General Description
The MAX25612/MAX25612B are single-channel high-brightness LED (HB LED) drivers for automotive front-light applications such as high beam, low beam, daytime running light (DRL), turn indicator, fog light and other LED lights. They can take an input voltage from 5V to 48V and can drive a string of LEDs with a maximum output voltage of 60V. The MAX25612/MAX25612B are fully synchronous and are suitable for boost, buck-boost, SEPIC, and high-side buck applications that need synchronous rectification providing efficiencies greater than 90%.

The MAX25612/MAX25612B sense output current at the high side of the LED string. High-side current sensing is required to protect against shorts from the output to the ground or battery input. It is also the most flexible scheme for driving LEDs, allowing boost, high-side buck, or buck-boost mode configurations. The PWM input provides LED dimming ratios of up to 5000:1, and the ICTRL input provides additional analog dimming capability in the MAX25612/MAX25612B. The MAX25612/MAX25612B also include a FLT flag that indicates open string, shorted string, and thermal shutdown. The MAX25612/MAX25612B have built-in spread-spectrum modulation for improved electromagnetic compatibility performance. The MAX25612/MAX25612B are available in a space-saving (4mm x 4mm), 20-pin side-wettable TQFN or a 20-pin TSSOP package and are specified to operate over the -40°C to +125°C automotive temperature range.

Applications
● Automotive Exterior Lighting:
   • High-Beam/Low-Beam/Signal/Position Lights
   • Daytime Running Lights (DRLs)
   • Fog Light and Adaptive Front-Light Assemblies
● Commercial, Industrial, and Architectural Lighting

Benefits and Features
● Integration Minimizes BOM and Cost
   • +5.0V to +48V Wide Input Voltage Range with a Maximum +65V Boost Output
   • Integrated pMOS Dimming FET Driver
   • ICTRL Input for Analog Dimming
   • Integrated High-Side Current-Sense Amplifier
   • 200Hz Ramp Generator Simplifies PWM Dimming

Simple to Optimize for Efficiency, Board Space, and Input Operating Range
● Synchronous MOSFET Driver Improves Efficiency by up to 5% for High-Current Boost, Buck-Boost, SEPIC, and High-Side Buck Applications
● Programmable Switching Frequency (200kHz to 2.2MHz)
● 20-Pin TSSOP Package with Exposed Pad and Thermally Enhanced 4mm x 4mm, 20-Pin Side-Wettable TQFN Packages

Protection Features Increase System Reliability
● Short Circuit, Overvoltage and Thermal Protection
● Fault Diagnosis through Fault Flag

Automotive Ready
● -40°C to +125°C Operating Temperature Range
● AEC-Q100 Qualified

Simplified Typical Operating Circuit

Ordering Information appears at end of data sheet.
MAX25612/MAX25612B  Automotive Synchronous High Voltage LED Controller

Absolute Maximum Ratings

IN, UVEN to PGND .............................................-0.3V to +52V
ISENSE+, ISENSE-, DIMOUT to PGND ...............-0.3V to +65V
ISENSE- to ISENSE+ ...........................................-0.6V to +0.3V
BST, DH to PGND .............................................-0.3V to +70V
BST to LX .............................................................-0.3V to +6V
LX to PGND .............................................................-0.3V to +6V
DH to LX .................................................................-0.3V to VCC+0.3V
BST to LX .................................................................-0.3V to +6V
CSP, CSN to SGND .............................................-0.3V to VCC+0.3V
CSP-CSN ...............................................................-0.3V to +0.3V
COMP, RT to SGND .............................................-0.3V to Vcc+0.3V
VCC to SGND .............................................................-0.3V to +6V
SGND to PGND .............................................................-0.3V to +0.3V

OVP, FLT, ICTRL, PWMDIM to SGND ...............-0.3V to +6V
Continuous Current on IN ........................................100mA
Continuous Current on DL ........................................+50mA
Short Circuit Duration on VCC ..........................Continuous
Continuous Power Dissipation (20-Pin TSSOP) (TA = +70°C, derate 26mW/°C above +70°C.) ..........2122mW
Continuous Power Dissipation (20-Pin TQFN SW) (TA = +70°C, derate 25.6mW/°C above +70°C.) ..........2050mW
Operating Temperature Range ...............-40°C to +125°C
Junction Temperature ............................................+150°C
Storage Temperature Range ...............-65°C to +150°C
Lead Temperature (Soldering, 10s) ...............+300°C
Soldering Temperature (Reflow) ...................+260°C

Package Information

20-TSSOP

<table>
<thead>
<tr>
<th>PACKAGE CODE</th>
<th>U20E+3C</th>
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<tbody>
<tr>
<td>Outline Number</td>
<td>21-100132</td>
</tr>
<tr>
<td>Land Pattern Number</td>
<td>90-100049</td>
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</table>

Thermal Resistance, Single-Layer Board:

Junction to Ambient (θJA) .............................................46°C/W
Junction to Case (θJC) .................................................2°C/W

Thermal Resistance, Four-Layer Board:

Junction to Ambient (θJA) .............................................37°C/W
Junction to Case (θJC) .................................................2°C/W

20-TQFN SW

<table>
<thead>
<tr>
<th>PACKAGE CODE</th>
<th>T2044Y+3C</th>
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<td>21-10068</td>
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<tr>
<td>Land Pattern Number</td>
<td>90-0037</td>
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Thermal Resistance, Single-Layer Board:

Junction to Ambient (θJA) .............................................59°C/W
Junction to Case (θJC) .................................................6°C/W

Thermal Resistance, Four-Layer Board:

Junction to Ambient (θJA) .............................................39°C/W
Junction to Case (θJC) .................................................6°C/W

For the latest package outline information and land patterns (footprints), go to www.maximintegrated.com/packages. Note that a “+”, “#”, or “-“ in the package code indicates RoHS status only. Package drawings may show a different suffix character, but the drawing pertains to the package regardless of RoHS status.

Package thermal resistances were obtained using the method described in JEDEC specification JESD51-7, using a four-layer board. For detailed information on package thermal considerations, refer to www.maximintegrated.com/thermal-tutorial.
**Electrical Characteristics**

\((V_{IN} = 12\, \text{V}, \, C_{IN} = C_{VCC} = 1\mu\text{F}, \, DL = \text{COMP} = \text{DIMOUT} = \text{PWMDIM} = \text{FLT} = \text{unconnected}, \, V_{OVP} = V_{CS} = V_{PGND} = V_{SGND} = 0\, \text{V}, \, V_{ISENSE+} = V_{ISENSE-} = 45\, \text{V}, \, V_{ICTRL} = 1.40\, \text{V}, \, T_A = T_J = -40^\circ\text{C} \text{ to } +125^\circ\text{C}, \) unless otherwise noted. Typical values are at \(T_A = +25^\circ\text{C}\)

(Note 2)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SYMBOL</th>
<th>CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply Voltage</td>
<td>(V_{IN})</td>
<td></td>
<td>5</td>
<td>48</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>Supply Current</td>
<td>(I_{INQ})</td>
<td>(V_{OVP} = 1.5, \text{V}, \text{no switching})</td>
<td>1.8</td>
<td>5</td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td>Undervoltage Lockout</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Undervoltage Lockout Rising</td>
<td>(V_{UVEN_THUP})</td>
<td>(V_{UVEN_\text{rising}})</td>
<td>1.12</td>
<td>1.24</td>
<td>1.37</td>
<td>V</td>
</tr>
<tr>
<td>Undervoltage Lockout Hysteresis</td>
<td>(Hys)</td>
<td></td>
<td></td>
<td></td>
<td>106</td>
<td>mV</td>
</tr>
<tr>
<td>(V_{CC}) Regulator</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regulator Output Voltage</td>
<td>(V_{CC})</td>
<td>(I_{VCC} = 0.1, \text{mA to 50mA, (6, \text{V} &lt; V_{IN} &lt; 16, \text{V})})</td>
<td>4.875</td>
<td>5.0</td>
<td>5.125</td>
<td>V</td>
</tr>
<tr>
<td>Undervoltage Lockout</td>
<td>(V_{CC_UVLOR})</td>
<td>(\text{rising})</td>
<td>4.0</td>
<td></td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>Undervoltage Lockout Hysteresis</td>
<td></td>
<td></td>
<td></td>
<td>0.4</td>
<td></td>
<td>V</td>
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<tr>
<td>Oscillator (RT)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Switching Frequency Range</td>
<td>(f_{SW})</td>
<td></td>
<td>200</td>
<td>2200</td>
<td></td>
<td>kHz</td>
</tr>
<tr>
<td>Bias Voltage at RT</td>
<td>(V_{RT})</td>
<td></td>
<td>1.25</td>
<td></td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>Minimum OFF time</td>
<td></td>
<td>(V_{COMP} = \text{HIGH, } V_{CS} = 0, \text{V})</td>
<td>85</td>
<td></td>
<td></td>
<td>ns</td>
</tr>
<tr>
<td>Oscillator Frequency Accuracy</td>
<td></td>
<td>(\text{(dither disabled)})</td>
<td>-10</td>
<td>+10</td>
<td></td>
<td>%</td>
</tr>
<tr>
<td>Frequency Dither</td>
<td>(f_{DITH})</td>
<td>(\text{Dither enabled, } f_{SW} = 200, \text{kHz to 2.2MHz})</td>
<td></td>
<td>±6</td>
<td></td>
<td>%</td>
</tr>
<tr>
<td>Slope Compensation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slope-Compensation Current</td>
<td>(I_{SLOPE})</td>
<td>(\text{Peak current ramp added to CS input per switching cycle})</td>
<td>42.5</td>
<td>50</td>
<td>57.5</td>
<td>μA</td>
</tr>
<tr>
<td>Ramp Height</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Analog Dimming</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ICTRL Input Control Voltage</td>
<td>(ICTRL_\text{RNG})</td>
<td></td>
<td>0.2</td>
<td>1.2</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>Range</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ICTRL Zero Current Threshold</td>
<td>(ICTRL_ZC_VTH)</td>
<td>((V_{ISENSE^+} - V_{ISENSE^-}) &lt; 5, \text{mV})</td>
<td>0.16</td>
<td>0.18</td>
<td>0.2</td>
<td>V</td>
</tr>
<tr>
<td>ICTRL Clamp Voltage</td>
<td>(ICTRL_\text{CLMP})</td>
<td>(\text{ICTRL sink } = 1, \mu\text{A})</td>
<td>1.25</td>
<td>1.30</td>
<td>1.35</td>
<td>V</td>
</tr>
<tr>
<td>ICTRL Input Bias Current</td>
<td>(ICTRL_\text{IN})</td>
<td>(V_{ICTRL} &lt; = 5.5, \text{V})</td>
<td>-500</td>
<td>20</td>
<td>500</td>
<td>nA</td>
</tr>
<tr>
<td>LED Current-Sense Amp</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Common-Mode Input Range</td>
<td></td>
<td></td>
<td>-0.2</td>
<td>+60</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>Differential Signal Range</td>
<td></td>
<td></td>
<td>0</td>
<td>225</td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td>ISENSE+ Input Bias Current</td>
<td>(I_{B_ISENSE^+})</td>
<td>((V_{ISENSE^+} - V_{ISENSE^-}) = 200, \text{mV, } V_{I_\text{SENSE^+}} = 60, \text{V})</td>
<td>350</td>
<td>550</td>
<td></td>
<td>μA</td>
</tr>
<tr>
<td>ISENSE- Input Bias Current</td>
<td>(I_{B_ISENSE^-})</td>
<td>((V_{ISENSE^+} - V_{ISENSE^-}) = 200, \text{mV, } V_{I_\text{SENSE^+}} = 60, \text{V})</td>
<td>22</td>
<td>60</td>
<td></td>
<td>μA</td>
</tr>
<tr>
<td>Voltage Gain</td>
<td></td>
<td>((V_{ISENSE^+} - V_{ISENSE^-}) = 200, \text{mV, } 3, \text{V} &lt; [V_{ISENSE^+}, V_{ISENSE^-}] &lt; 60, \text{V})</td>
<td>4.9</td>
<td>5.0</td>
<td>5.1</td>
<td>V/V</td>
</tr>
</tbody>
</table>
## Electrical Characteristics (continued)

\( V_{IN} = 12V,\; C_{IN} = C_{VCC} = 1\mu F,\; DL = COMP = DIMOUT = PWMDIM = FLT = \) unconnected, \( V_{OVP} = V_{CS} = V_{PGND} = V_{SGND} = 0V,\)
\( V_{ISENSE+} = V_{ISENSE-} = 45V,\; V_{ICTRL} = 1.40V,\; T_A = T_J = -40ºC \) to +125ºC, unless otherwise noted. Typical values are at \( T_A = +25ºC \)

(Note 2)

### LED Current-Sense Regulation Voltage

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SYMBOL</th>
<th>CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>LED Current-Sense Regulation Voltage</td>
<td>VSENSE</td>
<td>( V_{ICTRL} = 1.3V,)</td>
<td>213.8</td>
<td>220</td>
<td>226.2</td>
<td>mV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( 3V &lt; [V_{ISENSE+}, V_{ISENSE-}] &lt; 60V )</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>( V_{ICTRL} = 1.2V,)</td>
<td>194</td>
<td>200</td>
<td>206</td>
<td>mV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( 3V &lt; [V_{ISENSE+}, V_{ISENSE-}] &lt; 60V )</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>( V_{ICTRL} = 0.4V,)</td>
<td>36</td>
<td>40</td>
<td>44</td>
<td>mV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( 3V &lt; [V_{ISENSE+}, V_{ISENSE-}] &lt; 60V )</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### LED Current-Sense Regulation Voltage (Low Range)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SYMBOL</th>
<th>CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>LED Current-Sense Regulation Voltage (Low Range)</td>
<td>VSENSE</td>
<td>( V_{ICTRL} = 1.2V,)</td>
<td>192</td>
<td>200</td>
<td>208</td>
<td>mV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( 0V &lt; [V_{ISENSE+}, V_{ISENSE-}] &lt; 3V )</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>( V_{ICTRL} = 0.4V,)</td>
<td>35</td>
<td>40</td>
<td>45</td>
<td>mV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( 0V &lt; [V_{ISENSE+}, V_{ISENSE-}] &lt; 3V )</td>
<td></td>
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</tbody>
</table>

### Common-Mode Input Range Selector

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<th>PARAMETER</th>
<th>SYMBOL</th>
<th>CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common-Mode Input Range Selector</td>
<td>RNGSEL</td>
<td>( V_{ISENSE+} ) rising</td>
<td>2.72</td>
<td>2.85</td>
<td>2.98</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( V_{ISENSE+} ) falling</td>
<td>2.48</td>
<td>2.6</td>
<td>2.72</td>
<td>V</td>
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### ERROR AMP

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<th>CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNITS</th>
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<tbody>
<tr>
<td>Transconductance</td>
<td>( 9M )</td>
<td>( (V_{ISENSE+} - V_{ISENSE-}) = 200mV )</td>
<td>170</td>
<td>180</td>
<td>2430</td>
<td>( \mu S )</td>
</tr>
<tr>
<td>COMP Sink Current</td>
<td>COMP_SINK</td>
<td>( V_{COMP} = 5V )</td>
<td>300</td>
<td></td>
<td></td>
<td>( \mu A )</td>
</tr>
<tr>
<td>COMP Source Current</td>
<td>COMP_SRC</td>
<td>( V_{COMP} = 0V )</td>
<td>300</td>
<td></td>
<td></td>
<td>( \mu A )</td>
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</table>

### PWM Comparator

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SYMBOL</th>
<th>CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNITS</th>
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</thead>
<tbody>
<tr>
<td>Input Offset Voltage</td>
<td></td>
<td></td>
<td>1</td>
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<td></td>
<td>V</td>
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</table>

### CS Limit Comparator

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<th>SYMBOL</th>
<th>CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNITS</th>
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</thead>
<tbody>
<tr>
<td>Current-Limit Threshold</td>
<td>V_CS_LIMIT</td>
<td></td>
<td>190</td>
<td>210</td>
<td>230</td>
<td>mV</td>
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### Gate Drivers (DH and DL)

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<th>PARAMETER</th>
<th>SYMBOL</th>
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<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>( R_{DS(ON)} ) Pullup pMOS</td>
<td></td>
<td></td>
<td>1.3</td>
<td></td>
<td></td>
<td>( \Omega )</td>
</tr>
<tr>
<td>( R_{DS(ON)} ) Pulldown nMOS</td>
<td></td>
<td></td>
<td>0.9</td>
<td></td>
<td></td>
<td>( \Omega )</td>
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### PWM Dimming

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<th>CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNITS</th>
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</thead>
<tbody>
<tr>
<td>Internal Ramp Frequency</td>
<td>( f_{RAMP} )</td>
<td></td>
<td>160</td>
<td>200</td>
<td>240</td>
<td>Hz</td>
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<tr>
<td>External Sync Frequency Range</td>
<td>( f_{DIM} )</td>
<td></td>
<td>60</td>
<td>2000</td>
<td></td>
<td>Hz</td>
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<tr>
<td>External Sync Low-Level Voltage</td>
<td>( V_{LTH} )</td>
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<td>0.4</td>
<td></td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>External Sync High-Level Voltage</td>
<td>( V_{HTH} )</td>
<td></td>
<td>2.0</td>
<td></td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>DIM Comparator Offset Voltage</td>
<td>( V_{DIMOF} )</td>
<td></td>
<td>170</td>
<td>200</td>
<td>230</td>
<td>mV</td>
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</tbody>
</table>

| DIM Voltage for 100% Duty Cycle                |        |                                 | 3.3  |      |      | V     |
MAX25612/MAX25612B  Automotive Synchronous
High Voltage LED Controller

Electrical Characteristics (continued)

\( V_{IN} = 12\, \text{V}, \, C_{IN} = C_{VCC} = 1\, \mu\text{F}, \, DL = COMP = DIMOUT = PWMDIM = FLT = \text{unconnected}, \, V_{OVP} = V_{CS} = V_{PGND} = V_{SGND} = 0\, \text{V}, \, V_{ISENSE+} = V_{ISENSE-} = 45\, \text{V}, \, V_{ICTRL} = 1.40\, \text{V}, \, T_A = T_J = -40^\circ\text{C} \text{ to } +125^\circ\text{C}, \text{ unless otherwise noted. Typical values are at } T_A = +25^\circ\text{C} \) (Note 2)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SYMBOL</th>
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<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNITS</th>
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<tbody>
<tr>
<td><strong>pMOS Gate Driver (DIMOUT)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak Pullup Current</td>
<td>( I_{DIMOUTPU} )</td>
<td>( V_{PWMDIM} = 0, \text{V}, , (V_{ISENSE+} - V_{DIMOUT}) = 7, \text{V} )</td>
<td>40</td>
<td>73</td>
<td>120</td>
<td>mA</td>
</tr>
<tr>
<td>Peak Pulldown Current</td>
<td>( I_{DIMOUTPD} )</td>
<td>( (V_{ISENSE+} - V_{DIMOUT}) = 0, \text{V} )</td>
<td>15</td>
<td>35</td>
<td>65</td>
<td>mA</td>
</tr>
<tr>
<td>DIMOUT Low Voltage with</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Respect to ISENSE+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overvoltage Protection (OVP)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OVP Threshold Rising</td>
<td>( V_{OVP} )</td>
<td>Output rising</td>
<td>1.17</td>
<td>1.23</td>
<td>1.29</td>
<td>V</td>
</tr>
<tr>
<td>Hysteresis</td>
<td></td>
<td></td>
<td>70</td>
<td></td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td>Input Bias Current</td>
<td>( I_{BOVP} )</td>
<td>( V_{OVP} = 1.235, \text{V} )</td>
<td>500</td>
<td></td>
<td>500</td>
<td>nA</td>
</tr>
<tr>
<td>Short-Circuit Hiccup Mode</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Short-Circuit Threshold</td>
<td>( V_{SHORT-HIC} )</td>
<td>( (V_{ISENSE+} - V_{ISENSE-}) )</td>
<td>369</td>
<td>398</td>
<td>427</td>
<td>mV</td>
</tr>
<tr>
<td>Hiccup Time</td>
<td>( T_{HICCUP} )</td>
<td></td>
<td>8192</td>
<td></td>
<td></td>
<td>Clock Cycles</td>
</tr>
<tr>
<td>Buck-Boost Short Detect</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buck-Boost Short Detect Threshold</td>
<td>( V_{SHORT-VOUT} )</td>
<td>( (V_{ISENSE+} - V_{IN}) ) falling, ( V_{IN} = 12, \text{V} )</td>
<td>1.15</td>
<td>1.55</td>
<td>1.95</td>
<td>V</td>
</tr>
<tr>
<td>Open-Drain Fault (FLT)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output Voltage Low</td>
<td>( V_{OL-FLT} )</td>
<td>( V_{IN} = 4.75, \text{V}, , V_{OVP} = 2, \text{V}, , I_{SINK} = 5, \text{mA} )</td>
<td>68.6</td>
<td>200</td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td>Thermal Shutdown</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermal Shutdown Temperature</td>
<td>( T_{SHDN} )</td>
<td>Temperature rising</td>
<td>165</td>
<td></td>
<td></td>
<td>ºC</td>
</tr>
<tr>
<td>Thermal Shutdown Hysteresis</td>
<td></td>
<td></td>
<td>10</td>
<td></td>
<td></td>
<td>ºC</td>
</tr>
</tbody>
</table>

**Note 1:** All devices are 100% tested at \( T_A = +25^\circ\text{C} \). Limits over temperature are guaranteed by design
Typical Operating Characteristics
($V_{IN} = 13.5V$, $T_A = 25^\circ C$ unless otherwise noted.)
Typical Operating Characteristics (continued)

\( V_{IN} = 13.5\, V, \, T_A = 25^\circ C \) unless otherwise noted.)
Pin Configurations

MAX25612/MAX25612B

Automotive Synchronous High Voltage LED Controller

www.maximintegrated.com
### Pin Description

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<tr>
<th>PIN</th>
<th>NAME</th>
<th>FUNCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSSOP</td>
<td>TQFN</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>19</td>
<td>ISENSE-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Negative LED Current-Sense Input. A 100Ω resistor is recommended to be placed in series with ISENSE- input and the negative terminal of the LED current-sense resistor.</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>DIMOUT</td>
</tr>
<tr>
<td></td>
<td></td>
<td>External Dimming pMOS Gate Driver</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>UVEN</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Undervoltage-Lockout (UVLO) Threshold/Enable Input. UVEN is a dual-function adjustable UVLO threshold input with an enable feature. Connect UVEN to VIN through a resistive voltage-divider to program the UVLO threshold. Observe the absolute maximum value for this pin.</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>PWMDIM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dimming Control Input. Connect PWMDIM to an external PWM signal for PWM dimming. For analog-voltage-controlled PWM dimming, connect PWMDIM to VCC through a resistive voltage-divider. The dimming frequency is 200Hz under these conditions. Connect PWMDIM to SGND to turn off the LEDs.</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>FLT</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Active-Low, Open-Drain Fault Indicator Output. See the Fault Indicator (FLT) section.</td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td>RT</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PWM Switching Frequency Programming. Connect a resistor (RRT) from RT to SGND to set the internal clock frequency.</td>
</tr>
<tr>
<td>7</td>
<td>5</td>
<td>OVP</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Overvoltage Protection Input. Connect a resistive divider between the converter output, OVP, and ground. When the voltage on OVP exceeds 1.23V, a fast-acting comparator immediately stops PWM switching. This comparator has hysteresis of 70mV.</td>
</tr>
<tr>
<td>8</td>
<td>6</td>
<td>ICTRL</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Analog Dimming Control Input. The voltage at ICTRL sets the LED current level when VCTRL &lt; 1.25V. This voltage reference can be set using a resistor-divider from VCC to SGND. For VCTRL &gt; 1.25V, the internal reference sets the LED current.</td>
</tr>
<tr>
<td>9</td>
<td>7</td>
<td>SGND</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Signal Ground</td>
</tr>
<tr>
<td>10</td>
<td>8</td>
<td>COMP</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Compensation Network Connection. For proper compensation connect a suitable RC network from COMP to SGND.</td>
</tr>
<tr>
<td>11</td>
<td>9</td>
<td>CSN</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Current-Sense Amplifier Negative Input for the Switching Regulator</td>
</tr>
<tr>
<td>12</td>
<td>10</td>
<td>CSP</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Current-Sense Amplifier Positive Input for the Switching Regulator. Add a series resistor from CSP to the switching MOSFET current-sense resistor terminal for programming the slope compensation.</td>
</tr>
<tr>
<td>13</td>
<td>11</td>
<td>PGND</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Power Ground</td>
</tr>
<tr>
<td>14</td>
<td>12</td>
<td>DL</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low-Side nMOS Gate Driver Output</td>
</tr>
<tr>
<td>15</td>
<td>13</td>
<td>VCC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5V Low-Dropout Voltage Regulator Output. VCC supplies the bias current for the gate drive and internal control logic. Bypass VCC to GND with a 4.7µF and a 0.1µF ceramic capacitor.</td>
</tr>
<tr>
<td>16</td>
<td>14</td>
<td>LX</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Switch Node of the Converter</td>
</tr>
<tr>
<td>17</td>
<td>15</td>
<td>DH</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High-Side nMOS Gate Driver Output</td>
</tr>
<tr>
<td>18</td>
<td>16</td>
<td>BST</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bootstrap Supply Input for the High-Side Driver</td>
</tr>
<tr>
<td>19</td>
<td>17</td>
<td>IN</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Positive Power-Supply Input. Bypass with a 1µF ceramic capacitor to PGND.</td>
</tr>
<tr>
<td>20</td>
<td>18</td>
<td>ISENSE+</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Positive LED Current-Sense Input. The voltage between ISENSE+ and ISENSE- is proportionally regulated to the lesser of (VCTRL, 1.23V).</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>EP</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Exposed Pad. Connect EP to the ground plane for heatsinking. Do not use EP as the only electrical connection to ground</td>
</tr>
</tbody>
</table>
Detailed Description
The MAX25612/MAX25612B are single-channel HBLED drivers for automotive front-light applications such as high beam, low beam, daytime running light (DRL), turn indicator, fog light, and other LED lights. They can take an input voltage from 5V to 48V and can drive a string of LEDs with a maximum output voltage of 60V. The MAX25612/MAX25612B feature both low- and high-side nMOS drivers for synchronous rectification. Synchronous rectification greatly improves efficiency compared to asynchronous switching converters, especially in high-current applications. Reverse recovery losses of the synchronous MOSFET will increase at higher output voltages; therefore, the efficiency benefit may be reduced when driving large numbers of LEDs. Refer to the Typical Operating Characteristics section for comparisons of synchronous and asynchronous switching efficiency with different currents and voltages.

The MAX25612/MAX25612B sense output current at the high side of the LED string. High-side current sensing is required to protect against shorts from the output to the ground or battery input. It is also the most flexible scheme for driving LEDs, allowing boost, high-side buck, SEPIC, or buck-boost mode configurations. The PWMDIM input provides LED dimming ratios of up to 5000:1, and the ICTRL input provides additional analog dimming capability in the MAX25612/MAX25612B. The MAX25612/MAX25612B also include a FLT flag that indicates open string, shorted string and thermal shutdown. The MAX25612/MAX25612B have built-in spread-spectrum modulation for improved electromagnetic compatibility performance.

Functional Operation
The operation of the MAX25612/MAX25612B is best understood by referring to the block diagram of the device. The devices are enabled when the UVEN pin goes above 1.24V. In addition to the UVEN input, the 5V regulator input also needs to be above its respective UVLO limit before switching on DL and DH can start. The MAX25612/MAX25612B are constant-frequency, current-mode controllers with low-side and high-side NMOS gate drivers for synchronous switching. Switching is initiated when PWM goes high. The RT oscillator can be programmed from 200kHz to 2.2MHz by the resistor between RT and SGND. Spread-spectrum dithering is added to the oscillator to alleviate EMI problems in the LED driver. The RT oscillator is synchronized to the positive edge of the PWM pulse. This means that the DL pulse goes high at the same instant as the positive pulse on PWMDIM. Synchronizing the RT oscillator to the PWMDIM pulse also guarantees that the switching frequency variation over a period of a PWMDIM pulse is the same from one PWMDIM pulse to the next. This prevents flicker during PWM dimming when spread spectrum is added to the RT oscillator.

Once PWMDIM transitions high, the external low-side switching MOSFET is turned on. A current flows through the low-side MOSFET, and this current is sensed by the voltage across the current-sense resistor from the source of the external low-side MOSFET to PGND. The MOSFET source is connected to the CSP input of the MAX25612/MAX25612B through a slope-compensation resistor (RSC). See the Typical Application Circuits section. The ground side of the current-sense resistor is connected to the CSN input. The slope-compensation current flows out of CSP and through the RSC resistor. The differential voltage across CSP and CSN is the voltage across the current-sense resistor (RCS_FET) + (slope-compensation current x RSC). Slope compensation prevents sub-harmonic oscillation when the duty cycle exceeds 50%. Current in the external inductor increases steadily when the external low-side MOSFET is on. The differential voltage across CSP and CSN is fed to the input of the current-limit comparator. This current-limit comparator is used to protect the external low-side switch from overcurrent and will cause switching to stop for that particular cycle if (VCSP - VCSN) exceeds 0.21V. The differential current-sense voltage signal is amplified by a gain factor of two. The output of the amplifier has a 1.0V offset added before being applied to the positive input of a PWM comparator. The negative input of this comparator is a control voltage from the error amplifier that regulates the LED current. When the positive input of the PWM comparator exceeds the control voltage from the error amplifier, the switching is stopped for that particular cycle and the external low-side nMOS stays off until the next switching cycle. The inductor current decays when the low-side nMOS is turned off. The inductor current starts ramping back up when the next switching cycle starts and the external low-side MOSFET turns back on. Through this repetitive action, the PWM control
algorithm establishes a switch duty cycle to regulate the current in the LED load.

When PWMDIM transitions high, the external dimming MOSFET that is driven by DIMOUT is also turned on. This external dimming MOSFET is a p-channel MOSFET and is connected on the high side of the LED load. The source of this pMOS is connected to ISENSE+ and the gate is connected to DIMOUT. The drain of this MOSFET is connected to the anode of the external LED string. In certain applications it is not necessary to use this dimming MOSFET, and in these cases the DIMOUT output is left open. The external pMOS is turned on when PWMDIM is high and is turned off when PWMDIM is low. During normal operation when PWMDIM is high, the voltage across the resistor from ISENSE+ to ISENSE- is regulated to a programmed voltage. This programmed voltage is 0.2 x (VICTRL - 0.2). The external pMOS switch is also used for fault protection. Once a fault condition is detected, DIMOUT is pulled high to turn off the pMOS switch. This isolates the LED string from the fault condition and prevents excessive voltage or current from damaging the LEDs.

Input Voltage (IN)
The input supply (IN) must be locally bypassed with a minimum of 1μF capacitance close to the pin. All the input current that is drawn by the MAX25612/MAX25612B goes through this input.

UVLO
The MAX25612/MAX25612B feature an adjustable UVLO using the undervoltage enable input (UVEN). Connect UVEN to IN through a resistive divider to set the UVLO threshold. The MAX25612/MAX25612B are enabled when VUVEN exceeds the 1.24V (typ) threshold. UVEN also functions as an enable/disable input to the device. Drive UVEN low to disable the device. Drive UVEN high to enable the device.

VCC Regulator
The VCC supply is the low-voltage analog supply for the chip and derives power from the input voltage from IN to PGND. An internal power-on reset (POR) monitors the VCC voltage and the IN voltage. The input voltage to the VCC regulator is disconnected when the voltage at IN goes below the UVLO threshold. A POR is generated when VCC goes below its UVLO threshold, causing the IC to reset. The chip will come out of reset state once the input voltage goes back up and the VCC regulator output is back in regulation.

Dimming MOSFET Driver (DIMOUT)
The IC requires an external p-channel MOSFET for PWM dimming. For normal operation, connect the gate of the MOSFET to the output of the dimming driver (DIMOUT). The dimming driver can sink up to 35mA or source up to 73mA of peak current for fast charging and discharging of the p-MOSFET gate. When the PWMDIM signal is high, this driver pulls the p-MOSFET gate to 7V below VISENSE+ to completely turn on the p-channel dimming MOSFET. The DIMOUT output inverts and level-shifts the signal on PWMDIM to drive the gate of the external PMOS. In some applications, the dimming FET is not used. In this case, the DIMOUT output can be left open.

LED Current-Sense Inputs (ISENSE+/ISENSE-)
The differential voltage from ISENSE+ to ISENSE- is fed to an internal current-sense amplifier. This amplified signal is then connected to the negative input of the transconductance error amplifier. The voltage-gain factor of this amplifier is 5. The offset voltage for this amplifier is +1mV. A resistor is connected between ISENSE+ and ISENSE- to program the maximum LED current. The full-scale signal is 200mV. The ISENSE+ input should be connected to the positive terminal of the current-sense resistor and the ISENSE- input should be connected to the negative terminal of the current-sense resistor (LED string anode side).

Internal Oscillator (RT)
The internal oscillator of the MAX25612/MAX25612B are programmable from 200kHz to 2.2MHz using a single resistor at RT. Use the following formula to calculate the switching frequency:

\[ f_{OSC}(kHz) = \frac{34200}{R_{RT}(k\Omega)} \]

where RRT is the resistor from RT to SGND. This equation is a linear approximation of the relationship between fOSC and RRT. See Table 1 and the Typical Operating
The current-sense voltage across \( V_{CS} \) is provided to prevent premature turn-off of the switching MOSFET in each switching cycle. Resistor \( R_{SC} \) is connected between the source of the n-channel switching MOSFET and PGND. During switching, a current ramp with a slope of \( 50 \mu Axf_{SW} \) is sourced from the CSP input. This current ramp, along with resistor \( R_{SC} \), programs the amount of slope compensation.

**Overvoltage Protection Input (OVP)**

OVP sets the overvoltage threshold limit across the LEDs. Use a resistive divider from ISENSE+ to OVP to SGND to set the overvoltage threshold limit. An internal overvoltage protection comparator senses the differential voltage across OVP and SGND. If the differential voltage is greater than 1.23\( V \), DL goes low, DH and DIMOUT go high, and FLT asserts. When the differential voltage drops by 70\( mV \), DL is enabled, DIMOUT goes low, and FLT deasserts.

**Output Short-Circuit Protection**

The MAX25612/MAX25612B feature output short-circuit protection. This feature is most useful where the LEDs are connected over long cables and there exists the possibility of shorts occurring when connectors are exposed. For the MAX25612, short circuit is detected when the following two conditions are met:

- \( V_{ISENSE+} \) is lower than \( V_{IN} \) by the \( V_{SHORT_\text{-}VOUT} \) threshold, 1.55\( V \) (typ).
- The current-sense voltage across \( V_{ISENSE+} - V_{IN} \) exceeds the \( V_{SHORT\_\text{HIC}} \) threshold, 398\( mV \) (typ).

The MAX25612B has disabled the \( V_{SHORT_\text{-}VOUT} \) threshold flag for applications where \( (V_{ISENSE+} - V_{IN}) \) is expected to be less than 1.55\( V \) (typ) during normal operation. In this case, the \( V_{SHORT\_\text{HIC}} \) threshold is the only criteria for detecting a short circuit.

The MAX25612/MAX25612B respond by stopping DL and DH switching and pulling DIMOUT high to \( V_{ISENSE+} \) to turn off the dimming FET, which disconnects the output capacitors from the shorted output. The device waits 8192 clock cycles before attempting to drive the LEDs again. The 8192-clock-cycle counter is only active while PWMDIM is HIGH.

**Internal Transconductance Error Amplifier**

The IC has a built-in transconductance amplifier that is used to amplify the error signal inside the feedback loop. When the dimming signal is low, COMP is disconnected from the output of the error amplifier and DIMOUT goes high. When the dimming signal is high, the output of the error amplifier is connected to COMP and DIMOUT goes low. This enables the compensation capacitor to hold the charge when the dimming signal has turned off the internal switching MOSFET gate drive. To maintain the charge on the compensation capacitor...
C\textsubscript{COMP}, the capacitor should be a low-leakage ceramic type. When the internal dimming signal is enabled, the voltage on the compensation capacitor forces the converter into steady state almost instantaneously. The transconductance of the amplifier is 1800\mu S.

**Analog Dimming**

The devices offer an analog dimming control input (ICCTRL). The voltage at ICTRL sets the LED current level when V\textsubscript{ICCTRL} < 1.3V (typ). The LED current can be linearly adjusted from zero with the voltage on ICTRL. For V\textsubscript{ICCTRL} > 1.3V (typ), an internal reference sets the LED current. The LED current is guaranteed to be at zero when the ICTRL voltage is at or below ICTRL\textsubscript{ZC_VTH(MIN)}. The LED current can be linearly adjusted from zero to full scale for the ICTRL voltage in the range of 0.2V to 1.2V.

**Pulse-Dimming Input**

The PWMDIM input of the MAX25612/MAX25612B functions with either analog or PWM control signals. Once the internal pulse detector detects three successive edges of a PWM signal with a frequency between 60Hz and 2kHz, the MAX25612/MAX25612B synchronize to the external signal and pulse-width modulates the LED current at the external DIM input frequency with the same duty cycle as the DIM input. PWM dimming outside this frequency range is also possible, with the caveat that the switching clock may not be synchronized to the PWM rising edge. If an analog control signal is applied to DIM, the MAX25612/MAX25612B compare the DC input to an internally generated 200Hz ramp to pulse-width-modulate the LED current (f\textsubscript{DIM} = 200Hz). The output-current duty cycle is linearly adjustable from 0% to 100% (0.2V < V\textsubscript{DIM} < 3.0V). Use the following formula to calculate the voltage, V\textsubscript{DIM}, necessary for a given output-current duty cycle D

\[ V\textsubscript{DIM} = (D \times 2.8) + 0.2V \]

where V\textsubscript{DIM} is the voltage applied to DIM in volts.

**Power Ground (PGND)**

The power ground (PGND) connection acts as the ground reference for the switching power components. Connect PGND as close as possible to the negative plate of the V\textsubscript{CC} decoupling capacitor.

**Signal Ground (SGND)**

This is the analog ground pin for all of the control circuitry of the LED driver. Connect the PGND (power ground) and the SGND together at the negative terminal of the input bypass capacitor.

**Thermal Shutdown**

The devices feature thermal protection. When the junction temperature exceeds +165°C, the external switching MOSFET starts operating at the minimum pulse width to reduce the power dissipation in the internal power MOSFETs. The part returns to regulation mode once the junction temperature goes below +155°C. This results in a cycled output during continuous thermal-overload conditions.

**Fault Indicator (FLT)**

The MAX25612/MAX25612B feature an active-low, open-drain fault indicator (FLT). FLT asserts when one of the following conditions occur:

1) Overvoltage across the LED string
2) Short-circuit condition across the LED string
3) Overtemperature condition

When the output voltage drops below the overvoltage set point minus the hysteresis, FLT deasserts. Similarly, during overtemperature fault, the FLT signal remains asserted until the junction temperature falls 10ºC below the thermal-shutdown threshold.

**Exposed Paddle**

The MAX25612/MAX25612B package features an exposed thermal pad on its underside that should be used as a heat sink. This pad lowers the package’s thermal resistance by providing a direct heat-conduction path from the die to the PCB. Connect the exposed pad and GND to the system ground using a large pad or ground plane, or multiple vias to the ground plane layer.
Applications Information

VCC Regulator
The internal 5V regulator is used to power the internal control circuitry inside the MAX25612/MAX25612B, as well as the low-side FET gate driver. This regulator can provide a load of 10mA to external circuitry. The 5V regulator requires an external ceramic capacitor for stable operation. A 4.7µF ceramic capacitor is adequate for most applications. Place the ceramic capacitor close to the IC to minimize trace length to the internal VCC pin and also to the IC ground. Choose a 10V rated low-ESR, X7R ceramic capacitor for optimal performance.

Programming the UVLO Enable Threshold
The UVLO threshold is set by resistors RUVEN1 and RUVEN2 (see the Typical Application Circuits section). The MAX25612/MAX25612B turn on when the voltage across RUVEN2 exceeds 1.24V, the UVLO threshold. Use the following equation to set the desired UVLO enable threshold:

\[
V_{UVEN} = 1.24 \times \frac{R_{UVEN1} + R_{UVEN2}}{R_{UVEN2}}
\]

where \(V_{UVEN}\) is the rising undervoltage threshold in volts. The UVEN input can also be used as a digital enable by applying an external logic signal that can turn the MAX25612/MAX25612B on and off.

Programming LED Current
Normal sensing of the LED current should be done on the high side where the LED current-sense resistor is connected to the anode of the LED string. The LED current is programmed using the resistor RCS_LED (see the Typical Application Circuits section). When ICTRL is connected to a voltage greater than 1.3V, the internal reference regulates the voltage across RCS_LED to 220mV. The current is given by:

\[
I_{LED} = \frac{0.22}{R_{CS\_LED}}
\]

The LED current can also be programmed by adjusting the voltage on ICTRL when \(V_{ICTRL} \leq 1.2V\) (analog dimming). The current is given by:

\[
I_{LED} = \frac{(V_{ICTRL} - 0.2)}{5 \times R_{CS\_LED}}
\]

Programming the Switching Frequency
The internal oscillator of the MAX25612/MAX25612B is programmable from 200kHz to 2.2MHz using a single resistor at RT. Use the following formula to calculate the value of the resistor \(R_{RT}\):

\[
R_{RT} (k\Omega) = \frac{34200}{f_{OSC}}
\]

where \(f_{OSC}\) is the desired switching frequency in kHz. This equation is a linear approximation of the relationship between \(R_{RT}\) and \(f_{OSC}\). See Table 1 and the Typical Operating Characteristics section for more data points showing the relationship between \(R_{RT}\) and \(f_{OSC}\).

Additional ±6% spread spectrum is added internally to the oscillator to improve EMI performance.

Setting the Overvoltage Threshold
The overvoltage threshold is set by resistors ROVP1 and ROVP2 (see the Typical Application Circuits section). The overvoltage circuit in the MAX25612/MAX25612B is activated when the voltage on OVP with respect to GND exceeds 1.23V. Use the following equation to set the desired overvoltage threshold:

\[
V_{OVP} = 1.23 \times (R_{OVP1} + R_{OVP2})/R_{OVP2}
\]

Table 1. Typical \(R_{RT}\) Programming Values

<table>
<thead>
<tr>
<th>(R_{RT}) (kΩ)</th>
<th>(f_{OSC}) (kHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>188</td>
<td>200</td>
</tr>
<tr>
<td>34.2</td>
<td>1000</td>
</tr>
<tr>
<td>14.7</td>
<td>2200</td>
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</table>
Inductor Selection

Boost Configuration

In the boost converter, the average inductor current varies with the line voltage. The maximum average current occurs at the lowest line voltage. For the boost converter, the average inductor current is equal to the input current. Calculate maximum duty cycle using the equation below:

\[
D_{\text{MAX}} = \left( V_{\text{LED}} - V_{\text{FET2}} - V_{\text{INMIN}} \right) / \left( V_{\text{LED}} + V_{\text{FET2}} - V_{\text{FET1}} \right)
\]

where \( V_{\text{LED}} \) is the forward voltage of the LED string in volts, \( V_{\text{INMIN}} \) is the minimum input supply voltage in volts, and \( V_{\text{FET1}} \) and \( V_{\text{FET2}} \) are the average drain-to-source voltages of the MOSFETs N1 and N2 in volts when they are on. Use an approximate value of 0.2V initially to calculate \( D_{\text{MAX}} \). A more accurate value of maximum duty cycle can be calculated once the power MOSFET is selected based on the maximum inductor current.

Use the equations below to calculate the maximum average inductor current \( I_{\text{AVG}} \), peak-to-peak inductor current ripple \( \Delta I_{L} \), and the peak inductor current \( I_{Lp} \) in amperes:

\[
I_{\text{AVG}} = I_{\text{LED}}(1 - D_{\text{MAX}})
\]

Allowing the peak-to-peak inductor ripple to be \( \Delta I_{L} \), the peak inductor current is given by:

\[
I_{Lp} = I_{\text{AVG}} + 0.5 \times \Delta I_{L}
\]

The inductance value (\( L \)) of inductor L1 in Henries (\( H \)) is calculated as:

\[
L = (V_{\text{INMIN}} - V_{\text{FET1}}) \times D_{\text{MAX}} / (f_{\text{SW}} \times \Delta I_{L})
\]

where \( f_{\text{SW}} \) is the switching frequency in Hertz, \( V_{\text{INMIN}} \) and \( V_{\text{FET1}} \) are in volts, and \( \Delta I_{L} \) is in amperes. Choose an inductor that has a minimum inductance greater than the calculated value. The current rating of the inductor should be higher than \( I_{Lp} \) at the operating temperature.

Buck-Boost Configuration

In the buck-boost LED driver, the average inductor current is equal to the input current plus the LED current. Calculate the maximum duty cycle using the following equation:

\[
D_{\text{MAX}} = \left( V_{\text{LED}} + V_{\text{FET2}} \right) / \left( V_{\text{LED}} + V_{\text{FET2}} + V_{\text{INMIN}} - V_{\text{FET1}} \right)
\]

where \( V_{\text{LED}} \) is the forward voltage of the LED string in volts, \( V_{\text{INMIN}} \) is the minimum input supply voltage in volts, and \( V_{\text{FET1}} \) and \( V_{\text{FET2}} \) are the average drain-to-source voltages of the MOSFETs N1 and N2 in volts when they are on. Use an approximate value of 0.2V initially to calculate \( D_{\text{MAX}} \). A more accurate value of maximum duty cycle can be calculated once the power MOSFET is selected based on the maximum inductor current.

Use the equations below to calculate the maximum average inductor current \( I_{\text{AVG}} \), peak-to-peak inductor current ripple \( \Delta I_{L} \), and the peak inductor current \( I_{Lp} \) in amperes:

\[
I_{\text{AVG}} = I_{\text{LED}}(1 - D_{\text{MAX}})
\]

Allowing the peak-to-peak inductor ripple to be \( \Delta I_{L} \), the peak inductor current is given by:

\[
I_{Lp} = I_{\text{AVG}} + 0.5 \times \Delta I_{L}
\]

where \( I_{Lp} \) is the peak inductor current. The inductance value (\( L \)) of inductor L1 in Henries is calculated as:

\[
L = (V_{\text{INMIN}} - V_{\text{FET1}}) \times D_{\text{MAX}} / (f_{\text{SW}} \times \Delta I_{L})
\]

where \( f_{\text{SW}} \) is the switching frequency in Hertz, \( V_{\text{INMIN}} \) and \( V_{\text{FET1}} \) are in volts, and \( \Delta I_{L} \) is in amperes. Choose an inductor that has a minimum inductance greater than the calculated value.

High-Side Buck Configuration

In the high-side buck LED driver, the average inductor current is the same as the LED current. The peak inductor current occurs at the maximum input line voltage where the duty cycle is at the minimum.

\[
D_{\text{MIN}} = \left( V_{\text{LED}} + V_{\text{FET2}} \right) / \left( V_{\text{INMAX}} - V_{\text{FET1}} \right)
\]

where \( V_{\text{LED}} \) is the forward voltage of the LED string in volts, \( V_{\text{INMAX}} \) is the maximum input supply voltage in volts, and \( V_{\text{FET1}} \) and \( V_{\text{FET2}} \) are the average drain-to-source voltages of the MOSFETs N1 and N2 in volts when they are on. Use an approximate value of 0.2V initially to calculate \( D_{\text{MIN}} \). The maximum peak-to-peak inductor ripple \( \Delta I_{L} \) occurs at the maximum input line. The peak inductor current is given by

\[
I_{Lp} = I_{\text{LED}} + 0.5 \times \Delta I_{L}
\]

The inductance value (\( L \)) of inductor L1 in Henries is calculated as:

\[
L = (V_{\text{INMAX}} - V_{\text{FET1}} - V_{\text{LED}}) \times D_{\text{MIN}} / (f_{\text{SW}} \times \Delta I_{L})
\]

where \( f_{\text{SW}} \) is the switching frequency in Hertz, \( V_{\text{INMAX}} \) and \( V_{\text{FET1}} \) are in volts, and \( \Delta I_{L} \) is in amperes. Choose an inductor that has a minimum inductance greater than the calculated value.
SEPIC Configuration

The SEPIC converter provides the option to use either a coupled inductor or two separate inductors (see Typical Application Circuits). The average L1 inductor current is equal to the input current. The average L2 inductor current is equal to the LED current. Neglecting voltage drops across the FETs, the maximum duty cycle can be calculated as follows:

\[ D_{\text{MAX}} = \frac{V_{\text{LED}}}{(V_{\text{INMIN}} + V_{\text{LED}})} \]

Where \( V_{\text{LED}} \) is the LED string voltage and \( V_{\text{INMIN}} \) is the minimum input voltage. The inductor value of L1 is given by:

\[ L_1 = \frac{V_{\text{INMIN}} \times D_{\text{MAX}}}{f_{\text{SW}} + \Delta I_{\text{IN}}} \]

Where \( \Delta I_{\text{IN}} \) is the desired maximum input current ripple. The L1 peak inductor current, \( I_{\text{L1}}^{\text{INPK}} \), is given by:

\[ I_{\text{L1}}^{\text{INPK}} = I_{\text{LED}} \times D_{\text{MAX}} \times \frac{1}{1 - D_{\text{MAX}}} + \frac{\Delta I_{\text{IN}}}{2} \]

The average current in inductor L2 is the same as the LED current. The desired maximum peak-to-peak output current ripple is \( \Delta I_{\text{OUT}} \). The value of the inductor L2 is given by:

\[ L_2 = \frac{V_{\text{INMIN}} \times D_{\text{MAX}}}{f_{\text{SW}} \times \Delta I_{\text{OUT}}} \]

The L2 peak inductor current, \( I_{\text{L2}}^{\text{OUTPK}} \), is given by:

\[ I_{\text{L2}}^{\text{OUTPK}} = I_{\text{LED}} + \frac{\Delta I_{\text{OUT}}}{2} \]

To simplify further SEPIC calculations, use the following values of L and \( I_{\text{AVG}} \):

\[ L = \frac{L_1 \times L_2}{L_1 + L_2} \]

\[ I_{\text{AVG}} = I_{\text{L1AVG}} + I_{\text{L2AVG}} \]

choose the value of \( C_{\text{SEPIC}} \) such that the peak to peak ripple on it is less than 2% of the minimum input supply voltage. This ensures that the second-order effects created by the series resonant circuit comprising L1, \( C_{\text{SEPIC}} \), and L2 does not affect the normal operation of the converter. Use the following equation:

\[ C_{\text{SEPIC}} \geq \frac{I_{\text{LED}} \times D_{\text{MAX}}}{V_{\text{INMIN}} \times 0.02 \times f_{\text{SW}}} \]

Switching MOSFET (N1) Selection

The switching MOSFET (N1) should have a voltage rating sufficient to withstand the maximum output voltage together with the voltage drop of synchronous high-side nMOS (N2), and any possible overshoot due to ringing caused by parasitic inductances and capacitances. Use a MOSFET with a drain-to-source voltage rating higher than that calculated by the following equations:

Boost configuration:

\[ V_{\text{DS\_MAX}} = (V_{\text{LED}} + V_{\text{FET2}} + V_{\text{RCS\_LED}} + V_{\text{PFET}}) \times 1.2 \]

Buck-boost configuration:

\[ V_{\text{DS\_MAX}} = (V_{\text{LED}} + V_{\text{inMax}} + V_{\text{FET2}} + V_{\text{RCS\_LED}} + V_{\text{PFET}}) \times 1.2 \]

The factor 1.2 provides 20% safety margin. A resistor is also typically added in series with the gate of the switching MOSFET (N1) to adjust the slew rate, minimize ringing on the switch node, and improve EMI performance.

Synchronous MOSFET (N2) Selection

The synchronous MOSFET (N2) should have a similar voltage rating as N1, such that it can withstand the output voltage while N1 is on and the LX node is pulled to ground, including any possible undershoot due to ringing.

Dimming MOSFET Selection

Select a dimming MOSFET (P1) with continuous current rating at the operating temperature higher than the LED current by 30%. The drain-to-source voltage rating of the dimming MOSFET must be higher than \( V_{\text{LED}} \) by 20%. A resistor may also be added in series with the gate of the dimming MOSFET to control the slew rate and help reduce current spikes that can occur when the dimming FET turns on and connects the switching converter output capacitor to any capacitors at the LED load. A capacitor may be added across the gate and drain of the dimming FET to get better control of the RC time constant that controls the slew rate. Otherwise, the RC time constant is controlled by the parasitic capacitance of the chosen pMOS.

Slope Compensation

Slope compensation should be added to converters with peak current-mode-control operating in continuous-conduction mode with more than 50% duty cycle to avoid current-loop instability and subharmonic oscillations. The minimum amount of slope compensation required for stability is given by the following equation:

\[ V_{\text{SLOPE\(\text{MIN}\)}} = 0.5 \times (\text{inductor current downslope - inductor current upslope}) \times R_{\text{CS\_FET}} \]
In the MAX25612/MAX25612B, the slope-compensating ramp is added to the current-sense signal before it is fed to the PWM comparator. Connect a resistor (R_SC) from CSP to the switch current-sense resistor terminal for programming the amount of slope compensation.

The devices generate a current ramp with a slope of 50μA/tOSC for slope compensation. The current-ramp signal is forced into an external resistor (R_SC) connected between CSP and the source of the external MOSFET, thereby adding a programmable slope-compensating voltage (V_SLOPE) at the current-sense input CSP. Therefore:

\[
\frac{dV_{\text{SLOPE}}}{dt} = \left(\frac{R_{\text{SLOPE}} \times 50\mu A}{t_{\text{OSC}}}\right)
\]

The slope-compensation voltage that needs to be added to the current signal at minimum line voltage, with margin of 1.2x, is given by the following equation:

**Boost configuration:**

\[
V_{\text{SLOPE}} = D_{\text{MAX}} \left(\frac{V_{\text{LED}} - 2 \times V_{\text{INMIN}}}{2 \times L \times f_{\text{SW}}}\right) \times 1.2
\]

**Buck-boost and SEPIC configuration:**

\[
V_{\text{SLOPE}} = D_{\text{MAX}} \left(\frac{V_{\text{LED}} - V_{\text{INMIN}}}{2 \times L \times f_{\text{SW}}}\right) \times 1.2
\]

**High-side buck configuration:**

\[
V_{\text{SLOPE}} = D_{\text{MAX}} \left(\frac{2 \times V_{\text{LED}} - V_{\text{INMIN}}}{2 \times L \times f_{\text{SW}}}\right) \times 1.2
\]

### MOSFET Current-Sense Resistor

The minimum value of the peak current-limit comparator is 0.19V. The current-sense resistor value is given by:

\[
R_{\text{CS,FET}} = \frac{0.19}{\left[\frac{V_{\text{LED}} - 2 \times V_{\text{INMIN}}}{L \times f_{\text{SW}}}\right]}
\]

For buck-boost configuration:

\[
R_{\text{CS,FET}} = \frac{0.19}{\left[\frac{V_{\text{LED}} - V_{\text{INMIN}}}{L \times f_{\text{SW}}}\right]}
\]

For SEPIC configuration:

\[
R_{\text{CS,FET}} = \frac{0.19}{\left[\frac{V_{\text{LED}} - V_{\text{INMIN}}}{L \times f_{\text{SW}}}\right]}
\]

For high-side buck configuration:

\[
R_{\text{CS,FET}} = \frac{0.19}{\left[\frac{V_{\text{LED}} - V_{\text{INMIN}}}{L \times f_{\text{SW}}}\right]}
\]

### Input Capacitor Selection

The input-filter capacitor bypasses the ripple current drawn by the converter and reduces the amplitude of high-frequency current conducted to the input supply. The ESR, ESL, and bulk capacitance of the input capacitor contribute to the input ripple. Use a low-ESR input capacitor that can handle the maximum input RMS ripple current from the converter. For the boost configuration, the input current is the same as the inductor current. For buck-boost configuration, the input current is the inductor current minus the LED current. However, for both configurations, the ripple current that the input filter capacitor has to supply is the same as the inductor ripple current with the condition that the output filter capacitor should be connected to ground for buck-boost configuration. This reduces the size of the input capacitor, as the inductor current is continuous with maximum ΔIL/2. Neglecting the effect of LED current ripple, the calculation of the input capacitor for boost, as well as buck-boost configurations is the same.
Neglecting the effect of the ESL, the ESR, and the bulk capacitance at the input contributes to the input-voltage ripple. For simplicity, assume that the contribution from the ESR and the bulk capacitance is equal. This allows 50% of the ripple for the bulk capacitance. The capacitance is given by:

\[
C_{IN} \geq \frac{\Delta I_L}{4 \times \Delta V_{IN} \times f_{SW}}
\]

where \(\Delta I_L\) is in amperes, \(C_{IN}\) is in Farads, \(f_{SW}\) is in Hertz, and \(\Delta V_{IN}\) is in volts. The remaining 50% of allowable ripple is for the ESR of the output capacitor.

Use X7R ceramic capacitors for optimal performance. The selected capacitor should have the minimum required capacitance at the operating voltage.

In buck mode, the input capacitor has large pulsed currents due to the current flowing in the synchronous MOSFET N2 when the switching MOSFET N1 is off. It is very important to consider the ripple-current rating of the input capacitor in this application.

**Output Capacitor Selection**

The function of the output capacitor is to reduce the output ripple to acceptable levels. The ESR, ESL, and bulk capacitance of the output capacitor contribute to the output ripple. In most applications, the output ESR and ESL effects can be dramatically reduced by using low-ESR ceramic capacitors. To reduce the ESL and ESR effects, connect multiple ceramic capacitors in parallel to achieve the required bulk capacitance. To minimize audible noise generated by the ceramic capacitors during PWM dimming, it may be necessary to minimize the number of ceramic capacitors on the output. In these cases, an additional electrolytic or tantalum capacitor provides most of the bulk capacitance.

**Boost and Buck-Boost Configurations**

The calculation of the output capacitance is the same for both boost and buck-boost configurations. The output ripple is caused by the ESR and bulk capacitance of the output capacitor if the ESL effect is considered negligible. For simplicity, assume that the contributions from ESR and bulk capacitance are equal, allowing 50% of the ripple for the bulk capacitance. The capacitance is given by:

\[
C_{OUT} = \frac{I_{LED} \times 2 \times D_{MAX}}{V_{OUT_RIPPLE} \times f_{SW}}
\]

The remaining 50% of allowable ripple is for the ESR of the output capacitor.

Based on this, the ESR of the output capacitor is given by:

\[
ESR_{COUT} = \frac{V_{OUT_RIPPLE}}{I_{LPK} \times 2}
\]

**Feedback Compensation**

The LED current-control loop comprising the switching converter, LED current amplifier, and error amplifier should be compensated for stable control of the LED current. The switching converter small-signal transfer function has a right half-plane (RHP) zero for boost, SEPIC, and buck-boost configurations, as the inductor current is in continuous-conduction mode. The RHP zero adds a 20dB/decade gain together with a 90° phase lag, which is difficult to compensate. The easiest way to avoid this zero is to roll off the loop gain to 0dB at a frequency less than 1/5 of the RHP zero frequency with a -20dB/decade slope.

The worst-case RHP zero frequency \(f_{ZRHP}\) is calculated as follows:

**Boost configuration:**

\[
f_{ZRHP} = \frac{V_{LED} \times (1 - D_{MAX})^2}{2\pi \times L \times I_{LED}}
\]

**Buck-boost configuration:**

\[
f_{ZRHP} = \frac{(V_{LED} + V_{IN_MIN}) \times (1 - D_{MAX})^2}{2\pi \times L \times I_{LED}}
\]

**SEPIC configuration:**

\[
f_{ZRHP} = \frac{V_{LED}(1 - D_{MAX})^2}{2\pi \times L \times I_{LED} \times D_{MAX}}
\]

The switching converter small-signal transfer function also has an output pole for both boost and buck-boost configurations. The effective output impedance that determines the output pole frequency together with the output filter capacitance is calculated as:

**Boost configuration:**

\[
R_{OUT} = \frac{(R_{LED} + R_{CS_LED}) \times V_{LED}}{(R_{LED} + R_{CS_LED}) \times I_{LED} + V_{LED}}
\]
Buck-boost configuration:

\[
R_{OUT} = \frac{(R_{LED} + R_{CSLED}) \times V_{LED}}{(R_{LED} + R_{CSLED}) \times I_{LED} \times D_{MAX} + V_{LED}}
\]

where \( R_{LED} \) is the dynamic impedance of the LED string at the operating current.

The output pole frequency for both boost and buck-boost configurations is calculated as follows:

\[
f_P = \frac{1}{2\pi R_{OUT} C_{OUT}}
\]

The feedback-loop compensation is done by connecting a resistor (\( R_{COMP} \)) and capacitor (\( C_{COMP} \)) in series from COMP to SGND. \( R_{COMP} \) is chosen to set the high-frequency integrator gain for fast transient response, while \( C_{COMP} \) is chosen to set the integrator zero to maintain loop stability. For optimum performance, choose the components using the following equations:

\[
f_C = 0.2 \times f_{ZRHP}
\]

The value of \( R_{COMP} \) and \( C_{COMP} \) can be calculated as:

\[
R_{COMP} = \frac{2 \times f_{ZRHP} \times R_{CSFET}}{f_C \times (1 - D_{MAX}) \times R_{CSLED} \times 5 \times G_M}
\]

\[
C_{COMP} = \frac{25}{\pi \times f_{ZRHP} \times R_{COMP}}
\]

the \( C_{COMP\_HF} \) capacitor will add a higher frequency pole, which helps to ensure good gain margin and stability. It is typically chosen to cancel the zero from the output capacitor ESR, or such that the pole is at one half the switching frequency, whichever is lower.

\[
f_{P2} = \frac{1}{2\pi R_{COMP} C_{COMP\_HF}}
\]

A large resistor, such as 499kΩ or 1MΩ, should be added from COMP to SGND in applications where the ICTRL input is supplied by a programmed voltage source, which may be less than 0.2V. For applications in which the ICTRL is connected to a fixed voltage from a resistor-divider, the COMP pulldown resistor is not needed.

**High-Side Buck Compensation**

The high-side buck configuration does not have a right half-plane zero to avoid, so in most cases a single capacitor from COMP to GND will suffice to compensate the loop. Calculate \( C_{COMP} \) according to the following equation:

\[
C_{COMP} = \frac{G_M \times A_V \times R_{CSLED}}{2\pi f_C \times R_{CSFET}}
\]

Where \( C_{COMP} \) is the compensation capacitor value in nF, \( G_M \) is the \( G_M \) amplifier transconductance in \( \mu A/V \), \( AV \) is the LED current-sense voltage gain, and \( f_C \) is the desired crossover frequency in kHz. Choose a crossover frequency that is lower than \( f_{SW}/15 \).

The output pole is set by the dynamic resistance of the LED string and the \( C_{OUT} \) capacitor

\[
f_{POUT} = \frac{1}{2\pi R_{DYN} \times C_{OUT}}
\]

If the output pole is within a decade of the crossover frequency, then it can be compensated by adding a resistor, \( R_{COMP} \), in series with \( C_{COMP} \).

\[
R_{COMP} = \frac{C_{OUT}}{C_{COMP}} \times R_{DYN}
\]
Typical Application Circuits
Boost LED Driver Using MAX25612
Typical Application Circuits (continued)
Buck-Boost LED Driver Using MAX25612

[Diagram of Buck-Boost LED Driver Using MAX25612]
Typical Application Circuits (continued)

High-Side Buck LED Driver Using MAX25612B

MAX25612/MAX25612B Automotive Synchronous High Voltage LED Controller
Typical Application Circuits (continued)

SEPIC01 LED Driver Using MAX25612B

MAX25612B Automotive Synchronous High Voltage LED Controller
MAX25612/MAX25612B
Automotive Synchronous
High Voltage LED Controller

Typical Application Circuits (continued)
SEPIC02 LED Driver Using MAX25612B

Ordering Information

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<thead>
<tr>
<th>PART</th>
<th>TEMPERATURE RANGE</th>
<th>PIN-PACKAGE</th>
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<td>MAX25612AUP/V+</td>
<td>-40°C to +125°C</td>
<td>20-TSSOP-EP*</td>
</tr>
<tr>
<td>MAX25612ATP/VY+</td>
<td>-40°C to +125°C</td>
<td>20-TQFN-EP*</td>
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<td>MAX25612BAUP/V+</td>
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<tr>
<td>MAX25612BATP/VY+</td>
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<td>20-TQFN-EP*</td>
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*Denotes a lead (Pb)-free/RoHS-compliant package.
/V denotes an automotive qualified part.
Y = Side-wettable package.
*EP = Exposed pad.
Revision History

<table>
<thead>
<tr>
<th>REVISION NUMBER</th>
<th>REVISION DATE</th>
<th>DESCRIPTION</th>
<th>PAGES CHANGED</th>
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<tr>
<td>0</td>
<td>6/19</td>
<td>Initial release</td>
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<tr>
<td>1</td>
<td>6/19</td>
<td>Added future-product notation to MAX25612ATP/VY+** in Ordering Information</td>
<td>21</td>
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<tr>
<td>2</td>
<td>12/19</td>
<td>Updated title to add MAX25612B; updated General Description, Benefits and Features, Electrical Characteristics, Functional Diagrams, Detailed Description, Applications Information, Typical Application Circuits, and Ordering Information</td>
<td>1–21</td>
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<td>Updated Absolute Maximum Ratings, Pin Configurations, and Applications Information; removed future-product notation from MAX25612ATP/VY+ in Ordering Information</td>
<td>2, 8, 15, 25</td>
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<td>4</td>
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