

AN-1872 LM3423 Boost Evaluation Board

1 Introduction

This evaluation board has been designed to demonstrate the LM3423 low-side controller as a step-up (boost) regulator to deliver constant current to high power LEDs. A complete circuit schematic and bill of materials for the evaluation board are included at the end of this document. The printed circuit board consists of two layers of two ounce copper on FR4 material.

2 Device Description

The LM3423 is a high voltage, low-side NFET controller with an adjustable output current sense voltage. Output voltage regulation is based on peak current-mode control, which eases the design of loop compensation while providing inherent input voltage feed-forward compensation. The LM3423 includes a high-voltage start-up regulator that operates over a wide input range of 4.5V to 75V. The PWM controller is designed for high speed capability including a switching frequency range to 2.0 MHz. Additional features include “zero” current shutdown, error amplifier, precision reference, logic-compatible DIM input suitable for fast PWM dimming of the output, cycle-by-cycle current limit, LED ready flag, fault flag, programmable fault timer, and thermal shutdown.

Standard Evaluation Board Operating Configuration:

- $f_{SW} = 600 \text{ kHz}$
- Over-voltage protection set at 42V
- V_{IN} range 4.5V to 35V
- Low side PWM fast dimming
- 2 to 8 series connected LEDs ($V_O < 35V$)
- UVLO set at 8.4V
- $I_{LED} = 1A$

Available features that can be configured on the standard evaluation board by the user are:

- Fixed or programmable LED current
- High-speed PWM high-side or low-side dimming
- User programmable over-voltage protection (OVP)
- Under-voltage lock-out (UVLO) protection
- Fault protection
- Soft-start
- Hysteretic current-mode control
- **Higher Input and / or Output Voltage Modifications**
 - Although the standard LM3423 evaluation board is designed to operate at input and output voltages up to 35V, the device is capable of operating with input and output voltages up to 75V. Operation up to 75V can be achieved by changing the voltage ratings of the input capacitors (C1, C8, C17), output capacitors (C4, C7, C11, C16), and transistors Q1, Q7, Q9. For output voltages greater than 35V the OVP resistors R11 and R12 will need to be adjusted.

3 Board Connections and Configuration

Connecting the evaluation board to a power supply and load is accomplished through banana-plug type connectors (refer to [Table 1](#)).

Configuration of the evaluation board is accomplished through the use of on-board jumpers (refer to [Table 2](#)).

Table 1. LM3423 Evaluation Board Connectors

Connector Designation	Function or Use
V _{IN}	Power supply (Positive) primary connection
GND	Power supply (Negative) primary connection
LED+	Connect to anode of LED.
LED-	Connect to cathode of LED.

Table 2. LM3423 Evaluation Board Jumpers

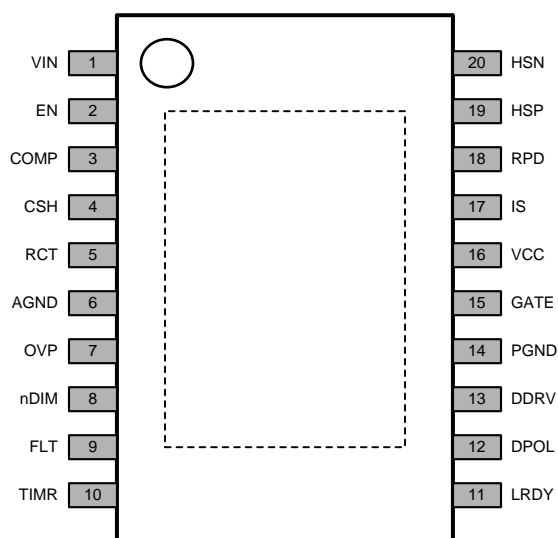
Jumper Designation	Function or Use
J1	Enable (EN)
	OPEN: Disables LM3423.
	CLOSED: Enables LM3423.
J2	Current Limit (IS)
	OPEN: Disables MOSFET RDS(ON) current sensing "Q5".
	CLOSED: Enables MOSFET RDS(ON) current sensing "Q5".
J3	Current Limit (IS)
	OPEN: Disables external sense resistor MOSFET current sensing "Q5".
	CLOSED: Enables external sense resistor MOSFET current sensing "Q5".
J4A, J4B	Current Limit (IS): Must be used in conjunction with jumper J2.
	OPEN: Enables sensing MOSFET switch current across sense resistor "R6".
	CLOSED: Disables sensing MOSFET switch current across sense resistor "R6".
J6	Fault Timer (FLT)
	OPEN: External capacitor programs fault condition time to set flag (FLT).
	CLOSED: Disables fault timer and flag (FLT).
J7	PWM Dimming
	OPEN: Enables high-side PWM dimming.
	CLOSED: Disables high-side PWM dimming.
J8	PWM Dimming
	OPEN: Disables high-side PWM dimming.
	CLOSED: Enables high-side PWM dimming.
J13	PWM Dimming
	OPEN: Enables low-side PWM dimming (Q6).
	CLOSED: Disables low-side PWM dimming.
J14	DIM Polarity Flag
	OPEN: For low side dimming
	CLOSED: For high side dimming.
J16	External Soft - Start
	OPEN: Enables soft-start feature.
	CLOSED: Disables soft-start feature.

Test points in the form of clip-on pegs are available to the user for making measurements on the LM3423 evaluation board (refer to [Table 3](#)).

Table 3. LM3423 Evaluation Board Test Points

Test Point Designation	Function or Use
TP1	Test point for "LED+" connector (LED anode).
TP2	Test point for "LED-" connector (LED cathode).
TP3	Test point for regulated output voltage.
TP5	Test point for L-RDY pin.
TP6	Test point for "PWM Dimming" input signal.
TP7	Test point for IS pin.
TP8	Test point for nDIM pin.
TP9	Test point for FLT pin.
TP10	Test point for GROUND.
TP11	Test point for TIMR pin.
TP12	Test point for switch-node.
TP13	Test point for RSNS.
TP14	Test point for CSH pin.
TP15	Test point for COMP pin.

4 LM3423 TSSOP Pin Connection


**Figure 1. Top View
LM3423 Pin Connection**

5 Board Features

This evaluation board has all the necessary connections and jumpers to evaluate the LM3423 controller in a boost converter topology with the following operating features and options:

5.1 Setting Average LED Current

The LM3423 uses peak current-mode control to regulate the boosted output voltage. An external current sense resistor R_{SENSE} (that is, R9) in series with the LED load is used to convert the LED current, I_{LED} , into a voltage that is sensed by HSP (pin 19) and HSN (pin 20), see Figure 2. HSP and HSN are the inputs to a high side sense amplifier that is used in combination with a resistor tied to CSH (pin 4) and an error amplifier to program a desired I_{LED} current.

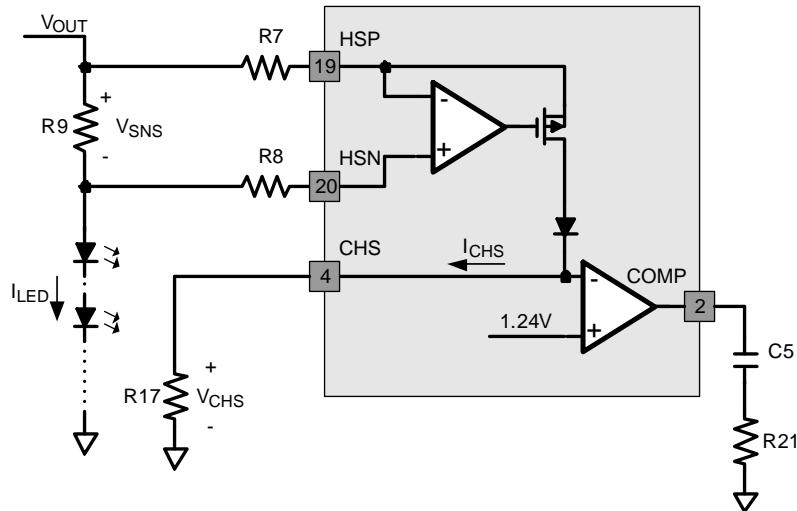


Figure 2. High-Side Sensing Circuit

This establishes a current gain determined by a resistor ratio consisting of R17 and R7 along with R9 as described in the equation:

$$I_{\text{LED}} = \left(\frac{R7}{R17} \right) \times \left(\frac{1.24\text{V}}{R9} \right) \quad (1)$$

Substituting in the resistor values as listed in the board schematic gives a fixed I_{LED} current of 1A.

5.2 Setting the Current Sense Voltage

By substituting in different resistor values, the LED average current can be user adjusted. The LM3423 controller uses a high-side sense amplifier to regulate LED average current (Figure 2). The CSH pin is regulated by the error amplifier to be V_{REF} . Understanding how average LED current is regulated comes down to understanding the relationship between V_{CSH} and V_{SNS} , because V_{SNS} and R_{SNS} set the LED current. The high side amplifier in Figure 2 forces its input terminals to equal potential. Because of this, the V_{SNS} voltage is forced across R_{HSP} . Another way to view this is that the amplifier's output transistor pulls current through R7 (R_{HSP}) until $V_{\text{HSP}} = V_{\text{HSN}}$ and this happens when the voltage across R7 is equal to V_{SNS} .

The current flowing down to the CSH pin is given by:

$$I_{\text{CSH}} = \left(\frac{V_{\text{SNS}}}{R7} \right) \quad (2)$$

and the voltage at the CSH pin is then given by:

$$V_{\text{CSH}} = (R17 \times I_{\text{CSH}}) = V_{\text{SNS}} \times \left(\frac{R17}{R7} \right) \quad (3)$$

The CSH voltage is the sense voltage gained up by the ratio of R17 to R7. In addition, the control system's error amplifier regulates the CSH voltage to V_{REF} . Using Equation 3, the following equations are derived,

$$V_{SNS} = V_{REF} \times \left(\frac{R7}{R17} \right)$$

$$I_{LED} = \left(\frac{V_{SNS}}{R9} \right) = \left(\frac{V_{REF}}{R9} \right) \times \left(\frac{R7}{R17} \right) \quad (4)$$

Equation 4 shows how current in the LED relates to the regulated voltage V_{REF} , which is approximately 1.25V for the LM3423.

The selection of resistors is not arbitrary, for matching and noise performance, the CSH current should be set to be around 100 μ A. This current does not flow in the LEDs and will not affect either off state LED current or the regulated LED current. CSH current can be above or below this value, but high side amplifier offset characteristics and jitter performance may be affected slightly.

5.3 Peak Current Limit

Due to its peak current-mode control architecture, the LM3423 has inherent cycle-to-cycle current limit control. Inductor current flowing through the low-side power MOSFET (Q5) is sensed as a voltage between IS (pin 17) and PGND (pin 14), see Figure 3. This voltage is fed into an internal comparator which establishes the peak current allowed during each switching cycle.

Two methods of switch current sensing are available on the evaluation board. The first is accomplished through the use of an external sense resistor which allows for higher accuracy in sensing the peak current. For the LM3423 evaluation board, the sense resistor R6 can be utilized using the jumper configuration as described in Table 4.

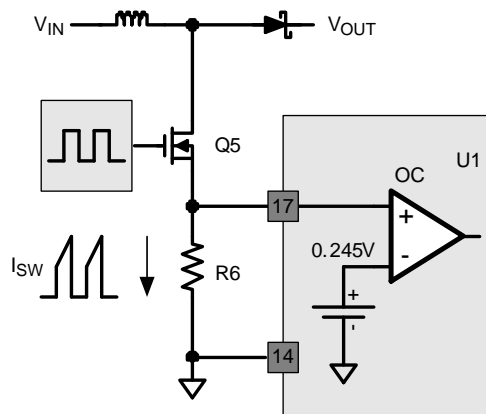


Figure 3. External R_{SENSE} I_{SW} Current Sense

Table 4. External R_{SENSE} Resistor Configuration

Jumper	Operation
J2	Open Jumper
J3	Close Jumper
J4A, J4B	Open Jumper
R6	Populate

The current limit (I_{CL}) is calculated by the equation:

$$I_{CL} = \left(\frac{0.245V}{R6} \right) \quad (5)$$

Substituting in the resistor value as listed in the board schematic gives a current limit I_{CL} of approximately 4.1A.

MOSFET switch current can also be sensed directly across the $R_{DS(ON)}$ of MOSFET Q5, eliminating the need for a sense resistor (see Table 5).

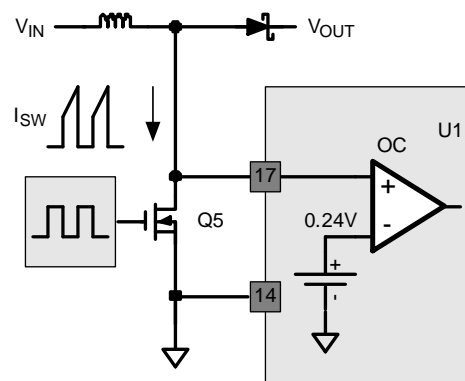


Figure 4. MOSFET $R_{DS(ON)}$ Sensing

Table 5. MOSFET $R_{DS(ON)}$ Sensing Configuration

Jumper	Operation
J2	Close Jumper
J3	Open Jumper
J4A, J4B	Close Jumper
R6	No Load

The trade-off will be less accuracy and performance flexibility for reduced component count, and increased efficiency. The current limit (I_{CL}) using this sense method is calculated by the equation:

$$I_{CL} = \left(\frac{0.245V}{R_{DS(ON)}} \right) \quad (6)$$

Substituting in the resistor values as listed in the board schematic and an $R_{DS(ON)}$ of 0.025Ω for Q5 (SUD40N10-25) gives a current limit I_{CL} of approximately 10A.

5.4 PWM Dimming

The average LED forward current is often controlled or reduced with a pulse-width modulated (PWM) signal. By reducing the average LED current, light from the LEDs is reduced.

This dimming method allows the converter to operate the LEDs at a specific peak output current level (i_L), which is usually a set point determined by the LED manufacturer. This allows the LED to illuminate with a consistent light color while still having the ability to reduce its lumens output.

The dimming frequency should be fast enough so that the ON and OFF blinking of the LEDs is not perceived by the human eye. Usually the dimming frequency should be greater than 120 Hz, but less than 5 kHz for best results.

The LM3423 evaluation board implements PWM dimming by placing a series connected MOSFET in series with the LED stack. The PWM signal is applied to this MOSFET, and the LED current is interrupted when the MOSFET turns OFF.

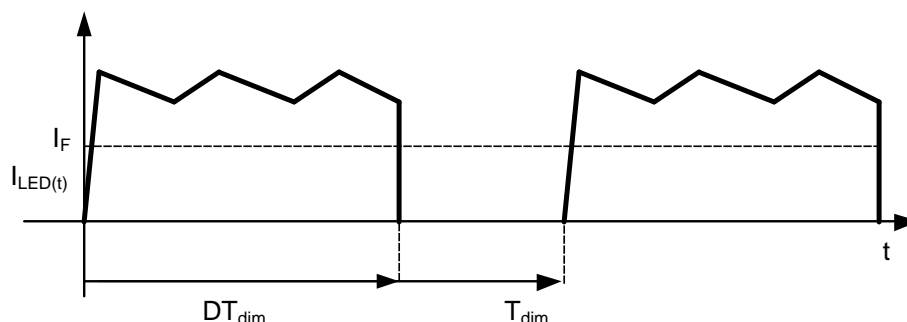


Figure 5. Illustration of Current through LED Stack with PWM Dimming

The LM3423 evaluation board can be configured for either high-side PWM dimming or low-side PWM dimming. The definition of high side dimming is when a MOSFET that interrupts the forward current through the LED stack is placed on the anode side of the LED stack. Low side dimming places the MOSFET on the cathode side of the LED stack. The PWM dimming signal should be applied to either the BNC connector or test point TP6.

Dimming on the high-side (anode) of the LED load is enabled using the jumper configuration described in [Table 6](#).

Dimming on the low-side (cathode) of the LED load is enabled using the jumper configuration described in [Table 7](#).

If the dimming MOSFETs are removed and no dimming is to be used, then the jumper configuration described in [Table 8](#) should be used.

Table 6. High-Side PWM Dimming Configuration

Jumper	Operation
J7	Open Jumper
J8	Close Jumper
J13	Close Jumper
J14	Close Jumper
Q6	No Load
Q7, Q1, R3, R23, C10, Z2	Populate

Table 7. Low-Side PWM Dimming Configuration

Jumper	Operation
J7	Close Jumper
J8	Open Jumper
Q6	Populate
J13	Open Jumper
J14	Open Jumper
Q7, Q1, R3, R23, C10, Z2	No Load

Table 8. No PWM Dimming Configuration

Jumper	Operation
J7	Close Jumper
J8	Open Jumper
Q6	Populate
J13	Close Jumper
J14	Open Jumper
Q6, Q7, Q1, R3, R23, C10, Z2	No Load

5.5 Shutdown Operation

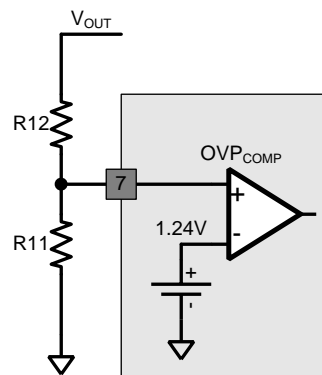
The LM3423 can be configured for either a very low quiescent current shut down (“Zero Current” $I_Q < 1\mu A$), or the standard enable/disable configuration ($I_Q < 3mA$).

“Zero Current” is achieved by tying the bottom resistor of all external resistor dividers (that is, V_{IN} UVLO, OVP) to the RPD Pin 18. Bias currents in the resistor dividers are essentially eliminated during shutdown. The evaluation board is designed using the “zero” shutdown feature.

5.6 Over-Voltage Protection

An over-voltage protection (OVP) with programmable hysteresis feature is available on the LM3423 to protect the device from damage when the boosted output voltage goes above a maximum value.

The OVP threshold is set up by the resistor divider network of R12 and R11 that is referenced to the regulated output voltage (VO). The OVP threshold and hysteresis can be programmed completely independent of each other. OVP hysteresis is accomplished with an internal $23\mu A$ current source that is switched on and off into the impedance of the OVP set-point resistor divider. When the OVP pin exceeds 1.24V, the current source is activated to instantly raise the voltage at the OVP pin. When the OVP pin voltage falls below the 1.24V threshold, the current source is turned off, causing the voltage at the OVP pin to fall.


Figure 6. Calculating OVP Hysterisis and Set Points

Step 1: Determine V_{HYST} , $V_{HYST} = (V_{OVP_UP} - V_{OVP_DN})$

Step 2: Calculate R12:

$$R12 = \frac{V_{HYST}}{23\mu A}$$

(7)

The V_O OVP release point (which includes the OVP hysteresis) is described by the equation:

$$R11 = \left(\frac{R12 \times 1.24V}{V_{OVP_UP} - 1.24V} \right) \quad (8)$$

The evaluation board is already configured with OVP, and the V_O OVP threshold is programmed on the evaluation board to 42.3V with 2.3V of hysteresis. OVP will therefore release when V_O reaches 40V ($R12 = 100 \text{ k}\Omega$, $R11 = 3.01 \text{ k}\Omega$).

5.7 Under-Voltage Protection

The LM3423 can be configured for under-voltage lockout (UVLO) protection with hysteresis using the dimming input nDIM (pin 8) and a resistor divider from input voltage to ground. UVLO protects the power devices during power supply startup and shutdown to prevent operation at voltages less than the minimum operating input voltage. The UVLO threshold is set up by the resistor divider network of R13 and R25 (see Figure 7).

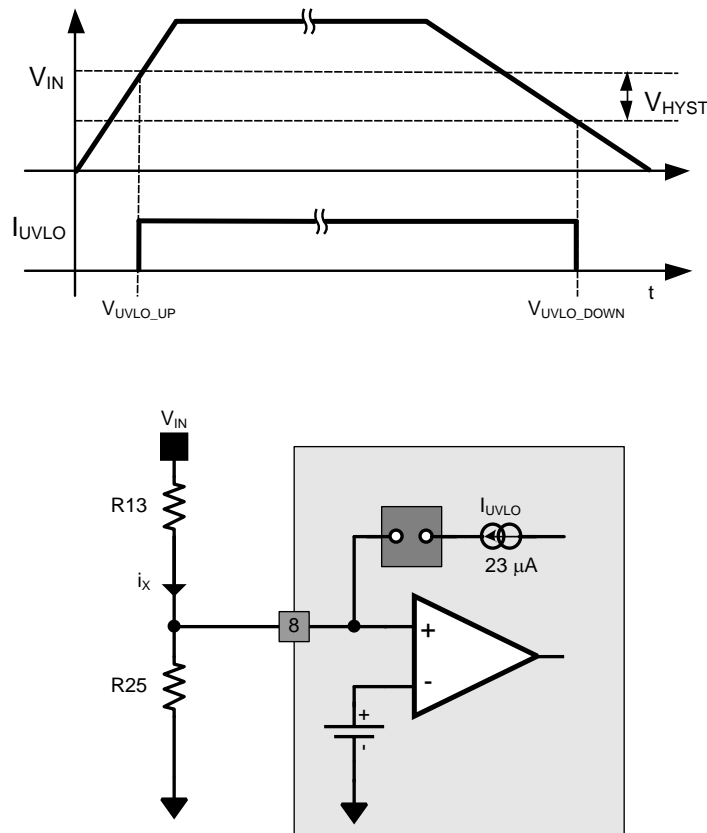


Figure 7. UVLO Circuit During Start-Up

The UVLO threshold and hysteresis can be programmed completely independent of each other. UVLO hysteresis is accomplished with an internal 23 μA current source that is switched on and off into the impedance of the UVLO set-point resistor divider. When the UVLO pin exceeds 1.24V, the current source is activated to instantly raise the voltage at the UVLO pin. When the UVLO pin voltage falls below the 1.24V threshold, the current source is turned off, causing the voltage at the UVLO pin to fall. The UVLO hysteresis range can be user adjusted using the gain resistor R26.

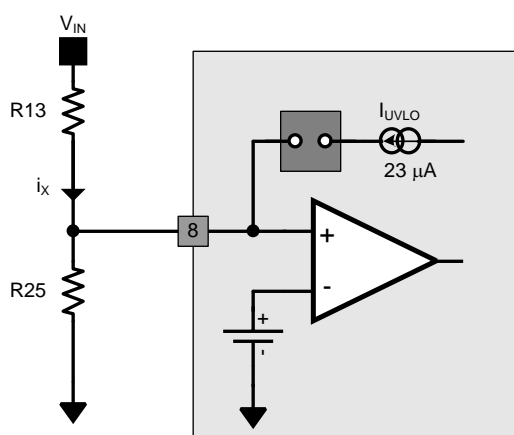


Figure 8. UVLO Circuit During Normal Operation

Step 1: Choose V_{IN} voltage where converter starts to operate (V_{UV_UP}) and choose V_{IN} voltage where converter shuts down (V_{UV_DN}). $V_{HYST} = (V_{UVLO_UP} - V_{UV_DN})$

Step 2: Solve for resistor value R13 with the following equation:

$$R13 = \frac{V_{HYST}}{23 \mu A} \quad (9)$$

Solve for resistor value R25 with the following equation:

$$R25 = \left(\frac{R13 \times 1.24V}{V_{INUV_UP} - 1.24V} \right) \quad (10)$$

Example Calculation of UVLO with Hysteresis:

- V_{IN} start-up = $V_{UV_UP} = 8.45V$
- V_{IN} shut down = $V_{UV_DN} = 8.2V$
- $I_{UVLO} = 23 \mu A$
- $V_{HYST} = 8.45V - 8.2 = 0.25V$
- $R13 \approx 10 k\Omega$
- $R25 \approx 1.74 k\Omega$

If a small amount of hysteresis is desired and V_{IN} is large, resistor R26 may need to be populated.

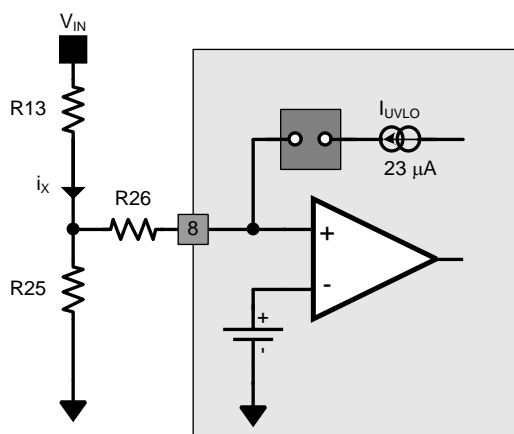


Figure 9. UVLO Circuit with R26 Populated for Small Hysteresis and Large Input Voltage

5.8 Fault Protection Flag

The LM3423 can be configured with fault protection by using the fault flag indicator FLT (pin 9).

When a fault condition is detected, the FLT pin will go high (pulled up to V_{IN} by resistor R16).

5.9 Soft-Start

The LM3423 evaluation board includes on-board circuitry to enable soft-start during device start-up. Soft-start allows the power converter to gradually reach the initial steady state operating point, thereby reducing start-up stresses, output overshoot and current surges. By closing jumper J16 (refer to [Table 9](#)), the soft-start feature is enabled.

The soft-start method involves ramping the compensation pin COMP (pin 3) of the internal current sense amplifier through an RC network (R28, C15) tied to VCC (pin 16). The capacitor voltage will ramp up slowly and will limit the COMP pin voltage and the duty cycle of the output pulses. This in turn limits the current being transferred to the LED load during each switching cycle which slows the current ramp at start-up. The soft-start can be tailored for a specific application by varying the capacitance value of C15.

Table 9. Soft-Start Configuration

Jumper	Operation
J16	- Close this jumper to enable soft-start feature.
	- Leave open to disable soft-start feature.

6 Evaluation Board Test Procedure

Be sure to choose the correct wire size when connecting the source supply and load. Monitor the current into and out of the unit under test (UUT). Monitor the voltages directly at the board terminals, as resistive voltage drops along the wires may decrease measurement accuracy. The LM3423 evaluation board has two pairs of positive and negative inputs connectors which allows for Kelvin connections to be made from the power supplies to the evaluation board. These precautions are especially important during measurement of conversion efficiency.

Table 10. Bill of Materials

Part ID	Part Value	Manufacturer	Part Number
U1	Boost controller, TSSOP20	Texas Instruments	LM3423MH
C1, C15	0.1 μ F 10% 25V	Vishay	VJ0805Y104KXXCW1BC
C2	2.2 μ F, 25V	Panasonic	ECJ-2FB1E225K
C3	Capacitor 0805 1200 pF, 100V	Murata	GRM2195C2A122JA01D
C4, C11	Capacitor 1210 10 μ F, 25V	Panasonic	ECJ-4YB1E106M
C5	Capacitor 0805 0.022 μ F, 50V	Panasonic	ECJ-2VB1H223K
C6	Capacitor 0805 0.01 μ F, 50V	Panasonic	ECJ-2VB1H103K
C7, C8	Capacitor 330 μ F, 35V 5mm Lead	Panasonic	ECA-1VM331
C12, C13, C18	Capacitor 0805 47 pF, 50V	Panasonic	ECJ 2VC1H470J
C16, C17	Capacitor 1206 0.1 μ F, 50V	Murata	GRM319R71H104KA01D
D1	D-Pak 12A, 100V	Vishay	12CWQ10FN
D13, D16	SOT-23 200 mA, 30V	Fairchild	BAT54S
VIN, GND, LED+, LED-	Connector	Keystone	575-8
J1-J4, J6,-J8, J13, J14, J16	Jumper	Molex	22-28-4023
L1	22 μ H	Coilcraft	DO5040H
Q5, Q6	N-channel MOSFET TO-252 40A, 100V	Vishay	SUD40N10-25-E3
Q9	N channel MOSFET SOT23 200 mA, 60V	ST Microelectronics	2N7002
R6	Resistor 2512 0.06 Ω	Vishay	WSL2512R0600FEA
R7, R8	Resistor 0805 1 kv	Vishay	CRCW08051001F
R9	Resistor 1812 0.1 Ω	Panasonic	ERJL12KF10CU
R11	Resistor 0805 3.01k	Vishay	CRCW08053011F
R12, R15, R16	Resistor 0805 100 k Ω	Vishay	CRCW08051003F
R13, R31	Resistor 1206 10k	Vishay	CRCW08051002F
R14	Resistor 0805 35.7k	Vishay	CRCW08053572F
R17	Resistor 0805 12.4 k Ω	Vishay	CRCW08051242F
R21, R26	Resistor 0805 4.99k	Vishay	CRCW08054991F
R25	Resistor 1206 1.74k	Vishay	CRCW12061741F
R27	Resistor 0805 10 Ω	Vishay	CRCW080510R0F
R28	Resistor 0805 1 M Ω	Vishay	CRCW08051004F
R30	Resistor 1206 2 Ω	Yageo	RC1206JR-072RL
Test Points	Connector	Keystone	1502-2

6.2 LM3423 Evaluation Board: High Side Current Sense with High Side High Speed Dimming

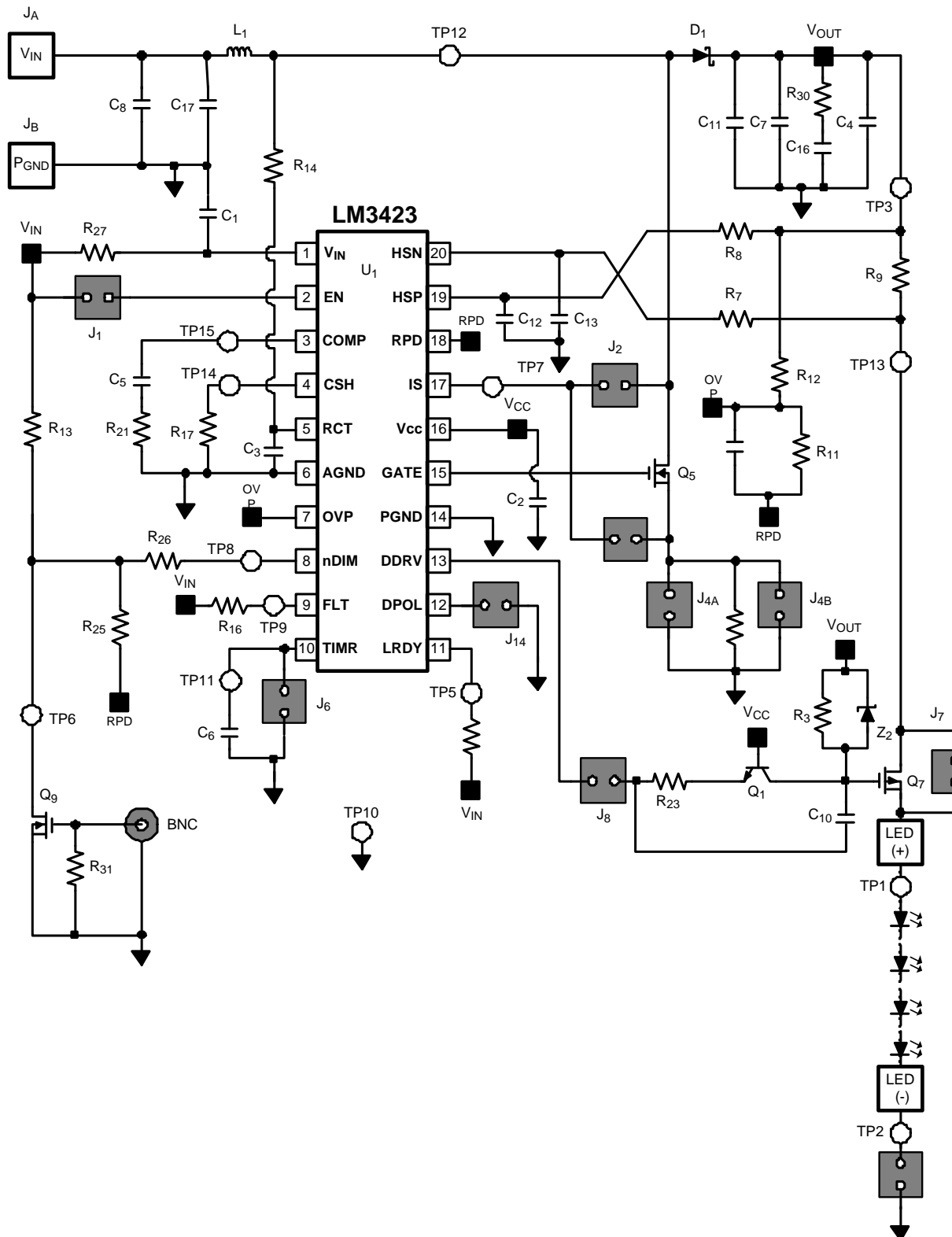


Figure 11. LM3423 Evaluation Board: High Side Current Sense with High Side High Speed Dimming

Table 11. Bill of Materials

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C3	Capacitor 0805 1200 pF, 100V	Murata	GRM2195C2A122JA01D
C4, C11	Capacitor 1210 10 μ F, 25V	Panasonic	ECJ-4YB1E106M
C5	Capacitor 0805 0.022 μ F, 50V	Panasonic	ECJ-2VB1H223K
C6	Capacitor 0805 0.01 μ F, 50V	Panasonic	ECJ-2VB1H103K
C7, C8	Capacitor 330 μ F, 35V 5mm Lead	Panasonic	ECA-1VM331
C10, C16, C17	Capacitor 1206 0.1 μ F, 50V	Murata	GRM319R71H104KA01D
C12, C13, C18	Capacitor 0805 47 pF, 50V	Panasonic	ECJ 2VC1H470J
D1	D-Pak 12A, 100V	Vishay	12CWQ10FN
D13, D16	SOT-23 200 mA, 30V	Fairchild	BAT54S
VIN, GND, LED+, LED-	Connector	Keystone	575-8
J1-J4, J6, -J8, J13, J14, J16	Jumper	Molex	22-28-4023
L1	22 μ H	Coilcraft	DO5040H
Q1	NPN Transistor SOT-23 200 mA, 40V	ON Semiconductor	MMBT3904LT1G
Q5	N-channel MOSFET TO-252 40A, 100V	Vishay	SUD40N10-25-E3
Q7	P channel MOSFET TO-252 19A, 60V	Vishay	SUD19P0660L- E3
Q9	N channel MOSFET SOT23 200 mA, 60V	ST Microelectronics	2N7002
R3, R12, R15, R16, R23	Resistor 0805 100 k Ω	Vishay	CRCW08051003F
R6	Resistor 2512 0.06 Ω	Vishay	WSL2512R0600FEA
R7, R8	Resistor 0805 1 k Ω	Vishay	CRCW08051001F
R9	Resistor 1812 0.1	Panasonic	ERJL12KF10CU
R11	Resistor 0805 3.01k	Vishay	CRCW08053011F
R13, R31	Resistor 0805 10k	Vishay	CRCW08051002F
R14	Resistor 0805 35.7k	Vishay	CRCW08053572F
R17	Resistor 0805 12.4 k Ω	Vishay	CRCW08051242F
R21, R26	Resistor 0805 4.99k	Vishay	CRCW08054991F
R25	Resistor 1206 1.74k	Vishay	CRCW12061741F
R27	Resistor 0805 10 Ω	Vishay	CRCW080510R0F
R28	Resistor 0805 1M Ω	Vishay	CRCW08051004F
R30	Resistor 1206 2 Ω	Yageo	RC1206JR-072RL
Test Points	Connector	Keystone	1502-2
Z2	Zener Diode 0805 10V, 350mW	Diodes Inc	MMBZ5240B-7-F

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