HIGH EFFICIENCY 40V 1.5A AUTOMOTIVE-GRADE BUCK LED DRIVER

Description

The AL8840Q is a hysteresis-mode DC-DC step-down LED driver, designed to deliver efficient current regulation for single or multiple series-connected LEDs. It operates from an input voltage higher than the combined forward voltage of LED string, ensuring optimal performance and reliability. The device operates from an input supply voltage ranging from 4.5V to 40V and supports an externally adjustable output current up to 1.5A in the MSOP-8EP package. Based on input voltage and external component selection, this converter can deliver up to 40W of output power.

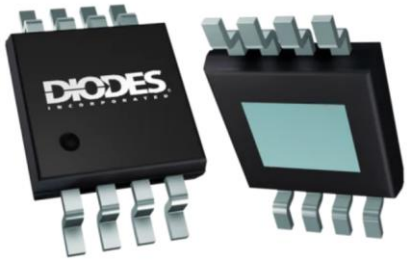
The AL8840Q integrates a power switch and high-side output current-sensing circuit, utilizing an external resistor to set the nominal average output current.

Dimming is achieved by applying an external control signal to the CTRL pin, which supports either a DC voltage or a PWM input.

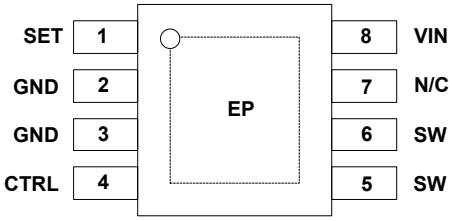
The default soft-start duration can be extended by connecting an external capacitor between the CTRL pin and ground. Applying a voltage of 0.2V or lower to the CTRL pin disables the power switch and places the device into standby mode with minimal power consumption.

The AL8840Q device is available in the thermally enhanced MSOP-8EP package with exposed pad.

Pin Assignments



Top View Bottom View



MSOP-8EP
(Top View)

Features

- AEC-Q100 Grade 1
- Wide Input Voltage: 4.5V to 40V
- Output Current: Up to 1.5A
- Switching Frequency: Up to 1MHz
- Single CTRL Pin Supporting PWM/Analog Dimming
- Built-In Soft-Start
- Integrated 40V NLDMOS Switch
- Typical Output Current Accuracy ±5%
- Efficiency > 95% Typically
- Protection Features:
  - LED Open/Short-Circuit Protection
  - Overtemperature Shutdown
- Pb-Free MSOP-8EP Package
- **Totally Lead-Free & Fully RoHS Compliant (Notes 1 & 2)**
- **Halogen and Antimony Free. "Green" Device (Note 3)**
- **The AL8840Q is suitable for automotive applications requiring specific change control; this part is AEC-Q100 qualified, PPAP capable, and manufactured in IATF 16949 certified facilities.**
  https://www.diodes.com/quality/product-definitions/

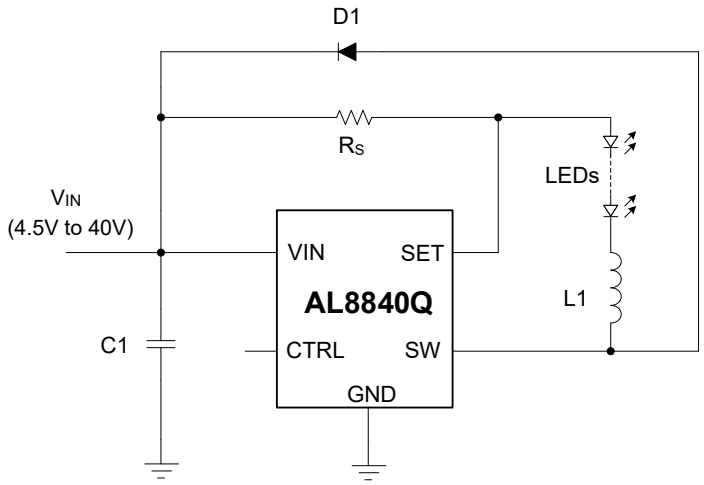
Applications

- Daytime running lights (DRLs)
- Front and rear fog lights
- Turn and stop (brake) lights
- Dimmable interior lights
- Instrument panel lights
- Puddle lights

Notes:
1. No purposely added lead. Fully EU Directive 2002/95/EC (RoHS), 2011/65/EU (RoHS 2) & 2015/863/EU (RoHS 3) compliant.
2. See https://www.diodes.com/quality/lead-free/ for more information about Diodes Incorporated's definitions of Halogen- and Antimony-free, "Green" and Lead-free.
3. Halogen- and Antimony-free "Green" products are defined as those which contain <900ppm bromine, <900ppm chlorine (<1500ppm total Br + Cl) and <1000ppm antimony compounds.

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Typical Application Circuit



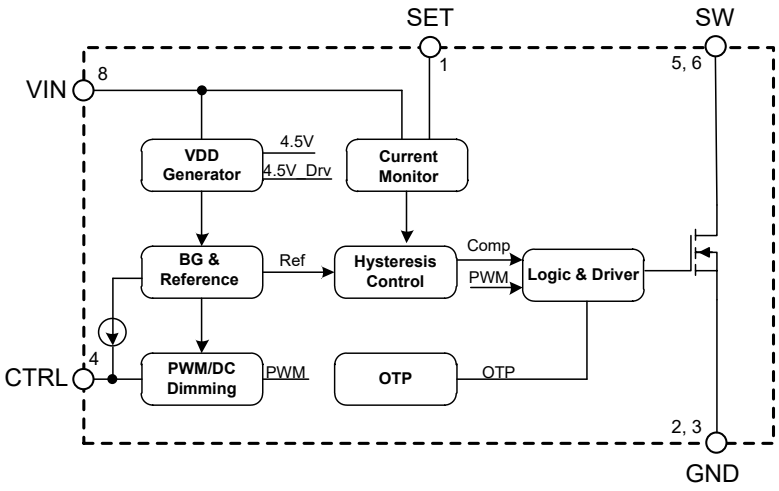
DC Power Source Input Buck Application

Pin Descriptions

Pin Number	Pin Name	Function
1	SET	Connect resistor R_S from this pin to VIN to define nominal average output current: $I_{OUT_NOM} = 0.1/R_S$
2, 3	GND	Ground
4	CTRL	Multi-function On/Off and brightness control pin: • Leave floating for normal operation. • Drive voltage below 0.2V to turn off output current. • Drive with DC voltage ($0.3V < V_{CTRL} < 2.5V$) to adjust output current from 0 to 100% of I_{OUT_NOM}. Linear adjustment ranges from 5% to 100% of I_{OUTNOM}. • Drive with PWM signal from open-collector or open-drain transistor to adjust output current. Linear adjustment ranges from 1% to 100% of I_{OUT_NOM} for f < 500Hz. • Connect a capacitor from this pin to ground to increase soft-start time. (Default soft-start time = 0.1ms. Additional soft-start time is approximately 1.5ms/1nF)
5, 6	SW	Drain of NDMOS switch.
7	N/C	No Connection.
8	VIN	Input voltage (4.5V to 40V). Decouple to ground with 10µF or higher X7R ceramic capacitor close to device.
EP	EP	Exposed pad. Connect to GND and thermal mass for enhanced thermal impedance. Should not be used as electrical ground conduction path.

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Functional Block Diagram



Absolute Maximum Ratings (Note 4)

Symbol	Parameter	Rating	Unit
V_{IN}	Input Voltage	-0.3 to 42	V
V_{SW}, V_{SET}	SW, SET Pin Voltage	-0.3 to 42	V
V_{CTRL}	CTRL Pin Voltage	-0.3 to 6	V
T_J	Operating Junction Temperature	-40 to +150	°C
T_{STG}	Storage Temperature Range	-65 to +150	°C
T_{LEAD}	Lead Temperature (Soldering, 10s)	+260	°C

Note: 4. Stresses greater than those listed under *Absolute Maximum Ratings* can cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions* is not implied. Exposure to *Absolute Maximum Ratings* for extended periods can affect device reliability. Besides, if the voltage on CTRL pin is bigger than 5V, the device will enter the test mode for parameter test. Therefore, the voltage on CTRL pin should be kept below 5V for normal operation.

ESD Ratings (Note 5)

Symbol	Parameter	Rating	Unit
V_{ESD}	Human Body Model (HBM), Per AEC-Q100-002	±3000	V
	Charged Device Model (CDM), Per AEC-Q100-011	±1000	

Note: 5. AEC-Q100-002 indicates that HBM stressing shall be accordance with the ANSI/ESDA/JEDEC JS-001 specification.

Recommended Operating Conditions

Symbol	Parameter	Min	Max	Unit
V_{IN}	Input Voltage	4.5	40	V
f_{SW}	Switching Frequency	—	1	MHz
I_{OUT}	Continuous Output Current	—	1.5	A
V_{CTRL}	Voltage Range for 10% to 100% DC Dimming Relative to GND Pin	0.4	2.5	V
V_{CTRL_HIGH}	Voltage High for PWM Dimming with Respect to GND Pin	2.6	5	V
V_{CTRL_LOW}	Voltage Low for PWM Dimming Relative to GND Pin	0	0.3	V
T_A	Operating Ambient Temperature	-40	+125	°C

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Thermal Information (Note 6)

Symbol	Parameter	Rating	Unit
$R_{\theta JA}$	Junction-to-Ambient Thermal Resistance	69.0	°C/W
$R_{\theta JC(TOP)}$	Junction-to-Case (Top) Thermal Resistance	43.6	°C/W
$R_{\theta JC(BOTTOM)}$	Junction-to-Case (Bottom) Thermal Resistance	8.0	°C/W
$R_{\theta JB}$	Junction-to-Board Thermal Resistance	40.2	°C/W
Ψ_{JT}	Junction-to-Top Characterization Parameter	7.7	°C/W
Ψ_{JB}	Junction-to-Board Characterization Parameter	39.9	°C/W

Note: 6. Device mounted on 114.3mm × 76.2mm 4layers JEDEC 2S2P substrate PC board, 2oz copper, with minimum recommended pad layout.

Electrical Characteristics (T_A = -40°C to +125°C, unless otherwise specified.)

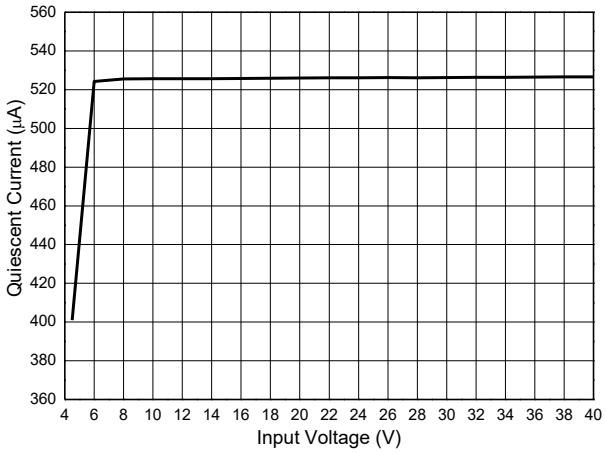
Symbol	Parameter	Condition	Min	Typ	Max	Unit
INPUT VOLTAGE						
V_{IN}	Input Voltage	—	4.5	—	40	V
V_{INSU}	Internal Regulator Startup Threshold	—	—	3.8	4.5	V
V_{INSH}	Internal Regulator Hysteresis Threshold	—	200	—	630	mV
I_Q	Quiescent Current	CTRL Pin Floating, V_{IN} = 16V	—	0.55	—	mA
I_{SHDN}	Shutdown Supply Current	CTRL Pin Grounded	—	50	80	μA
HYSTERESTIC CONTROL						
V_{SENSE}	Mean Current-Sense Threshold Voltage	Measured on SET Pin with Respect to VIN Pin (T_A = +25°C)	96	100	104	mV
		Measured on SET Pin with Respect to VIN Pin (T_A = -40°C to +125°C)	95	100	105	mV
V_{SENSE_HYS}	Sense Threshold Hysteresis	—	—	±20	—	%
I_{SET}	SET Pin Input Current	$V_{SET} = V_{IN} – 0.1$	—	8	—	μA
ENABLE						
V_{EN}	Voltage Range on CTRL Pin	For Analog Dimming	0.3	—	2.5	V
	Analog Dimming Range	For Analog Dimming	5	—	100	%
V_{EN_ON}	DC Voltage on CTRL Pin to Enable	V_{EN} Rising	—	0.25	—	V
V_{EN_OFF}	DC Voltage on CTRL Pin to Disable	V_{EN} Falling	—	0.2	—	V
SWITCHING OPERATION						
R_{ON}	SW Switch On-Resistance	@I_{SW} = 100mA	—	0.2	—	Ω
I_{SW_LEAK}	SW Switch Leakage Current	—	—	—	5	μA
t_{SS}	Soft-Start Time	V_{IN} = 16V, C_{EN} = 1nF	—	1.5	—	ms
f_{SW}	Operating Frequency (Note 7)	V_{IN} = 16V, V_O = 9.6V (3 LEDs), L = 33μF, ΔI = 0.25A (I_{LED} = 1A)	—	250	—	kHz
t_{ON_REC}	Recommended Minimum Switch ON Time	For 4% Accuracy	—	500	—	ns
f_{SW_MAX}	Recommended Maximum Switch Frequency	—	—	—	1.0	MHz
D_{SW_MAX}	Maximum Duty Cycle	—	—	98	—	%
t_{PD}	Internal Comparator Propagation Delay (Note 7)	—	—	100	—	ns
THERMAL SHUTDOWN						
T_{OTP}	Overtemperature Shutdown	—	—	+150	—	°C
T_{OTP_HYS}	Temperature Protection Hysteresis	—	—	+30	—	°C

Note: 7. Guaranteed by design.

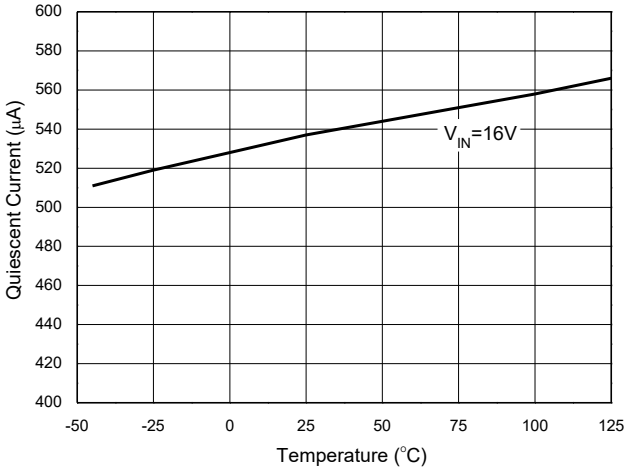
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Typical Performance Characteristics (T_A = +25°C, V_{IN} = 16V, unless otherwise specified.)

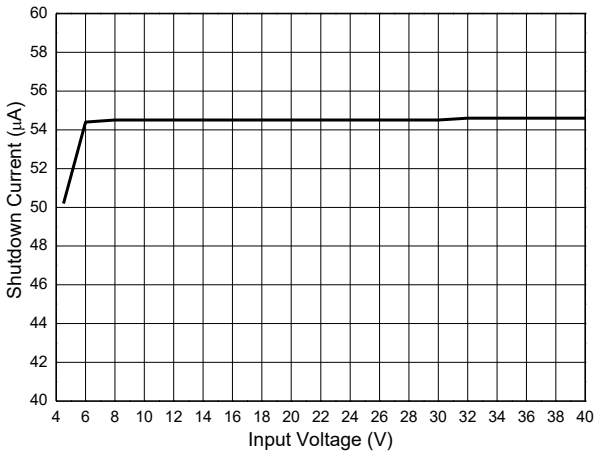
Quiescent Current vs. Input Voltage



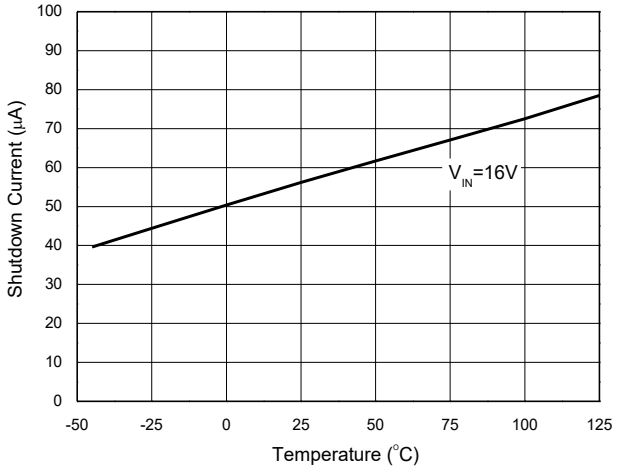
Quiescent Current vs. Temperature



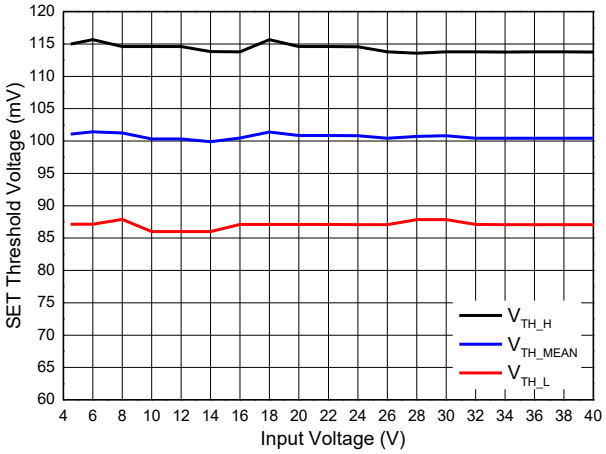
Shutdown Current vs. Input Voltage



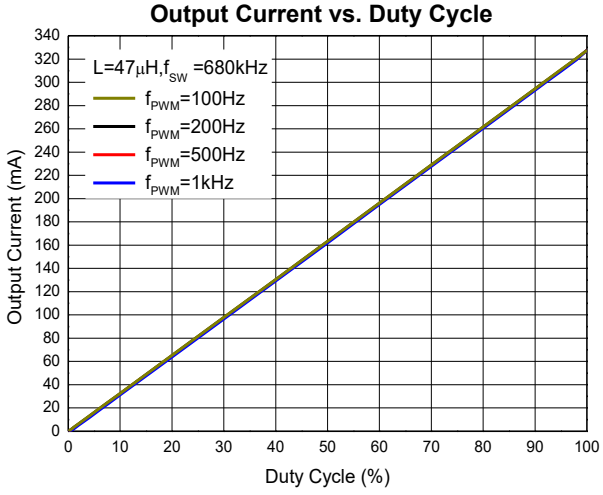
Shutdown Current vs. Temperature



SET Threshold Voltage vs. Input Voltage



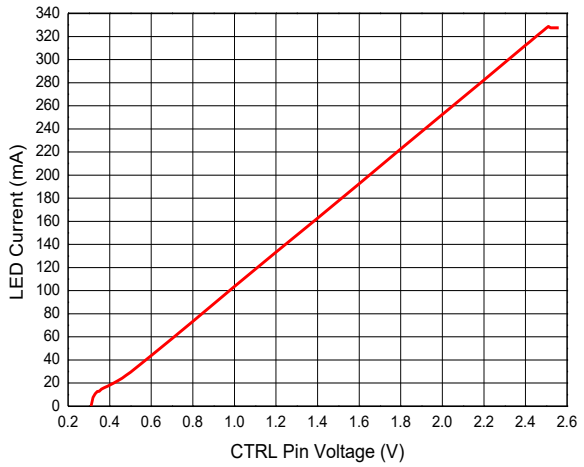
PWM Dimming (V_{IN}=16V, 3 LEDs, L= 47μH, R_S=0.3Ω) Output Current vs. Duty Cycle



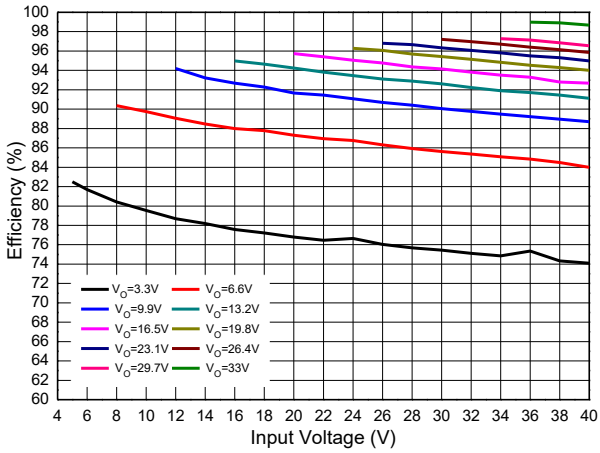
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Typical Performance Characteristics (T_A = +25°C, V_{IN} = 16V, unless otherwise specified.) (continued)

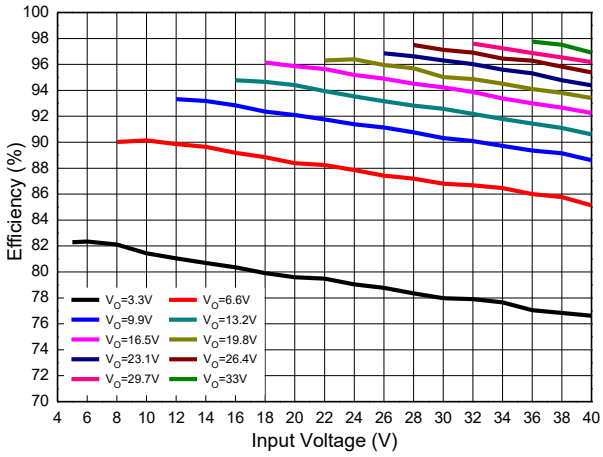
Analog Dimming (V_{IN}=16V, 3 LEDs, L=47μH, R_S=0.3Ω)
LED Current vs. CTRL Pin Voltage



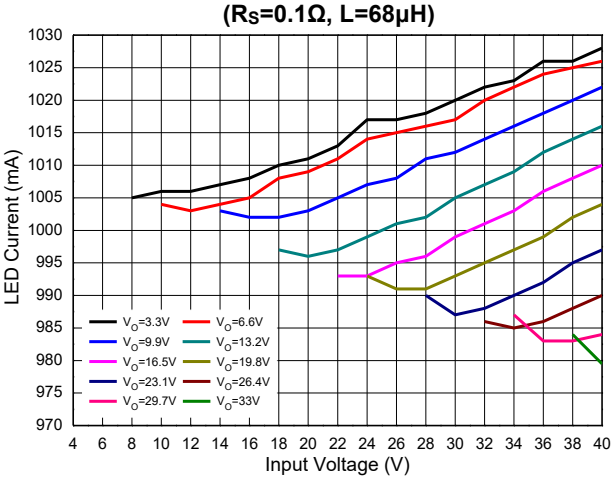
Efficiency vs. Input Voltage
(R_S=0.1Ω, L=68μH)



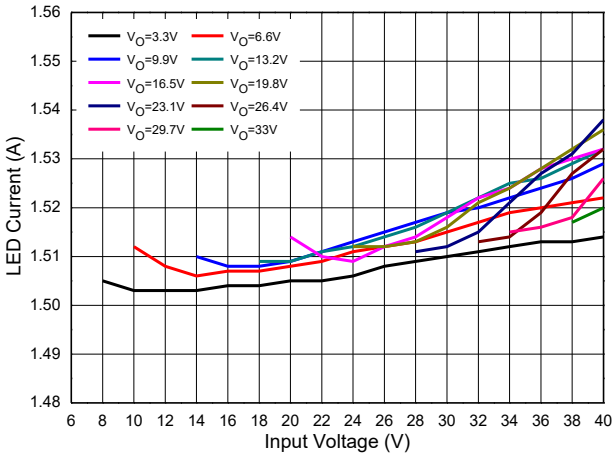
Efficiency vs. Input Voltage
(R_S=0.067Ω, L=47μH)



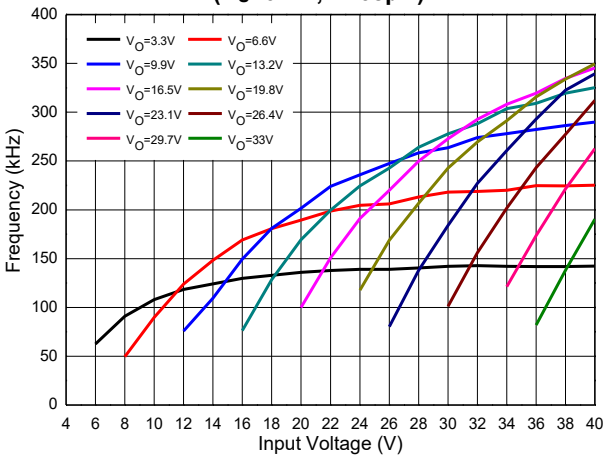
LED Current vs. Input Voltage
(R_S=0.1Ω, L=68μH)



LED Current vs. Input Voltage
(R_S=0.067Ω, L=47μH)



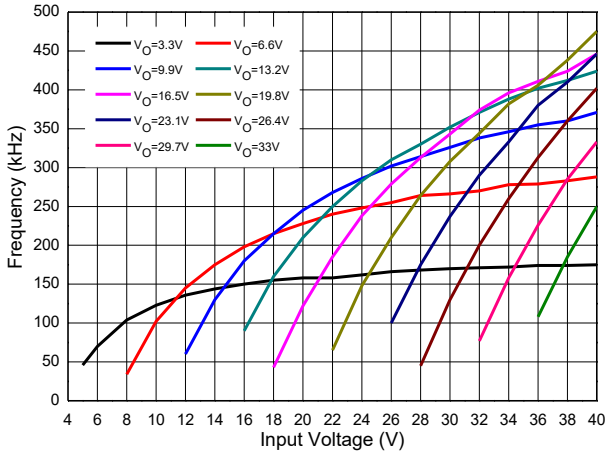
Operating Frequency vs. Input Voltage
(R_S=0.1Ω, L=68μH)



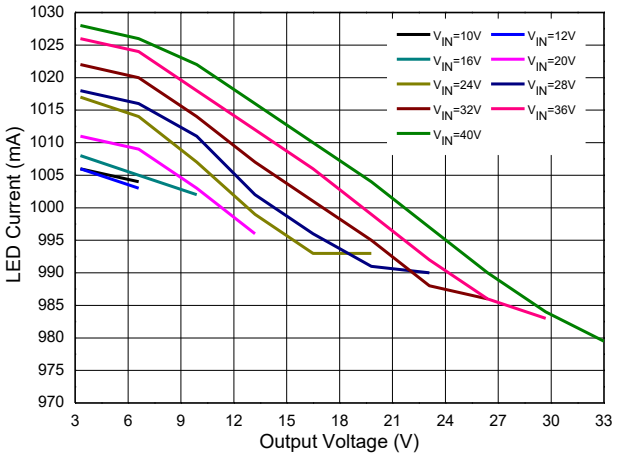
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Typical Performance Characteristics (T_A = +25°C, V_{IN} = 16V, unless otherwise specified.) (continued)

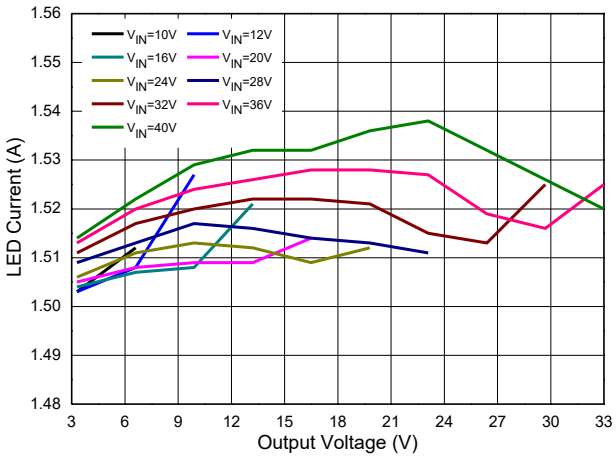
Operating Frequency vs. Input Voltage (R_S=0.067Ω, L=47μH)



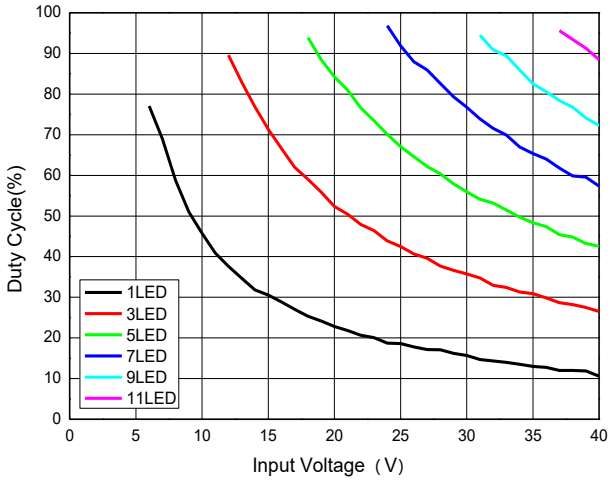
LED Current vs. Output Voltage (R_S=0.1Ω, L=68μH)



LED Current vs. Output Voltage (R_S=0.067Ω, L=47μH)



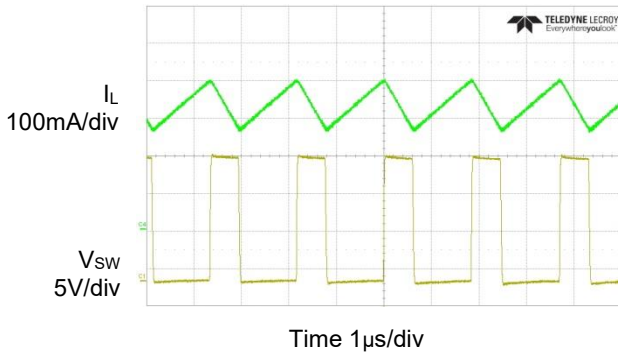
Switching Duty Cycle vs. Input Voltage (R_S=0.067Ω, L=68μH)



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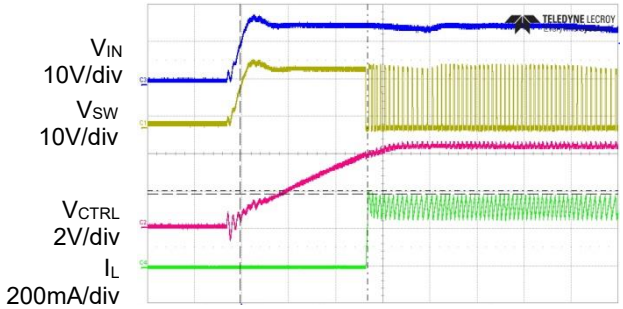
Performance Characteristics (V_{IN} = 16V, 3 LEDs, R_S = 0.3Ω, L = 47μH, T_A = +25°C, unless otherwise specified.)

Steady State



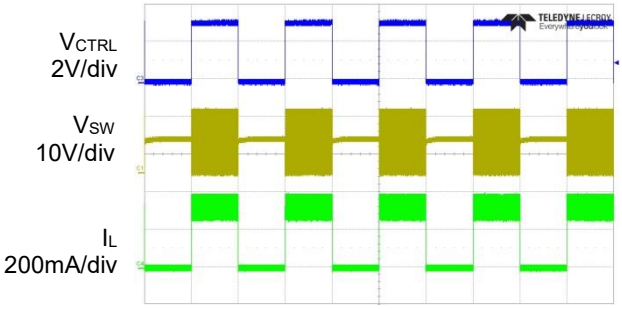
Time 1μs/div

Startup Delay Time



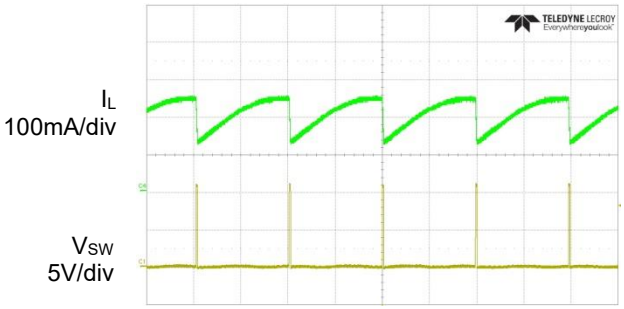
Time 20μs/div

PWM Dimming (100Hz, Duty=50%)



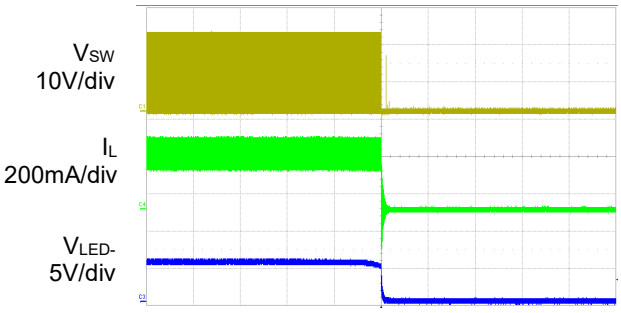
Time 5ms/div

Pulse Skip Mode



Time 20μs/div

LED Open Protection



Time 1ms/div

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Application Information

The AL8840Q is a hysteretic-mode LED driver with integrated power switch and is available in thermally enhanced MSOP-8EP package.

AL8840Q Operation

In normal operation, when normal input voltage is applied at VIN pin, the AL8840Q internal switch will turn on. Current starts to flow through the sense resistor R_S, inductor L1, and the LEDs. The current ramps up linearly, and the slew rate is determined by the input voltage V_{IN}, V_{OUT} and inductor L1.

This rising current produces a voltage ramp across R_S. The internal circuit of the AL8840Q senses the voltage across R_S and applies a proportional voltage to the input of the internal comparator. When this voltage reaches an internal upper threshold, the internal switch is turned off. The inductor current continues to flow through R_S, L1, LEDs and diode D1, and back to the supply rail, but it decays with the rate determined by the forward voltage drop of LEDs and diode D1.

This decaying current produces a falling voltage on R_S, which is sensed by the AL8840Q. A voltage proportional to the sense voltage across R_S will be applied at the input of internal comparator. When this voltage falls to the internal lower-set threshold, the internal switch is turned on again.

This switch-on-and-off cycle continues to provide the average LED current set by the sense resistor R_S.

LED Current Configuration

The nominal average output current in the LED(s) is determined by the value of the external current-sense resistor (R_S) connected between VIN pin and SET pin. It is given by:

$$I_{OUT(NOM)} = \frac{0.1}{R_S}$$

The table below provides values of nominal average output current for setting resistor (R_S) in the *Typical Application Circuit* shown on page 2.

R_S (Ω)	Nominal Average Output Current (mA)
0.066	1500
0.1	1000
0.13	760
0.15	667
0.3	333

The above values assume that the CTRL pin is floating and at a nominal reference voltage for internal comparator. It is possible to use different values of R_S if the CTRL pin is driven by an external dimming signal.

Analog Dimming

Applying a DC voltage from 0.3V to 2.5V on CTRL pin can adjust output current from 0 to 100% of I_{OUT_NOM} linearly, as shown in Figure 1. If the CTRL pin is brought higher than 2.5V, the LED current will be clamped to 100% of I_{OUT_NOM}. And the output switch will turn off if the CTRL voltage falls below the threshold of 0.3V.

PWM Dimming

The LED current can be adjusted digitally by applying a low-frequency pulse-width-modulated (PWM) logic signal to the CTRL pin to turn the device on and off. This will produce an average output current proportional to the duty cycle of the control signal. To achieve a high resolution, the PWM frequency is recommended to be lower than 500Hz; however, high dimming frequencies can be used at the expense of dimming dynamic range and accuracy. Typically, for a PWM frequency of 500Hz, the accuracy is better than 1% for PWM ranging from 1% to 100%.

The accuracy of the low duty-cycle dimming is affected by both the PWM frequency and the switching frequency of the AL8840Q. For best accuracy/resolution, the switching frequency should be increased while the PWM frequency should be reduced.

The CTRL pin is designed to be driven by 3.3V logic level directly from a logic output with either an open drain output or a push-pull output stage.

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Application Information (continued)

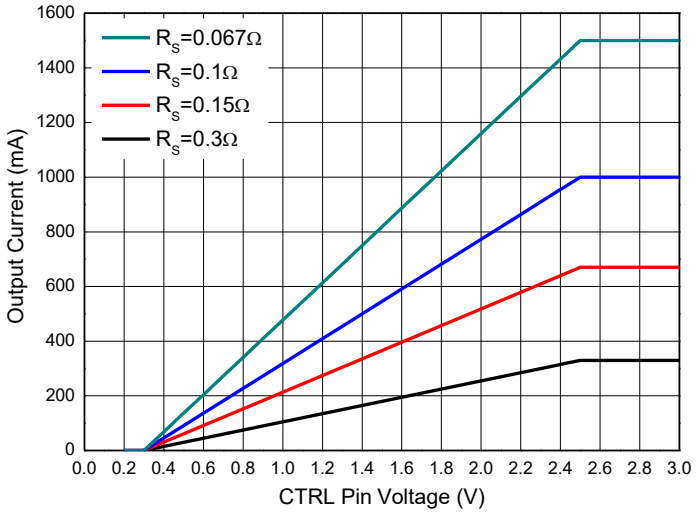


Figure 1. Analog Dimming Curve

Soft-Start

The default soft-start time for the AL8840Q is 0.1ms, and this can provide very fast turn-on of the output, improving the PWM dimming accuracy.

Nevertheless, adding an external capacitor from the CTRL pin to ground will provide a longer soft-start delay. This is achieved by increasing the time of the CTRL pin voltage rising to the turn-on threshold and slowing down the rising rate of the control voltage at the input of hysteresis comparator. The additional soft-start time is related to the capacitance between the CTRL pin and the GND pins, and the typical value will be 1.5ms/nF.

Capacitor Selection

A low ESR capacitor should be used for input decoupling, as the ESR of this capacitor appears in series with the supply source impedance and will reduce the overall efficiency. This capacitor can supply the relative high peak current to the coil and smooth the ripple on the input current.

The minimum capacity needed is determined by input power, cable length and peak current. A value between 4.7μF and 10μF is commonly used in most cases. A higher value will improve the performance at lower input voltages, especially when the source impedance is high. The input capacitor should be placed as close as possible to the IC.

For maximum stability overtemperature and voltage, capacitors with X7R, X5R, or better dielectric are recommended. Capacitors with Y5V dielectric are not suitable for decoupling in this application and should NOT be used.

Diode Selection

For maximum efficiency and performance, the freewheeling diode (D1) should be a fast low capacitance Schottky diode with low reverse leakage current. It also provides better efficiency than the silicon diodes, due to lower forward voltage and reduced recovery time.

It is important to select parts with a peak current rating above the peak coil current and a continuous current rating higher than the maximum output load current. It is very important to control the reverse leakage current of the diode when operating above +85°C. Excess leakage current will increase power dissipation.

The higher forward voltage and overshoot due to the reverse-recovery time in silicon diodes will increase the peak output voltage on the SW pins. If a silicon diode is used, more care should be taken to ensure the total voltage appearing on the SW pins including supply ripple won't exceed the specified maximum value.

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Application Information (continued)

Inductor Selection

Recommended inductor value for the AL8840Q is between 33μH and 100μH. Higher inductance is recommended at higher supply voltages in order to minimize output current tolerance due to the switching delays, which will result in increased ripple and lower efficiency. Higher inductance also results in better line regulation. The inductor should be mounted as close to the device as possible with low resistance connections to SW pins.

The chosen coil should have saturation current higher than the peak output current and a continuous current rating above the required mean output current.

The inductor value should be chosen to maintain the operating duty cycle and the switch-on/off times within the specified limits over the supply voltage and the load current range. The following equations can be used as a guide.

SW Pin Switch "On" Time:

$$t_{ON} = \frac{L\Delta I}{V_{IN} - V_{LED} - I_{LED}(R_S + R_L + R_{sw})}$$

SW Pin Switch "Off" Time:

$$t_{OFF} = \frac{L\Delta I}{V_{LED} + V_D + I_{LED}(R_S + R_L)}$$

Where: L is the coil inductance; R_L is the coil resistance; R_S is the current-sense resistance; I_{LED} is the required LED current; ΔI is the coil peak-peak ripple current (Internally set to 0.4 x I_{LED}); V_{IN} is the supply voltage; V_{LED} is the total LED forward voltage; R_{SW} is the switch resistance (0.3Ω nominal); V_D is the diode forward voltage at the required load current.

Thermal Protection

The AL8840Q includes overtemperature protection (OTP) circuitry that will turn off the device if its junction temperature reaches T_{OTP}. This is to protect the device from excessive heat damage. The OTP circuitry includes thermal hysteresis that will cause the device to restart normal operation once its junction temperature has cooled down by approximately T_{OTP_HYS}.

LED Open-Circuit Protection

The AL8840Q has the default open LED protection. If the LEDs become open circuit, the AL8840Q will stop switching; the voltage at the SET pin will rise to the voltage at the VIN pin, and the voltage at the SW pin will then fall to the voltage at the GND. No excessive voltages will be seen by the AL8840Q.

LED Short-Circuit Protection

If the LED chain becomes shorted together (the anode of the top LED becomes shorted to the cathode of the bottom LED). The AL8840Q will continue to switch and the current through the AL8840Q's internal switch will still be at the regulated current - so no excessive heat will be generated within the AL8840Q. However, the duty cycle will change dramatically, and the switching frequency will most likely decrease. See Figure 2 for an example of this status at 24V input voltage driving 3 LEDs.

The on-time of the internal power MOSFET switch is significantly reduced because almost all the input voltage is now developed across the inductor. The off-time is significantly increased because the reverse voltage across the inductor is now just the Schottky diode voltage (See Figure 2) causing a much slower decay in inductor current.

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Application Information (continued)

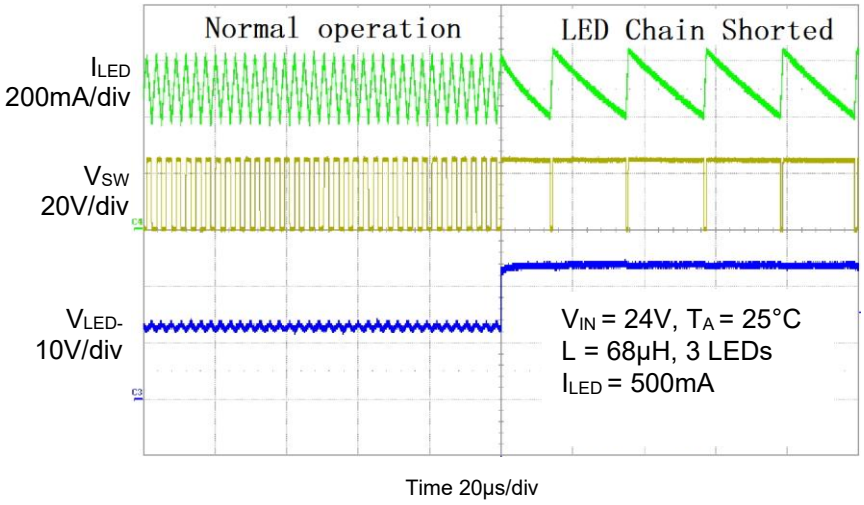


Figure 2. Switching Characteristics (Normal Operation to LED Chain Shorted Out)

EMI and Layout Considerations

The AL8840Q is a switching regulator with fast edges and measures small differential voltages; as a result, care must be taken with decoupling and layout of the PCB. To help with these effects, the AL8840Q has been developed to minimize radiated emissions by controlling the switching speeds of the internal power MOSFET. The rise and fall times are controlled to get the right compromise between power dissipation due to switching losses and radiated EMI. The turn-on edge (falling edge) dominates the radiated EMI which is due to an interaction among the Schottky diode (D1), switching MOSFET and PCB tracks. After the Schottky diode reverse-recovery time of around 5ns has occurred, the falling edge of the SW pin sees a resonant loop between the Schottky diode capacitance and the track inductance, L_{TRACK}. See Figure 3.

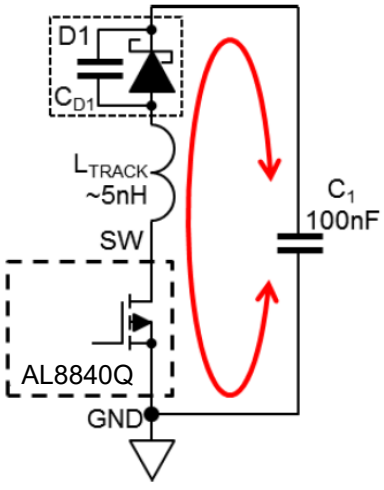


Figure 3. PCB Loop Resonance

The tracks from the SW pin to the anode of the Schottky diode, D1, and then from D1's cathode to the decoupling capacitors C1 should be as short as possible. There is an inductance internally in the AL8840Q which can be assumed to be around 1nH. For PCB tracks a figure of 0.5nH per mm can be used to estimate the primary resonant frequency. If the track is capable of handling 1A, increasing the thickness will have a minor effect on the inductance and length will dominate the size of the inductance. The resonant frequency of any oscillation is determined by the combined inductance in the track and the effective capacitance of the Schottky diode.

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Application Information (continued)

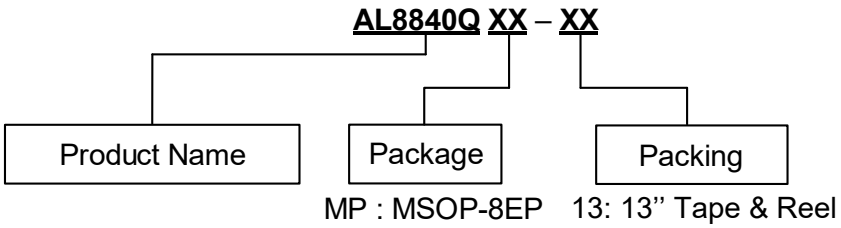
Recommendations for minimizing radiated EMI and other transients and thermal considerations are:

1. The decoupling capacitor (C1) must be placed as close as possible to the VIN pin and D1 cathode.
2. The freewheeling diode's (D1) anode, the SW pin and the inductor must be placed as close as possible to each other to avoid ringing.
3. The ground return path from C1 must be a low impedance path with the ground plane as large as possible.
4. The LED current-sense resistor (R_S) must be placed as close as possible to the VIN and SET pins.
5. Much of the conducted heat from the AL8840Q is through the GND pin 2. A maximum earth plane with thermal vias into a second earth plane will minimise self-heating.
6. To reduce emissions via long leads on the supply input and LEDs, low RF impedance capacitors should be used at the point where the wires are joined to the PCB.

Design Tools (https://www.diodes.com/design/tools/)

- AL8840Q Demo Board & User Guide
- Demo Board Gerber File for PCB Layout Reference
- PSPICE Model for Simulation

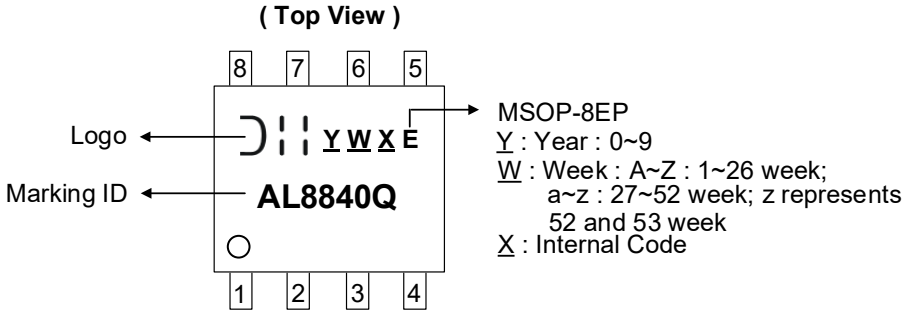
Ordering Information (Note 8)



Orderable Part Number	Package Code	Package	Packing	
			Qty.	Carrier
AL8840QMP-13	MP	MSOP-8EP	2,500	13'' Tape and Reel

Note: 8. For packaging details, go to our website at https://www.diodes.com/design/support/packaging/diodes-packaging/.

Marking Information



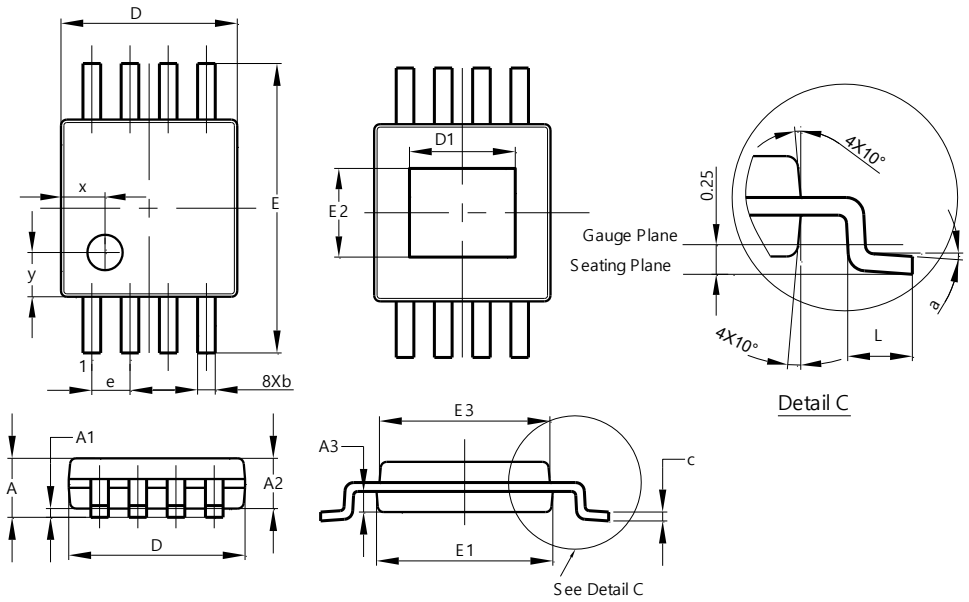
Orderable Part Number	Package	Marking ID
AL8840QMP-13	MSOP-8EP	AL8840Q

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Package Outline Dimensions

Please see http://www.diodes.com/package-outlines.html for the latest version.

MSOP-8EP

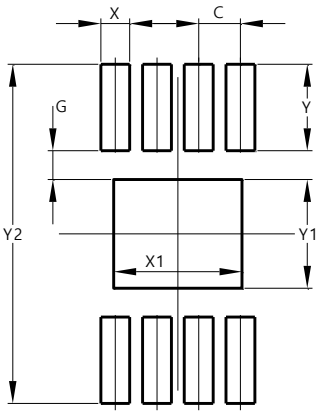


MSOP-8EP			
Dim	**Min**	**Max**	**Typ**
A	-	1.10	-
A1	0.05	0.15	0.10
A2	0.75	0.95	0.86
A3	0.29	0.49	0.39
b	0.22	0.38	0.30
c	0.08	0.23	0.15
D	2.90	3.10	3.00
D1	1.60	2.00	1.80
E	4.70	5.10	4.90
E1	2.90	3.10	3.00
E2	1.30	1.70	1.50
E3	2.85	3.05	2.95
e	-	-	0.65
L	0.40	0.80	0.60
a	0°	8°	4°
x	-	-	0.750
y	-	-	0.750
All Dimensions in mm			

Suggested Pad Layout

Please see http://www.diodes.com/package-outlines.html for the latest version.

MSOP-8EP



Dimensions	Value (in mm)
C	0.650
G	0.450
X	0.450
X1	2.000
Y	1.350
Y1	1.700
Y2	5.300

Mechanical Data

- Moisture Sensitivity: Level 1 per JESD22-A113
- Terminals: Finish – Matte Tin Plated Leads, Solderable per M2003 JESD22-B102 (e3)
- Weight: 0.026 grams (Approximate)

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