AN-1969 LM3424 Boost Evaluation Board

1 Introduction

This evaluation board showcases the LM3424 NFET controller used with a boost current regulator. It is designed to drive 9 to 12 LEDs at a maximum average LED current of 1A from a DC input voltage of 10 to 26V.

The evaluation board showcases many of the LM3424 features including thermal foldback, analog dimming, external switching frequency synchronization, and high frequency PWM dimming, among others. There are many external connection points to facilitate the full evaluation of the LM3424 device including inputs, outputs and test points. Refer to Table 1 for a summary of the connectors and test points.

The boost circuit can be easily redesigned for different specifications by changing only a few components (see Alternate Designs). Note that design modifications can change the system efficiency for better or worse.

This application note is designed to be used in conjunction with the *LM3424 Constant Current N-Channel Controller with Thermal Foldback for Driving LEDs* (SNVS603) data sheet as a reference for the LM3424 boost evaluation board and for a comprehensive explanation of the device, design procedures, and application information.

2 Key Features

- Input: 10V to 26V
- Output: 9 to 12 LEDs at 1A
- Thermal Foldback / Analog Dimming
- PWM Dimming up to 30 kHz
- External Synchronization > 360 kHz
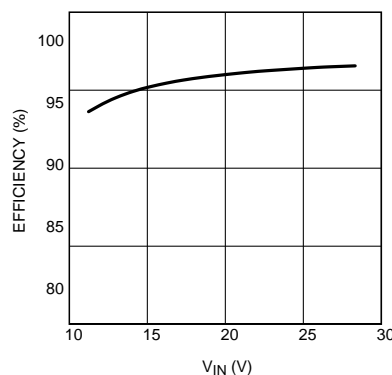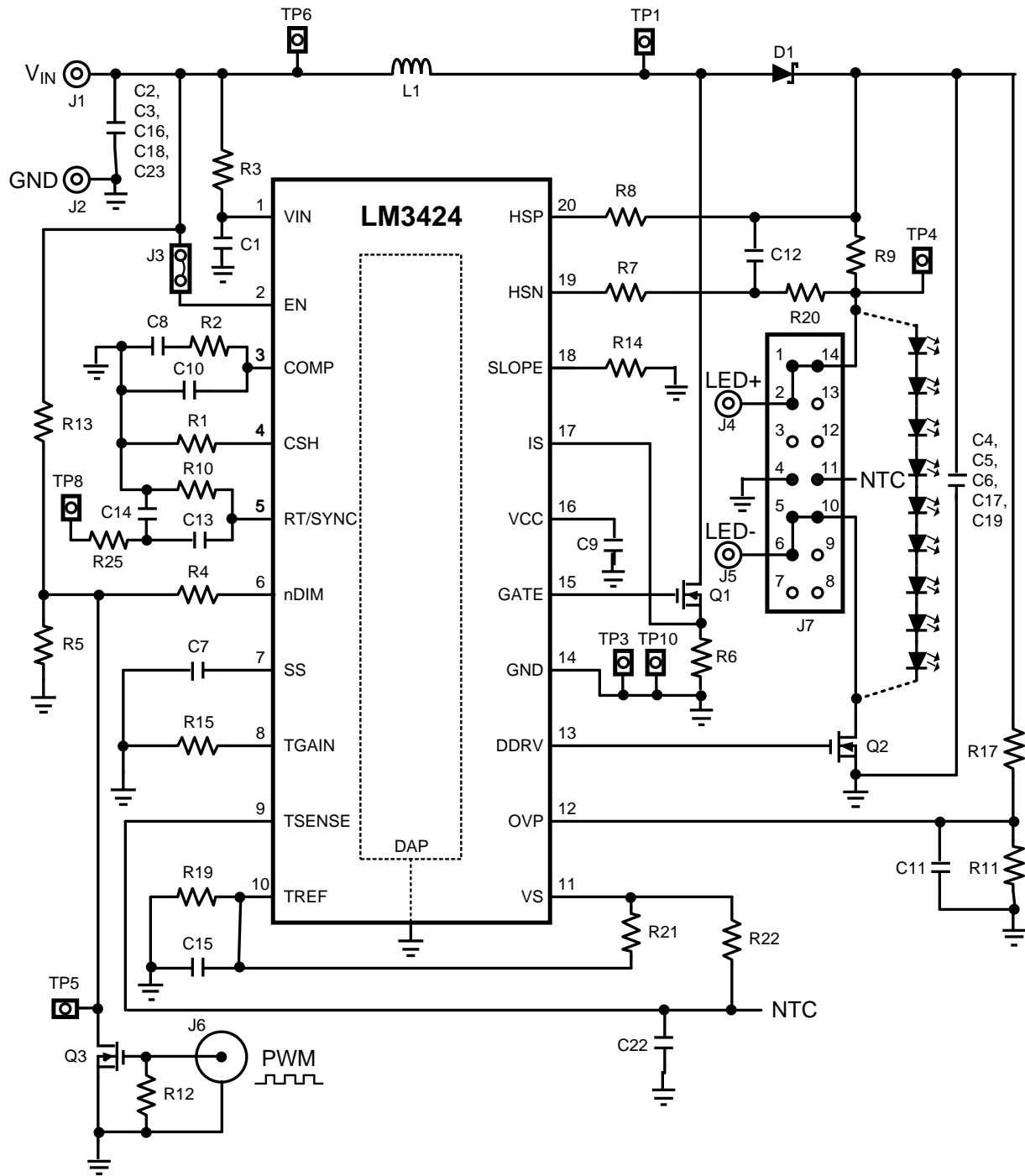- Input Under-voltage and Output Over-voltage Protection

Figure 1. Efficiency with 6 Series LEDS AT 1A

All trademarks are the property of their respective owners.

3   External Connection Descriptions

Table 1. Connectors and Test Points

Qty	Name	Description	Application Information
J1	V_{IN}	Input Voltage	Connect to positive terminal of supply voltage.
J2	GND	Input Ground	Connect to negative terminal of supply voltage (GND).
J3	EN	Enable On/Off	Jumper connected enables device.
J4	LED+	LED Positive	Connect to anode (top) of LED string.
J5	LED-	LED Negative	Connect to cathode (bottom) of LED string.
J6	BNC	Dimming Input	Connect a 3V to 10V PWM input signal up to 10 kHz for PWM dimming the LED load.
J7	OUT	Output with NTC	Alternative connector for LED+ and LED-. Pins 4 and 11 are used for connecting an external NTC thermistor. Refer to schematic for detailed connectivity.
TP1	SW	Switch Node Voltage	Test point for switch node (where Q1, D1, and L1 connect).
TP3	SGND	Signal Ground	Connection for GND when applying signals to TP5, TP8, and TP9.
TP4	LED+	LED Positive Voltage	Test point for anode (top) of LED string.
TP5	nDIM	Inverted Dim Signal	Test point for dimming input (inverted from input signal).
TP6	V_{IN}	Input Voltage	Test point for input voltage.
TP8	SYNC	Synchronization Input	Connect a 3V to 6V PWM clock signal > 500 kHz (pulse width of 100ns) to synchronize the LM3424 switching frequency to the external clock.
TP9	NTC	Temp Sense Input	Connect a 0V to 1.24V DC voltage to analog dim the LED current.
TP10	PGND	Power Ground	Test point for GND when monitoring TP1, TP4, or TP6.

4   Schematic

5   LM3424 Pin Descriptions

Pin	Name	Description	Application Information
1	V_{IN}	Input Voltage	Bypass with 100 nF capacitor to GND as close to the device as possible in the circuit board layout.
2	EN	Enable	Connect to > 2.4V to enable the device or to < 0.8V for low power shutdown.
3	COMP	Compensation	Connect a capacitor to GND to compensate control loop.
4	CSH	Current Sense High	Connect a resistor to GND to set the signal current. Can also be used to analog dim as explained in the *Thermal Foldback / Analog Dimming* section of the datasheet.
5	RT	Resistor Timing	Connect a resistor to GND to set the switching frequency. Can also be used to synchronize external clock as explained in the *Switching Frequency* section of the datasheet.
6	nDIM	Not DIM input	Connect a PWM signal for dimming as detailed in the *PWM Dimming* section of the datasheet 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 20 µA current source.
7	SS	Soft-start	Connect a capacitor to GND to extend start-up time.
8	TGAIN	Temperature Foldback Gain	Connect a resistor to GND to set the foldback slope.
9	TSENSE	Temperature Sense Input	Connect a resistor/ thermistor divider from V_S to sense the temperature as explained in the *Thermal Foldback / Analog Dimming* section of the datasheet.
10	TREF	Temperature Foldback Reference	Connect a resistor divider from V_S to set the temperature foldback reference voltage.
11	V_S	Voltage Reference	2.45V reference for temperature foldback circuit and other external circuitry.
12	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 20 µA current source.
13	DDRV	Dimming Gate Drive Output	Connect to gate of dimming MosFET.
14	GND	Ground	Connect to DAP to provide proper system GND
15	GATE	Gate Drive Output	Connect to gate of main switching MosFET.
16	V_{CC}	Internal Regulator Output	Bypass with a 2.2 µF–3.3 µF, ceramic capacitor to GND.
17	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	SLOPE	Slope Compensation	Connect a resistor to GND to set slope of additional ramp.
19	HSN	High-Side LED Current Sense Negative	Connect through a series resistor to the negative side of the LED current sense resistor.
20	HSP	High-Side LED Current Sense Positive	Connect through a series resistor to the positive side of the LED current sense resistor.
DAP (21)	DAP	Thermal pad on bottom of IC	Connect to GND and place 6 - 9 vias to bottom layer ground pour.

6   Bill of Materials

| Qty	Part ID	Part Value	Manufacturer	Part Number
3	C1, C5, C23	0.1 µF X7R 10% 100V	TDK	C2012X7R2A104K
4	C2, C3, C16, C18	6.8 µF X7R 10% 50V	TDK	C5750X7R1H685K
4	C4, C6, C17, C19	10 µF X7R 10% 50V	TDK	C5750X7R1H106K
2	C7, C22	0.47 µF X7R 10% 16V	MURATA	GRM21BR71C474KA01L
0	C8	DNP		
1	C9	2.2 µF X7R 10% 16V	MURATA	GRM21BR71C225KA12L
1	C10	1 µF X7R 10% 16V	MURATA	GRM21BR71C105KA01L
1	C11	47 pF COG/NPO 5% 50V	AVX	08055A470JAT2A
1	C12	0.22 µF X7R 10% 16V	MURATA	GRM219R71C224KA01D
2	C13, C14	100 pF COG/NPO 5% 50V	MURATA	GRM2165C1H101JA01D
1	C15	1 µF X7R 10% 16V	MURATA	GRM21BR71C105MA01L
1	D1	Schottky 100V 12A	VISHAY	12CWQ10FNPBF
4	J1, J2, J4, J5	Banana Jack	KEYSTONE	575-8
1	J3	1x2 Header Male	SAMTEC	TSW-102-07-T-S
1	J6	BNC connector	AMPHENOL	112536
1	J7	2x7 Header Male Shrouded RA	SAMTEC	TSSH-107-01-SDRA
1	L1	33 µH 20% 6.3A	COILCRAFT	MSS1278-333MLB
2	Q1, Q2	NMOS 100V 32A	FAIRCHILD	FDD3682
1	Q3	NMOS 60V 260mA	ON-SEMI	2N7002ET1G
2	R1, R11	12.4 kΩ 1%	VISHAY	CRCW080512K4FKEA
0	R2	DNP		
2	R3, R20	10Ω 1%	VISHAY	CRCW080510R0FKEA
1	R4	17.4 kΩ 1%	VISHAY	CRCW080517K4FKEA
1	R5	1.43 kΩ 1%	VISHAY	CRCW08051K43FKEA
1	R6	0.04Ω 1% 1W	VISHAY	WSL2512R0400FEA
2	R7, R8	1.0 kΩ 1%	VISHAY	CRCW08051K00FKEA
1	R9	0.1Ω 1% 1W	VISHAY	WSL2512R1000FEA
1	R10	20.0 kΩ 1%	VISHAY	CRCW080520K0FKEA
4	R12, R13, R14, R15	10.0 kΩ 1%	VISHAY	CRCW080510K0FKEA
1	R17	499 kΩ 1%	VISHAY	CRCW0805499KFKEA
3	R19, R21, R22	49.9 kΩ 1%	VISHAY	CRCW080549K9FKEA
1	R25	150Ω 1%	VISHAY	CRCW0805150RFKEA
8	TP1, TP3, TP4, TP5, TP6, TP8, TP9, TP10	Turret	Keystone	1502-2
1	U1	Boost controller	NSC	LM3424MH

7   PCB Layout
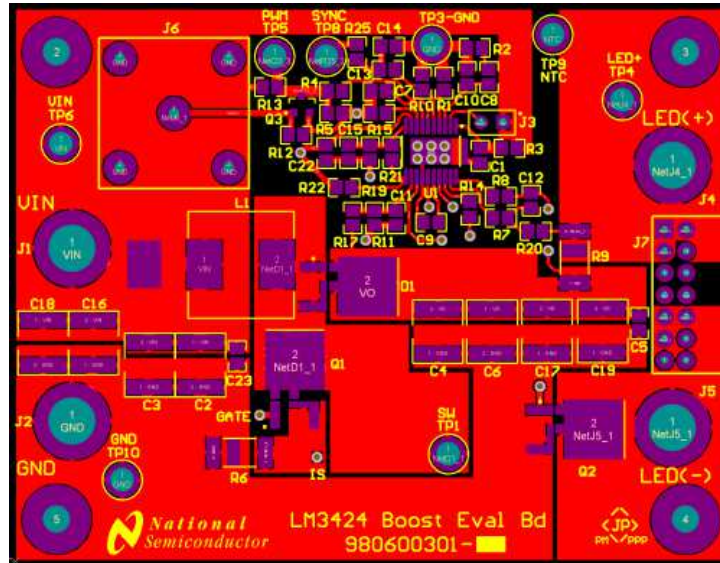
Figure 2. Top Layer

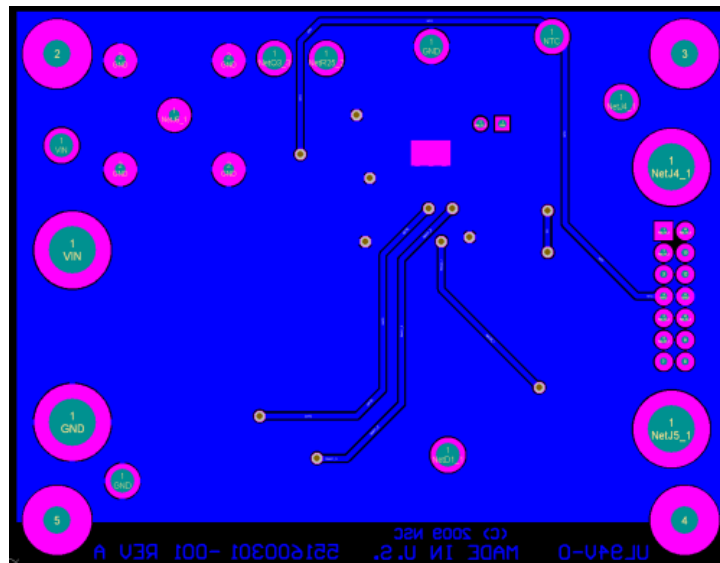**Figure 3. Bottom Layer**

8   Design Procedure

8.1   Specifications

N = 6

V_{LED} = 3.5V

r_{LED} = 325 mΩ

V_{IN} = 24V

V_{IN-MIN} = 10V

V_{IN-MAX} = 70V

f_{SW} = 500 kHz

V_{SNS} = 100 mV

I_{LED} = 1A

Δi_{L-PP} = 700 mA

Δi_{LED-PP} = 12 mA

Δv_{IN-PP} = 100 mV

I_{LIM} = 6A

$V_{TURN-ON}$ = 10V

V_{HYS} = 3V

$V_{TURN-OFF}$ = 40V

V_{HYSO} = 10V

T_{BK} = 70°C

T_{END}= 120°C

t_{TSU} = 30 ms

8.2   Operating Point

Solve for V_O and r_D:

$$V_O = N \times V_{LED} = 9 \times 3.5V = 31.5V \tag{1}$$

$$r_D = N \times r_{LED} = 9 \times 325 \, m\Omega = 2.925\Omega \tag{2}$$

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

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

$$D' = 1 - D = 1 - 0.238 = 0.762 \tag{4}$$

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

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

8.3   Switching Frequency

Solve for R_T:

$$R10 = \frac{1 + 1.95e^{-8} \times f_{SW}}{1.40e^{-10} \times f_{SW}} = \frac{1 + 1.95e^{-8} \times 360 \, kHz}{1.40e^{-10} \times 360 \, kHz} = 19.99 \, k\Omega \tag{7}$$

The closest standard resistor is 14.3 kΩ therefore f_{SW} is:

$$f_{SW} = \frac{1}{1.40e^{-10} \times R10 - 1.95e^{-8}}$$

$$f_{SW} = \frac{1}{1.40e^{-10} \times 20.0 \text{ k}\Omega - 1.95e^{-8}} = 360 \text{ kHz}$$

(8)

The chosen component from step 2 is:

$$\boxed{R10 = 20 \text{ k}\Omega}$$

(9)

8.4 *Average LED Current*

Solve for R_{SNS}:

$$R9 = \frac{V_{SNS}}{I_{LED}} = \frac{100 \text{ mV}}{1A} = 0.1\Omega$$

(10)

Assume R_{CSH} = 12.4 kΩ and solve for R_{HSP}:

$$R8 = \frac{I_{LED} \times R1 \times R9}{1.24V} = \frac{1A \times 1.24 \text{ k}\Omega \times 0.1\Omega}{1.24V} = 1.0 \text{ k}\Omega$$

(11)

The closest standard resistor for R_{SNS} is actually 0.1Ω and for R_{HSP} is actually 1 kΩ therefore I_{LED} is:

$$I_{LED} = \frac{1.24V \times R8}{R9 \times R1} = \frac{1.24V \times 1.0 \text{ k}\Omega}{0.1\Omega \times 1.24 \text{ k}\Omega} = 1.0A$$

(12)

The chosen components from step 3 are:

$$\boxed{\begin{aligned} R9 &= 0.1\Omega \\ R1 &= 12.4 \text{ k}\Omega \\ R8 &= R7 = 1 \text{ k}\Omega \end{aligned}}$$

(13)

8.5 *Thermal Foldback*

Using a standard 100k NTC thermistor (connected to pins 4 and ll), find the resistances corresponding to T_{BK} and T_{END} (R_{NTC-BK} = 243 kΩ and $R_{NTC-END}$ = 71.5 kΩ) from the manufacturer's datasheet. Assuming R_{REF1} = R_{REF2} = 49.9 kΩ, then $R_{BIAS} = R_{NTC-BK}$= 243 kΩ.

Solve for R_{GAIN}:

$$R_{GAIN} = \frac{\left(\dfrac{R_{REF1}}{R_{REF1} + R_{REF2}} - \dfrac{R_{NTC-END}}{R_{NTC-END} + R_{BIAS}} \right) \times 2.45V}{I_{CSH}}$$

$$R_{GAIN} = \frac{\left(\dfrac{1}{2} - \dfrac{71.5 \text{ k}\Omega}{71.5 \text{ k}\Omega + 243 \text{ k}\Omega} \right) \times 2.45V}{100 \text{ }\mu A} = 6.68 \text{ k}\Omega$$

(14)

The chosen components from step 4 are:

$$\boxed{\begin{aligned} R_{GAIN} &= 6.81 \text{ k}\Omega \\ R_{BIAS} &= 243 \text{ k}\Omega \\ R_{REF1} &= R_{REF2} = 49.9 \text{ k}\Omega \end{aligned}}$$

(15)

8.6 *Inductor Ripple Current*

Solve for L1:

$$L1 = \frac{V_{IN} \times D}{\Delta i_{L-PP} \times f_{SW}} = \frac{24V \times 0.238}{500 \text{ mA} \times 360 \text{ kHz}} = 31.7 \text{ }\mu H$$

(16)

The closest standard inductor is 33 µH therefore Δi_{L-PP} is:

$$\Delta i_{L-PP} = \frac{V_{IN} \times D}{L1 \times f_{SW}} = \frac{24V \times 0.238}{33\ \mu H \times 360\ kHz} = 481\ mA \tag{17}$$

Determine minimum allowable RMS current rating:

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

$$I_{L-RMS} = \frac{1A}{0.762} \times \sqrt{1 + \frac{1}{12} \times \left(\frac{481\ mA \times 0.762}{1A}\right)^2} = 1.32A \tag{18}$$

The chosen component from step 5 is:

$$\boxed{L1 = 33\ \mu H} \tag{19}$$

8.7 Output Capacitance

Solve for C_O:

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

$$C_O = \frac{1A \times 0.238}{2.925\Omega \times 6\ mA \times 360\ kHz} = 38\ \mu F \tag{20}$$

The closest capacitance totals 40 µF therefore Δi_{LED-PP} is:

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

$$\Delta i_{LED-PP} = \frac{1A \times 0.238}{2.925\Omega \times 40\ \mu F \times 360\ kHz} = 5.7\ mA \tag{21}$$

Determine minimum allowable RMS current rating:

$$I_{CO-RMS} = I_{LED} \times \sqrt{\frac{D_{MAX}}{1 - D_{MAX}}} = 1A \times \sqrt{\frac{0.683}{1 - 0.683}} = 1.47A \tag{22}$$

The chosen components from step 6 are:

$$\boxed{C4 = C6 = C17 = C19 = 10\ \mu F} \tag{23}$$

8.8 Peak Current Limit

Solve for R_{LIM}:

$$R6 = \frac{245\ mV}{I_{LIM}} = \frac{245\ mV}{6A} = 0.041\Omega \tag{24}$$

The closest standard resistor is 0.04 Ω therefore I_{LIM} is:

$$I_{LIM} = \frac{245\ mV}{R6} = \frac{245\ mV}{0.04\Omega} = 6.13A \tag{25}$$

The chosen component from step 7 is:

$$\boxed{R6 = 0.04\Omega} \tag{26}$$

8.9 Slope Compensation

Solve for R_{SLP}:

$$R_{SLP} = \frac{1.5e^{13} \times L1}{V_O \times R_T \times R_{SNS}}$$

$$R_{SLP} = \frac{1.5e^{13} \times 33\,\mu H}{21V \times 14.3\,k\Omega \times 0.1\Omega} = 16.5\,k\Omega \tag{27}$$

The chosen component from step 8 is:

$$\boxed{R_{SLP} = 16.5\,k\Omega} \tag{28}$$

8.10 Loop Compensation

ω_{P1} is approximated:

$$\omega_{P1} = \frac{2}{r_D \times C_O} = \frac{2}{2.925\Omega \times 40\,\mu F} = 17\,k\,\frac{rad}{sec} \tag{29}$$

ω_{Z1} is approximated:

$$\omega_{Z1} = \frac{r_D \times D'^2}{L1} = \frac{2.925\Omega \times 0.762^2}{33\,\mu H} = 52\,k\,\frac{rad}{sec} \tag{30}$$

T_{U0} is approximated:

$$T_{U0} = \frac{D' \times 310V}{I_{LED} \times R6} = \frac{0.762 \times 310V}{1A \times 0.04\Omega} = 5900 \tag{31}$$

To ensure stability, calculate ω_{P2}:

$$\omega_{P2} = \frac{\min(\omega_{P1}, \omega_{Z1})}{5 \times T_{U0}} = \frac{\omega_{P1}}{5 \times 5900} = \frac{17k\,\frac{rad}{sec}}{5 \times 5900} = 0.58\,\frac{rad}{sec} \tag{32}$$

Solve for C_{CMP}:

$$C10 = \frac{1}{\omega_{P2} \times 5e^6\Omega} = \frac{1}{0.58\,\frac{rad}{sec} \times 5e^6\Omega} = 0.35\,\mu F \tag{33}$$

To attenuate switching noise, calculate ω_{P3}:

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

$$\omega_{P3} = 52k\,\frac{rad}{sec} \times 10 = 520k\,\frac{rad}{sec} \tag{34}$$

Assume $R_{FS} = 10\Omega$ and solve for C_{FS}:

$$C12 = \frac{1}{10\Omega \times \omega_{P3}} = \frac{1}{10\Omega \times 520k\,\frac{rad}{sec}} = 0.19\,\mu F \tag{35}$$

The chosen components from step 9 are:

$$\boxed{\begin{array}{l} C10 = 1\,\mu F \\ R20 = 10\Omega \\ C12 = 0.22\,\mu F \end{array}} \tag{36}$$

8.11 Input Capacitance

Solve for the minimum C_{IN}:

$$C_{IN} = \frac{\Delta i_{L-PP}}{8 \times \Delta v_{IN-PP} \times f_{SW}} = \frac{481\,mA}{8 \times 50\,mV \times 360\,kHz} = 3.4\,\mu F \tag{37}$$

To minimize power supply interaction a 200% larger capacitance of approximately 20 µF is used, therefore the actual Δv_{IN-PP} is much lower. Since high voltage ceramic capacitor selection is limited, four 4.7 µF X7R capacitors are chosen.

Determine minimum allowable RMS current rating:

$$I_{IN\text{-}RMS} = \frac{\Delta i_{L\text{-}PP}}{\sqrt{12}} = \frac{481 \text{ mA}}{\sqrt{12}} = 139 \text{ mA}$$

(38)

The chosen components from step 10 are:

$$\boxed{C2 = C3 = C16 = C18 = 6.8 \text{ } \mu F}$$

(39)

8.12 NFET

Determine minimum Q1 voltage rating and current rating:

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

(40)

$$I_{T\text{-}MAX} = \frac{0.683}{1 - 0.683} \text{ x } 1A = 2.2A$$

(41)

A 100V NFET is chosen with a current rating of 32A due to the low $R_{DS\text{-}ON} = 50 \text{ m}\Omega$. Determine $I_{T\text{-}RMS}$ and P_T:

$$I_{T\text{-}RMS} = \frac{I_{LED}}{D'} \text{ x } \sqrt{D} = \frac{1A}{0.762} \text{ x } \sqrt{0.238} = 640 \text{ mA}$$

(42)

$$P_T = I_{T\text{-}RMS}^2 \text{ x } R_{DSON} = 640 \text{ mA}^2 \text{ x } 50 \text{ m}\Omega = 20 \text{ mW}$$

(43)

The chosen component from step 11 is:

$$\boxed{Q1 \rightarrow 32A, 100V, DPAK}$$

(44)

8.13 Diode

Determine minimum D1 voltage rating and current rating:

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

(45)

$$I_{D\text{-}MAX} = I_{LED} = 1A$$

(46)

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

$$P_D = I_D \text{ x } V_{FD} = 1A \text{ x } 600 \text{ mV} = 600 \text{ mW}$$

(47)

The chosen component from step 12 is:

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

(48)

8.14 Input UVLO

Solve for R_{UV2}:

$$R4 = \frac{R5 \text{ x } (V_{HYS} - 20 \text{ } \mu A \text{ x } R13)}{20 \text{ } \mu A \text{ x } (R5 + R13)}$$

$$R4 = \frac{1.43 \text{ k}\Omega \text{ x } (3V - 20 \text{ } \mu A \text{ x } 10 \text{ k}\Omega)}{20 \text{ } \mu A \text{ x } (1.43 \text{ k}\Omega + 10 \text{ k}\Omega)} = 17.5 \text{ k}\Omega$$

(49)

The closest standard resistor is 150 kΩ therefore V_{HYS} is:

$$V_{HYS} = \frac{20 \text{ } \mu A \text{ x } R4 \text{ x } (R5 + R13)}{R5} + 20 \text{ } \mu A \text{ x } R13$$

$$V_{HYS} = \frac{20 \text{ } \mu A \text{ x } 17.4 \text{ k}\Omega \text{ x } (1.43 \text{ k}\Omega + 10 \text{ k}\Omega)}{1.43 \text{ k}\Omega}$$
$$+ 20 \text{ } \mu A \text{ x } 10 \text{ k}\Omega = 2.98V$$

(50)

Solve for R_{UV1}:

$$R5 = \frac{1.24V \times R13}{V_{TURN-ON} - 1.24V} = \frac{1.24V \times 10\ k\Omega}{10V - 1.24V} = 1.42\ k\Omega$$

(51)

The closest standard resistor is 21 kΩ making $V_{TURN-ON}$:

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

$$V_{TURN-ON} = \frac{1.24V \times (1.43\ k\Omega + 10\ k\Omega)}{1.43\ k\Omega} = 9.91V$$

(52)

The chosen components from step 13 are:

R5 = 1.43 kΩ
R13 = 10 kΩ
R4 = 17.4 kΩ

(53)

8.15 Output OVLO

Solve for R_{OV2}:

$$R17 = \frac{V_{HYSO}}{20\ \mu A} = \frac{10V}{20\ \mu A} = 500\ k\Omega$$

(54)

The closest standard resistor is 499 kΩ therefore V_{HYSO} is:

$$V_{HYSO} = R17 \times 20\ \mu A = 499\ k\Omega \times 20\ \mu A = 9.98V$$

(55)

Solve for R_{OV1}:

$$R11 = \frac{1.24V \times R17}{V_{TURN-OFF} - 1.24V} = \frac{1.24V \times 499\ k\Omega}{50V - 620\ mV} = 12.5\ k\Omega$$

(56)

The closest standard resistor is 15.8 kΩ making $V_{TURN-OFF}$:

$$V_{TURN-OFF} = \frac{1.24V \times (R11 + R17)}{R11}$$

$$V_{TURN-OFF} = \frac{1.24V \times (12.4\ k\Omega + 499\ k\Omega)}{12.4\ k\Omega} = 51.1V$$

(57)

The chosen components from step 14 are:

R11 = 12.4 kΩ
R17 = 499 kΩ

(58)

8.16 Soft-Start

Solve for t_{SU}:

$$t_{SU} = 168\Omega \times C_{BYP} + 36\ k\Omega \times C_{CMP} + \frac{V_O}{I_{LED}} \times C_O$$

$$t_{SU} = 168\Omega \times 2.2\ \mu F + 36\ k\Omega \times 0.33\ \mu F + \frac{21V}{1A} \times 40\ \mu F$$

$$t_{SU} = 13.1\ ms$$

(59)

If t_{SU} is less than t_{TSU}, solve for $t_{SU-SS-BASE}$:

$$t_{SU-SS-BASE} = 168\Omega \times C_{BYP} + 28\ k\Omega \times C_{CMP} + \frac{V_O}{I_{LED}} \times C_O$$

$$t_{SU-SS-BASE} = 168\Omega \times 2.2\ \mu F + 28\ k\Omega \times 0.33\ \mu F + \frac{21V}{1A} \times 40\ \mu F$$

$$t_{SU-SS-BASE} = 10.5\ ms$$

(60)

Solve for C_{SS}:

$$C_{SS} = \frac{\left(t_{TSU} - t_{SU\text{-}SS\text{-}BASE}\right)}{20 \text{ k}\Omega} = \frac{\left(30 \text{ ms} - 10.5 \text{ ms}\right)}{20 \text{ k}\Omega} = 975 \text{ nF}$$

(61)

The chosen component from step 15 is:

$$\boxed{C_{SS} = 1\,\mu F}$$

(62)

9 Typical Waveforms
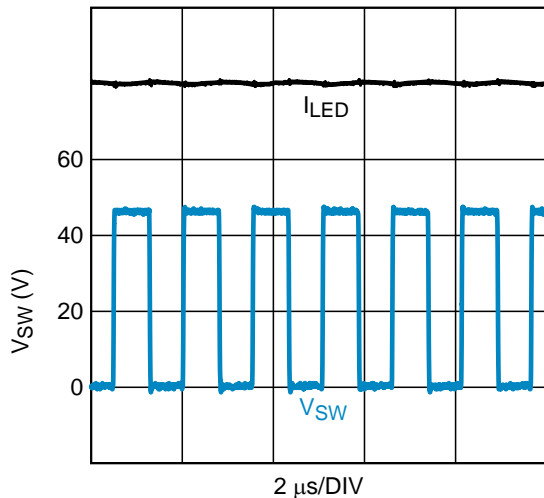
T_A = +25°C, V_{IN} = 24V and V_O = 32V.

Figure 4. Standard Operation
TP1 Switch Node Voltage (V_{SW})
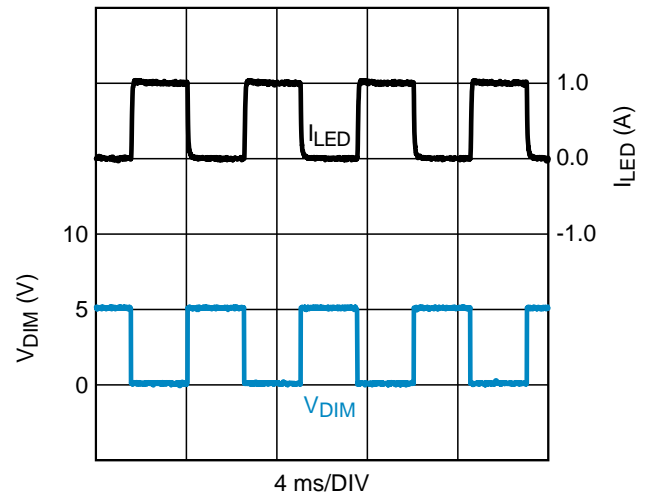**LED Current (I_{LED})**

Figure 5. 200Hz 50% PWM Dimming
TP5 Dim Voltage (V_{DIM})
LED Current (I_{LED})

10 Alternate Designs

Alternate designs with the LM3429 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 2 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 2. Alternate Design Specifications

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	12.1 kΩ	10.2 kΩ	14.3 kΩ	10.2 kΩ
L1	22µH	68µH	15µH	33µH

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as "components") are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI's terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers' products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers' products and applications, Buyers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of significant portions of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI components or services with statements different from or beyond the parameters stated by TI for that component or service voids all express and any implied warranties for the associated TI component or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI's goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or "enhanced plastic" are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have *not* been so designated is solely at the Buyer's risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

Products		Applications	
Audio	www.ti.com/audio	Automotive and Transportation	www.ti.com/automotive
Amplifiers	amplifier.ti.com	Communications and Telecom	www.ti.com/communications
Data Converters	dataconverter.ti.com	Computers and Peripherals	www.ti.com/computers
DLP® Products	www.dlp.com	Consumer Electronics	www.ti.com/consumer-apps
DSP	dsp.ti.com	Energy and Lighting	www.ti.com/energy
Clocks and Timers	www.ti.com/clocks	Industrial	www.ti.com/industrial
Interface	interface.ti.com	Medical	www.ti.com/medical
Logic	logic.ti.com	Security	www.ti.com/security
Power Mgmt	power.ti.com	Space, Avionics and Defense	www.ti.com/space-avionics-defense
Microcontrollers	microcontroller.ti.com	Video and Imaging	www.ti.com/video
RFID	www.ti-rfid.com		
OMAP Applications Processors	www.ti.com/omap	**TI E2E Community**	e2e.ti.com
Wireless Connectivity	www.ti.com/wirelessconnectivity		