSTONE	575-8
1	J3	1x2 male header (with shunt tab)	SAMTEC	TSW-102-07-T-S
1	J6	BNC connector	AMPHENOL	112536
1	J7	DNP		
1	L1	22 µH 20% 6.3A	COILCRAFT	DO5040H
2	Q1, Q2	NMOS 100V 40A	VISHAY	SUD40N10-25
1	Q3	NMOS 60V 260 mA	ON-SEMI	2N7002ET1G
2	R1, R11	12.4 kΩ 1%	VISHAY	CRCW080512k4FKEA
1	R2	0Ω 1%	VISHAY	CRCW08050000Z0EA
2	R3, R20	10Ω 1%	VISHAY	CRCW080510R0FKEA
1	R4	5.76 kΩ 1%	VISHAY	CRCW08055k76FKEA
1	R5	14.0 kΩ 1%	VISHAY	CRCW080514k0FKEA
2	R7, R8	1.40 kΩ 1%	VISHAY	CRCW08051k40FKEA
1	R6	0.06Ω 1% 1W	VISHAY	WSL2512R0600FEA
1	R9	0.2Ω 1% 1W	PANASONIC	ERJ12RSFR20U
1	R10	35.7 kΩ 1%	VISHAY	CRCW080535k7FKEA
1	R12	10.0 kΩ 1%	VISHAY	CRCW080510k0FKEA
3	R13, R14, R15	100 kΩ 1%	VISHAY	CRCW0805100kFKEA
2	R16, R21	DNP		
1	R17	432 kΩ 1%	VISHAY	CRCW0805432kFKEA
5	TP1, TP4, TP5, TP7, TP10	turret	KEYSTONE	1502-2
1	U1	Buck-boost controller	TI	LM3423

5 PCB Layout

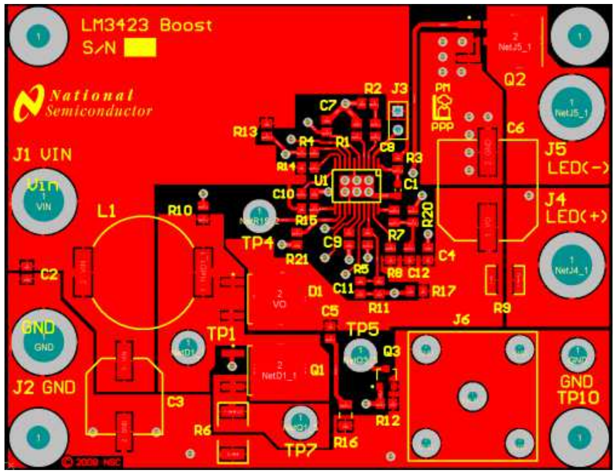

Figure 3. Top Layer

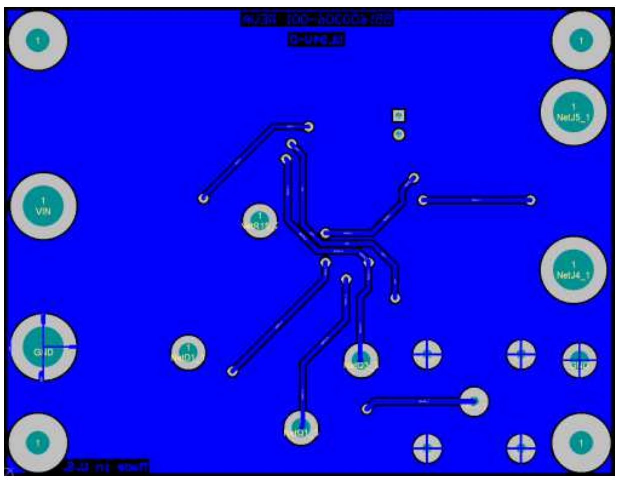

Figure 4. Bottom Layer

6 Design Procedure

Refer to *LM3421/21Q1/21Q0 LM3423/23Q1/23Q0 N-Ch Controllers for Constant Current LED Drivers* (SNVS574) for design considerations.

6.1 Specifications

N = 9

V_{LED} = 3.5V

r_{LED} = 325 mΩ

V_{IN} = 24V

V_{IN-MIN} = 10V; V_{IN-MAX} = 26V

f_{SW} = 700 kHz

V_{SNS} = 150 mV

I_{LED} = 700mA

Δi_{L-PP} = 350 mA

Δi_{LED-PP} = 25 mA

Δv_{IN-PP} = 100 mV

I_{LIM} = 4A

$V_{TURN-ON}$ = 10V; V_{HYS} = 3V

$V_{TURN-OFF}$ = 44V; V_{HYSO} = 10V

6.2 Operating Point

Solve for V_O and r_D:

$$V_O = N \times V_{LED} = 9 \times 3.5V = 31.5V \quad (1)$$

$$r_D = N \times r_{LED} = 9 \times 325\ m\Omega = 2.925\Omega \quad (2)$$

Solve for D, D', D_{MAX}, and D_{MIN}:

$$D = \frac{V_O - V_{IN}}{V_O} = \frac{31.5V - 24V}{31.5V} = 0.238 \quad (3)$$

$$D' = 1 - D = 1 - 0.238 = 0.762 \quad (4)$$

$$D_{MIN} = \frac{V_O - V_{IN-MAX}}{V_O} = \frac{31.5V - 26V}{31.5V} = 0.175 \quad (5)$$

$$D_{MAX} = \frac{V_O - V_{IN-MIN}}{V_O} = \frac{31.5V - 10V}{31.5V} = 0.683 \quad (6)$$

6.3 Switching Frequency

Assume C7 = 1 nF and solve for R10:

$$R10 = \frac{25}{f_{SW} \times C7} = \frac{25}{700\ kHz \times 1\ nF} = 35.7\ k\Omega \quad (7)$$

The closest standard resistor is actually 35.7 kΩ therefore the f_{SW} is:

$$f_{SW} = \frac{25}{R10 \times C7} = \frac{25}{35.7\ k\Omega \times 1\ nF} = 700\ kHz \quad (8)$$

The chosen components from step 2 are:

$$\boxed{\begin{array}{l} C7 = 1\ nF \\ R10 = 35.7\ k\Omega \end{array}} \quad (9)$$

6.4 Average LED Current

Solve for R9:

$$R9 = \frac{V_{SNS}}{I_{LED}} = \frac{150\ mV}{700\ mA} = 0.214\Omega \quad (10)$$

Assume R1 = 12.4 kΩ and solve for R8:

$$R8 = \frac{I_{LED} \times R1 \times R9}{1.24V} = \frac{700\ mA \times 12.4\ k\Omega \times 0.2\Omega}{1.24V} = 1.4\ k\Omega \quad (11)$$

The closest standard resistor for R9 is 0.2Ω and the closest for R8 (and R7) is actually 1.4 kΩ therefore I_{LED} is:

$$I_{LED} = \frac{1.24V \times R8}{R9 \times R1} = \frac{1.24V \times 1.4\ k\Omega}{0.2\Omega \times 12.4\ k\Omega} = 700\ mA \quad (12)$$

The chosen components from step 3 are:

$$\boxed{\begin{array}{l} R9 = 0.2\Omega \\ R1 = 12.4\ k\Omega \\ R8 = R7 = 1.4\ k\Omega \end{array}} \tag{13}$$

6.5 Inductor Ripple Current

Solve for L1:

$$L1 = \frac{V_{IN} \times D}{\Delta i_{L\text{-}PP} \times f_{SW}} = \frac{24V \times 0.238}{350\ mA \times 700\ kHz} = 23.3\ \mu H \tag{14}$$

The closest standard inductor is 22 µH therefore the actual $\Delta i_{L\text{-}PP}$ is:

$$\Delta i_{L\text{-}PP} = \frac{V_{IN} \times D}{L1 \times f_{SW}} = \frac{24V \times 0.238}{22\ \mu H \times 700\ kHz} = 371\ mA \tag{15}$$

Determine minimum allowable RMS current rating:

$$I_{L\text{-}RMS} = \frac{I_{LED}}{D'} \times \sqrt{1 + \frac{1}{12} \times \left(\frac{\Delta i_{L\text{-}PP} \times D'}{I_{LED}}\right)^2}$$

$$I_{L\text{-}RMS} = \frac{700\ mA}{0.762} \times \sqrt{1 + \frac{1}{12} \times \left(\frac{371\ mA \times 0.762}{700mA}\right)^2}$$

$$I_{L\text{-}RMS} = 925\ mA \tag{16}$$

The chosen component from step 4 is:

$$\boxed{L1 = 22\ \mu H} \tag{17}$$

6.6 Output Capacitance

Solve for C_O:

$$C_O = \frac{I_{LED} \times D}{r_D \times \Delta i_{LED\text{-}PP} \times f_{SW}}$$

$$C_O = \frac{700mA \times 0.238}{2.925\Omega \times 25\ mA \times 700\ kHz} = 3.25\ \mu F \tag{18}$$

A total value of 40 µF (using 4 10 µF ceramic capacitors) is chosen to improve PWM dimming response therefore the actual $\Delta i_{LED\text{-}PP}$ is:

$$\Delta i_{LED\text{-}PP} = \frac{I_{LED} \times D}{r_D \times C_O \times f_{SW}}$$

$$\Delta i_{LED\text{-}PP} = \frac{700\ mA \times 0.238}{2.925\Omega \times 40\ \mu F \times 700\ kHz} = 2\ mA \tag{19}$$

Determine minimum allowable RMS current rating:

$$I_{CO\text{-}RMS} = I_{LED} \times \sqrt{\frac{D_{MAX}}{1 - D_{MAX}}} = 700\ mA \times \sqrt{\frac{0.683}{1 - 0.683}} = 1.03A \tag{20}$$

The chosen components from step 5 are:

$$\boxed{C6 = 4 \times 10\ \mu F} \tag{21}$$

6.7 Peak Current Limit

Solve for R6:

$$R6 = \frac{245\ mV}{I_{LIM}} = \frac{245\ mV}{4A} = 0.061\Omega \tag{22}$$

The closest standard resistor is 0.06 Ω therefore I_{LIM} is:

$$I_{LIM} = \frac{245\ mV}{R6} = \frac{245\ mV}{0.06\Omega} = 4.1A \quad (23)$$

The chosen component from step 6 is:

$$\boxed{R6 = 0.06\Omega} \quad (24)$$

6.8 Loop Compensation

ω_{P1} is approximated:

$$\omega_{P1} = \frac{2}{r_D \times C_O} = \frac{2}{2.925\Omega \times 40\mu F} = 17k\frac{rad}{sec} \quad (25)$$

ω_{Z1} is approximated:

$$\omega_{Z1} = \frac{r_D \times D'^2}{L1} = \frac{2.925\Omega \times 0.762^2}{22\ \mu H} = 77k\frac{rad}{sec} \quad (26)$$

T_{U0} is approximated:

$$T_{U0} = \frac{D' \times 310V}{I_{LED} \times R_{LIM}} = \frac{0.762 \times 310V}{700mA \times 0.06\Omega} = 5620 \quad (27)$$

To ensure stability, calculate ω_{P2}:

$$\omega_{P2} = \frac{\min(\omega_{P1}, \omega_{Z1})}{5 \times T_{U0}} = \frac{\omega_{P1}}{5 \times 5620} = \frac{17k\frac{rad}{sec}}{5 \times 5620} = 0.60\ \frac{rad}{sec} \quad (28)$$

Solve for C8:

$$C8 = \frac{1}{\omega_{P2} \times 5e^6\Omega} = \frac{1}{0.60\ \frac{rad}{sec} \times 5e^6\Omega} = 0.33\mu F \quad (29)$$

To attenuate switching noise, calculate ω_{P3}:

$$\omega_{P3} = \max(\omega_{P1}, \omega_{Z1}) \times 10 = \omega_{Z1} \times 10$$

$$\omega_{P3} = 77\,k\frac{rad}{sec} \times 10 = 770\ k\ \frac{rad}{sec} \quad (30)$$

Assume R20 = 10Ω and solve for C12:

$$C12 = \frac{1}{10\Omega \times \omega_{P3}} = \frac{1}{10\Omega \times 770\,k\frac{rad}{sec}} = 0.130\mu F \quad (31)$$

Since PWM dimming can be evaluated with this board, a much larger compensation capacitor C8 = 1.0 µF is chosen and a smaller high frequency capacitor C12 = 0.1 µF is chosen.

The chosen components from step 7 are:

$$\boxed{\begin{array}{l} C8 = 1.0\ \mu F \\ R20 = 10\Omega \\ C12 = 0.1\ \mu F \end{array}} \quad (32)$$

6.9 Input Capacitance

Solve for the minimum C_{IN}:

$$C_{IN} = \frac{\Delta i_{L-PP}}{8 \times \Delta v_{IN-PP} \times f_{SW}} = \frac{371\ \text{mA}}{8 \times 100\ \text{mV} \times 700\ \text{kHz}} = 0.66\ \mu\text{F} \tag{33}$$

To minimize power supply interaction a much larger capacitance of 100 µF is used, therefore the actual Δv_{IN-PP} is much lower.

Determine minimum allowable RMS current rating:

$$I_{IN-RMS} = \frac{\Delta i_{L-PP}}{\sqrt{12}} = \frac{371\ \text{mA}}{\sqrt{12}} = 107\ \text{mA} \tag{34}$$

The chosen components from step 8 are:

$$\boxed{C3 = 100\ \mu\text{F}} \tag{35}$$

6.10 NFET

Determine minimum Q1 voltage rating and current rating:

$$V_{T-MAX} = V_O = 31.5\text{V} \tag{36}$$

$$I_{T-MAX} = \frac{0.683}{1 - 0.683} \times 700\ \text{mA} = 1.5\text{A} \tag{37}$$

A 100V NFET is chosen with a current rating of 40A due to the low R_{DS-ON} = 50 mΩ. Determine I_{T-RMS} and P_T:

$$I_{T-RMS} = \frac{I_{LED}}{D'} \times \sqrt{D} = \frac{700\ \text{mA}}{0.762} \times \sqrt{0.238} = 448\ \text{mA} \tag{38}$$

$$P_T = I_{T-RMS}{}^2 \times R_{DSON} = 448\ \text{mA}^2 \times 50\ \text{m}\Omega = 10\ \text{mW} \tag{39}$$

The chosen component from step 9 is:

$$\boxed{Q1 \rightarrow 40\text{A, 100V, DPAK}} \tag{40}$$

6.11 DIODE

Determine minimum D1 voltage rating and current rating:

$$V_{RD-MAX} = V_O = 31.5\text{V} \tag{41}$$

$$I_{D-MAX} = I_{LED} = 700\ \text{mA} \tag{42}$$

A 100V diode is chosen with a current rating of 12A and V_D = 600 mV. Determine P_D:

$$P_D = I_D \times V_{FD} = 700\ \text{mA} \times 600\ \text{mV} = 420\ \text{mW} \tag{43}$$

The chosen component from step 10 is:

$$\boxed{D1 \rightarrow 12\text{A, 100V, DPAK}} \tag{44}$$

6.12 Input UVLO

Since PWM dimming will be evaluated a three resistor network will be used. Assume R13 = 100 kΩ and solve for R5:

$$R5 = \frac{1.24V \times R13}{V_{TURN\text{-}ON} - 1.24V} = \frac{1.24V \times 100\ k\Omega}{10V - 1.24V} = 14.2\ k\Omega \tag{45}$$

The closest standard resistor is 14 kΩ therefore $V_{TURN\text{-}ON}$ is:

$$V_{TURN\text{-}ON} = \frac{1.24V \times (R5 + R13)}{R5}$$

$$V_{TURN\text{-}ON} = \frac{1.24V \times (14\ k\Omega + 100\ k\Omega)}{14\ k\Omega} = 10.1V \tag{46}$$

Solve for R4:

$$R4 = \frac{R5 \times (V_{HYS} - 23\ \mu A \times R13)}{23\ \mu A \times (R5 + R13)}$$

$$R4 = \frac{14\ k\Omega \times (3.4V - 23\ \mu A \times 100\ k\Omega)}{23\ \mu A \times (14\ k\Omega + 100\ k\Omega)} = 5.87\ k\Omega \tag{47}$$

The closest standard resistor is 5.76 kΩ making V_{HYS}:

$$V_{HYS} = \frac{23\ \mu A \times R4 \times (R5 + R13)}{R5} + 23\ \mu A \times R13$$

$$V_{HYS} = \frac{23\ \mu A \times 5.76\ k\Omega \times (14\ k\Omega + 100\ k\Omega)}{14\ k\Omega} + 23\ \mu A \times 100\ k\Omega = 3.4V \tag{48}$$

The chosen components from step 11 are:

$$\boxed{\begin{array}{l} R5 = 14\ k\Omega \\ R13 = 100\ k\Omega \\ R4 = 5.76\ k\Omega \end{array}} \tag{49}$$

6.13 Output OVLO

Solve for R17:

$$R18 = \frac{V_{HYSO}}{23\ \mu A} = \frac{10V}{23\ \mu A} = 435\ k\Omega \tag{50}$$

The closest standard resistor is 432 kΩ therefore V_{HYSO} is:

$$V_{HYSO} = R18 \times 23\ \mu A = 432\ k\Omega \times 23\ \mu A = 9.9V \tag{51}$$

Solve for R11:

$$R11 = \frac{1.24V \times R18}{V_{TURN\text{-}OFF} - 1.24V} = \frac{1.24V \times 432\ k\Omega}{44V - 1.24V} = 12.5\ k\Omega \tag{52}$$

The closest standard resistor is 12.4 kΩ making $V_{TURN\text{-}OFF}$:

$$V_{TURN\text{-}OFF} = \frac{1.24V \times (R11 + R18)}{R11}$$

$$V_{TURN\text{-}OFF} = \frac{1.24V \times (12.4\ k\Omega + 432\ k\Omega)}{12.4\ k\Omega} = 44V \tag{53}$$

The chosen components from step 12 are:

$$\boxed{\begin{array}{l} R11 = 12.4\ k\Omega \\ R18 = 432\ k\Omega \end{array}} \tag{54}$$

6.14 PWM Dimming

The LM3423 Boost Evaluation board is configured to demonstrate PWM dimming of the LEDs. For best operation, use a PWM signal that has greater than 3V amplitude at a frequency between 120Hz and 25kHz. Apply the PWM signal to the BNC connector (J6) and the inverted signal (seen by the nDIM pin) can be monitored at TP5.

The output DDRV signal is connected directly to the series dimming FET (Q2) to open and close the LED load. Achievable contrast ratios are dependant on the dimming frequency and operating point. The minimum pulse width is limited by the internal delays of the LM3423 and the slew time of the LED current from zero to its nominal value. This can be several microseconds in duration.

Using the evaluation board (24V input, 31.5V output), at 25kHz dimming frequency the best case contrast ratio is approximately 20:1, but at 200Hz the same system is more like 2500:1 ratio. In general, contrast ratios much above 4000:1 are not possible for any operating point using the LM3423 boost evaluation board.

6.15 Fault and LED Current Monitoring

The LM3423 has a fault detection flag in the form of an open-drain NFET at the FLT pin. Using the external pull-up resistor (R14) to VIN, the fault status can be monitored at the FLT pin (high = fault). The fault timer interval is set with the capacitor (C10) from TIMR to GND (10nF yields roughly 1ms). If a fault is detected that exceeds the programmed timer interval, such as an output over-voltage condition, the FLT pin transitions from high to low and internally GATE and DDRV are latched off. To reset the device once the fault is removed, either the input power must be cycled or the EN pin must be toggled.

This can be tested directly with the evaluation board by opening the LED load. An OVP fault will occur which disables GATE and DDRV. Then if the LEDs are reconnected, the EN pin jumper (J3) can be removed and reinserted to restart normal operation of the LM3423.

The LED status flag (LRDY) can be seen by monitoring TP4. LRDY is also an open-drain NFET connection which has an external pull-up resistor (R15) to V_{IN}. If the LED current is in regulation the voltage at TP4 will be high, but when it falls out of regulation the NFET turns on and pulls TP4 low. The LM3423 datasheet lists all of the conditions that affect LRDY, FLT, and TIMR.

7 Typical Waveforms

T_A = +25°C, V_{IN} = 24V and V_O = 31.5V.

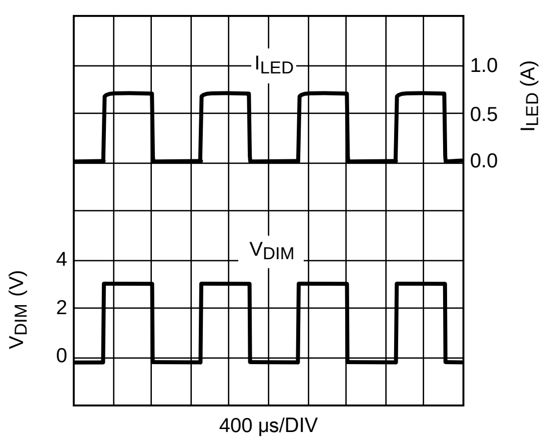

Figure 5. 1kHz 50% PWM DIMMING
TP5 dim voltage (V_{DIM})
LED current (I_{LED})

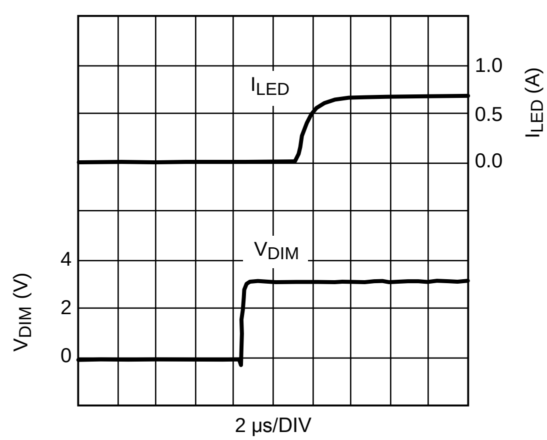

Figure 6. 1kHz 50% PWM DIMMING (Rising Edge)
TP5 dim voltage (V_{DIM})
LED current (I_{LED})

8 Alternate Designs

Alternate designs with the LM3423 evaluation board are possible with very few changes to the existing hardware. The evaluation board FETs and diodes are already rated higher than necessary for design flexibility. The input UVLO, output OVP, input and output capacitance can remain the same for the designs shown below. These alternate designs can be evaluated by changing only R9, R10, and L1.

Table 1 gives the main specifications for four different designs and the corresponding values for R9, R10, and L1. PWM dimming can be evaluated with any of these designs.

Table 1. Alternate Designs Specification

Specification / Component	Design 1	Design 2	Design 3	Design 4
V_{IN}	10V	15V	20V	25V
V_O	14V	21V	28V	35V
f_{SW}	600kHz	700kHz	500kHz	700kHz
I_{LED}	2A	500mA	2.5A	1.25A
R9	0.05Ω	0.2Ω	0.04Ω	0.08Ω
R10	41.2 kΩ	35.7 kΩ	49.9 kΩ	35.7 kΩ
L1	22µH	68µH	15µH	33µH

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