General Description
The MAX17651 ultra-low quiescent current, high-voltage linear regulator is ideal for use in industrial and battery-operated systems. The device operates from a 4V to 60V input voltage, delivers up to 100mA of load current, and consumes only 8μA of quiescent current at no load. The device consumes only 0.9μA current when in shutdown. Output voltage is adjustable in the 0.6V to 58V voltage range. Feedback voltage accuracy is ±2% over temperature. An open-drain, active-low PGOOD pin provides a power-good signal to the system upon achieving successful regulation of the output voltage. The device also incorporates an enable pin (EN) that allows the user to turn the part on or off. The device has a thermal shutdown feature that shuts down the part when the die temperature exceeds 165°C. The MAX17651 operates over the -40°C to +125°C industrial temperature range and is available in a 6 lead, compact TSOT package.

Applications
- Low-Current Industrial Power Supplies
- Battery-Powered Equipment
- Post Regulator for Switching Power Supplies
- Utility Meters
- Remote Sensors

Benefits and Features
- Extremely Easy to Use
  - Only 4 External Components Required
  - Stable with Tiny 4.7μF, 0805 Output Capacitor
  - All Ceramic Capacitors, Compact Layout
- Reduces Number of Linear Regulators to Stock
  - Wide 4V to 60V Input Voltage Range
  - Adjustable 0.6V to 58V Output
  - Up to 100mA Load Current Capability
- Operates Reliably in Adverse Industrial Environments
  - Built-In Output Voltage Monitoring with PGOOD Pin
  - High-Voltage ENABLE Input
  - Low 8μA Quiescent Current
  - Low Dropout Voltage of 560mV at 100mA
  - Overload Protection
  - Overtemperature Protection
  - High Industrial -40°C to +125°C Ambient Operating Temperature Range / -40°C to +150°C Junction Temperature Range

Ordering Information appears at end of data sheet.

Application Circuit for 5V Output
MAX17651 4V to 60V, 100mA, Ultra-Low Quiescent Current, Linear Regulator

Absolute Maximum Ratings

IN to GND ..............................................................-0.3V to +70V Junction Temperature .................................................................+150°C
EN, OUT to GND ..........................................................-0.3V to IN + 0.3V Storage Temperature Range .........................................-65°C to +160°C
FB, PGOOD to GND ......................................................-0.3V to +6V Continuous Power Dissipation (T_A = +70°C) (multilayer board)
Output Short-Circuit Duration ..................................................Continuous TSOT (derate 9.1mW/°C above +70°C) .......................727mW
Operating Temperature Range (Note 1) ...................................-40°C to +125°C Lead Temperature (soldering 10s) .................................+300°C

Note 1: Junction temperature greater than +125°C degrades operating lifetimes.

Package Information

<table>
<thead>
<tr>
<th>PACKAGE TYPE: 6 TSOT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Package Code</td>
</tr>
<tr>
<td>Outline Number</td>
</tr>
<tr>
<td>Land Pattern Number</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>THERMAL RESISTANCE, FOUR-LAYER BOARD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Junction to Ambient (θ_JA)</td>
</tr>
<tr>
<td>Junction to Case (θ_JC)</td>
</tr>
</tbody>
</table>

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.
MAX17651
4V to 60V, 100mA, Ultra-Low Quiescent Current, Linear Regulator

Electrical Characteristics

\( V_{IN} = V_{EN} = 12V, V_{FB} = V_{OUT}, \) PGOOD = OPEN, VGND = 0V, 
\( C_{OUT} = 4.7\mu F, T_A = -40^\circ C \) to \(+125^\circ C,\) unless otherwise noted. Typical values are at \( T_A = +25^\circ C.\) All voltages are referenced to GND, unless otherwise noted.) (Note 2)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SYMBOL</th>
<th>CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>INPUT SUPPLY (( V_{IN} ))</td>
<td>( V_{IN} )</td>
<td>Input Voltage Range</td>
<td>4</td>
<td>60</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( I_{IN-SH} )</td>
<td>( V_{EN} = 0V, ) shutdown mode</td>
<td>0.9</td>
<td>1.8</td>
<td>µA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( I_{IN-Q} )</td>
<td>( V_{EN} = V_{IN}, I_{LOAD} = 0mA )</td>
<td>8</td>
<td>15</td>
<td>µA</td>
<td></td>
</tr>
<tr>
<td>ENABLE (EN)</td>
<td>( V_{ENR} )</td>
<td>( V_{EN} ) rising</td>
<td>2</td>
<td></td>
<td>V</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( V_{ENF} )</td>
<td>( V_{EN} ) falling</td>
<td>0.6</td>
<td></td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>EN Leakage Current</td>
<td>( I_{EN} )</td>
<td>( T_A = +25^\circ C )</td>
<td>-100</td>
<td>+100</td>
<td>nA</td>
<td></td>
</tr>
<tr>
<td>FEEDBACK (FB)</td>
<td>( V_{FB-REG} )</td>
<td>FB Regulation Voltage</td>
<td>0.588</td>
<td>0.6</td>
<td>0.612</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>( I_{FB} )</td>
<td>( V_{FB} = 0.6V, T_A = 25^\circ C )</td>
<td>-25</td>
<td>+25</td>
<td>nA</td>
<td></td>
</tr>
<tr>
<td>CURRENT LIMIT</td>
<td>( I_{LIMIT} )</td>
<td>( V_{IN} = 5.5V, V_{OUT} = 4.5V )</td>
<td>101</td>
<td>140</td>
<td>165</td>
<td>mA</td>
</tr>
<tr>
<td>PGOOD</td>
<td>( V_{PGOOD-RISE} )</td>
<td>( V_{FB} ) rising</td>
<td>89.5</td>
<td>92</td>
<td>94.5</td>
<td>%</td>
</tr>
<tr>
<td></td>
<td>( V_{PGOOD-FALL} )</td>
<td>( V_{FB} ) falling</td>
<td>87</td>
<td>89.5</td>
<td>92</td>
<td>%</td>
</tr>
<tr>
<td></td>
<td>( I_{PGOOD} )</td>
<td>( V_{PGOOD} = 5.5V, T_A = +25^\circ C )</td>
<td>1</td>
<td></td>
<td>µA</td>
<td></td>
</tr>
<tr>
<td>OUTPUT VOLTAGE</td>
<td>( V_{DO} )</td>
<td>( V_{IN} = 4.5V, I_{LOAD} = 100mA )</td>
<td>280</td>
<td>550</td>
<td>mV</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( V_{IN} = 4V ) to 60V, ( V_{OUT} = FB, I_{LOAD} = 1mA )</td>
<td></td>
<td>0.1</td>
<td></td>
<td>%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( 0.1mA &lt; I_{LOAD} &lt; 100mA, V_{OUT} = FB )</td>
<td></td>
<td>0.5</td>
<td>1.2</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>THERMAL SHUTDOWN</td>
<td></td>
<td>Thermal-Shutdown Threshold</td>
<td>165</td>
<td></td>
<td>°C</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Thermal-Shutdown Hysteresis</td>
<td>15</td>
<td></td>
<td>°C</td>
<td></td>
</tr>
</tbody>
</table>

Note 2: All electrical specifications are 100% production tested at \( T_A = +25^\circ C.\) Specifications over the operating temperature range are guaranteed by design and characterization.
Typical Operating Characteristics
($V_{IN} = V_{EN} = 6V$, $V_{OUT} = 5V$, $C_{OUT} = 4.7\mu F$, $T_{A} = +25^\circ C$, unless otherwise noted.)

**NO LOAD SUPPLY CURRENT vs SUPPLY VOLTAGE**

**SHUTDOWN CURRENT vs SUPPLY VOLTAGE**

**SHUTDOWN SUPPLY CURRENT VS. TEMPERATURE**

**PGOOD THRESHOLD vs. TEMPERATURE**

**DROPOUT VOLTAGE vs. LOAD CURRENT**

**OUTPUT VOLTAGE vs. INPUT VOLTAGE**

**OUTPUT VOLTAGE vs. TEMPERATURE**

**LOAD TRANSIENT RESPONSE, LOAD CURRENT STEPPED FROM 1mA to 50mA, FIGURE 3 CIRCUIT**

MAX17651 4V to 60V, 100mA, Ultra-Low Quiescent Current, Linear Regulator

www.maximintegrated.com
Typical Operating Characteristics (continued)

($V_{IN} = V_{EN} = 6V$, $V_{OUT} = 5V$, $C_{OUT} = 4.7\mu F$, $T_A = +25^\circ C$, unless otherwise noted.)

LOAD TRANSIENT RESPONSE, LOAD CURRENT STEPPED FROM 50mA to 100mA, FIGURE 3 CIRCUIT

INPUT-VOLTAGE STEP RESPONSE WITH 100mA LOAD CURRENT, FIGURE 3 CIRCUIT

STARTUP RESPONSE WITH NO LOAD, FIGURE 3 CIRCUIT

STARTUP RESPONSE WITH 100mA LOAD, FIGURE 3 CIRCUIT

STARTUP RESPONSE WITH ENABLE (NO LOAD), FIGURE 3 CIRCUIT

POWER SUPPLY REJECTION RATIO, FIGURE 3 CIRCUIT

$V_{IN} = 7V$
$V_{OUT} = 5V$
$I_{OUT} = 100mA$
MAX17651
4V to 60V, 100mA, Ultra-Low Quiescent Current, Linear Regulator

Pin Configuration

![Top View of MAX17651](image)

Pin Description

<table>
<thead>
<tr>
<th>PIN</th>
<th>NAME</th>
<th>FUNCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>EN</td>
<td>Active-High, Enable Input. Force EN high (or connect to IN) to turn the regulator on. Pull EN to GND to place the device in a low-power shutdown mode.</td>
</tr>
<tr>
<td>2</td>
<td>GND</td>
<td>Ground. Connect GND to the ground plane.</td>
</tr>
<tr>
<td>3</td>
<td>IN</td>
<td>Power-Supply Input. Decouple to GND with a 0.1µF capacitor; place the capacitor close to the IN and GND pins.</td>
</tr>
<tr>
<td>4</td>
<td>OUT</td>
<td>Regulator Output. Connect at least 4.7µF, 0805 capacitor from OUT to GND.</td>
</tr>
<tr>
<td>5</td>
<td>PGOOD</td>
<td>Open-Drain PGOOD Output. Pull up PGOOD to an external power supply. PGOOD pulls low if FB drops below 89% of its set value. PGOOD goes high after FB rises above 92% of its set value. The PGOOD pin can be left floating if not used.</td>
</tr>
<tr>
<td>6</td>
<td>FB</td>
<td>Output Feedback Connection. Connect FB to a resistor divider between V\textsubscript{OUT} and GND to adjust the output voltage from 0.6V to 59V.</td>
</tr>
</tbody>
</table>

Functional Diagram

![Functional Diagram of MAX17651](image)

Figure 1. Block Diagram
Detailed Description
The MAX17651 ultra-low quiescent current, high-voltage linear regulator is ideal for use in industrial and battery-operated systems. The device operates from a 4V to 60V input voltage, delivers up to 100mA of load current and consumes only 8μA of quiescent current at no load. The device consumes only 0.9μA current when in shutdown. Output voltage is adjustable from 0.6V to 58V voltage range. Feedback voltage accuracy is ±2% over temperature.

An open-drain, active-low PGOOD pin provides a power-good signal to the system upon achieving successful regulation of the output voltage. The device also incorporates an enable pin (EN) that allows the user to turn the part on or off. The device has a thermal shutdown feature that shuts down the part when the die temperature exceeds 165°C. The MAX17651 operates over the -40°C to +125°C industrial temperature range and is available in a compact, 6-lead TSOT package.

EN Input
EN is an active-high, logic-level enable input that turns the device on or off. Drive EN high to turn the device on. While in shutdown, the device consumes only 0.9μA (typ). EN withstands voltages up to V_IN + 0.3V, allowing it to be driven by high input-level voltages, or be connected to IN for always-on operation.

Thermal Protection
When the junction temperature exceeds +165°C, an internal thermal sensor turns the pass transistor off, allowing the device to cool. The thermal sensor turns the pass transistor on again after the junction temperature cools by 15°C. This results in a cycled output during continuous thermal-overload conditions. Thermal protection protects the MAX17651 in the event of fault conditions.

Output Short-Circuit Current Limit
The MAX17651 features a 140mA (typ) current limit. The output can be shorted to GND for an indefinite period without damage to the device. During a short-circuit event, the power dissipated across the internal pass transistor can quickly heat the device. When the die temperature reaches +165°C, the MAX17651 shuts down and automatically restarts once the die temperature cools by 15°C.

Applications Information
Output Voltage Setting
The output voltage can be programmed from 0.6V to 58V. Set the output voltage by connecting a resistor divider from output to FB to GND. Choose R2 = 59kΩ, then calculate R1 with the following equation:

\[ R1 = 98.3 \times (V_{OUT} - 0.6)kΩ \]

Output Capacitor Selection
If the output voltage is less than 1.8V, use a low-ESR 10μF(min) 0805 ceramic output capacitor for good load transient response. If the output voltage is greater than or equal to 1.8V, use a low-ESR 4.7μF(min) 0805 ceramic output capacitor.

![Figure 2. Setting the Output Voltage](image-url)
**Available Output Current Calculation**

At a particular operating condition, the power loss that leads to the temperature rise of the part is estimated as follows:

\[
P_{\text{LOSS}} = (V_{\text{IN}} - V_{\text{OUT}}) \times I_{\text{LOAD}}
\]

where \(V_{\text{IN}}\) is the input voltage, \(V_{\text{OUT}}\) is the output voltage, and \(I_{\text{LOAD}}\) is the load current.

For a multilayer board, the thermal performance metrics for the package are given below:

\[
\theta_{JA} = 110°C/W
\]

**Typical Application Circuit**

The junction temperature of the MAX17651 can be estimated at any given maximum ambient temperature (\(T_{A_{\text{MAX}}}\)) from the equation below:

\[
T_J = T_{A_{\text{MAX}}} + (\theta_{JA} \times P_{\text{LOSS}})
\]

Junction temperature greater than +125°C degrades operating lifetimes. Calculate the maximum allowable output current, using the following formula:

\[
I_{\text{LOAD (MAX)}} = \frac{(125 - T_{A_{\text{MAX}}})}{110 \times (V_{\text{IN}} - V_{\text{OUT}})}
\]

Example: \(T_{A_{\text{MAX}}} = +70°C\), \(V_{\text{IN}} = 24V\), \(V_{\text{OUT}} = 5V\)

\[
I_{\text{LOAD (MAX)}} = \frac{(125 - 70)}{110 \times (24 - 5)} \approx 26mA
\]

**Ordering Information**

<table>
<thead>
<tr>
<th>PART</th>
<th>TEMP RANGE</th>
<th>PIN-PACKAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAX17651AZT+</td>
<td>-40°C to +125°C</td>
<td>6 pin TSOT</td>
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</table>

**Chip Information**

PROCESS: BICMOS
MAX17651  
4V to 60V, 100mA, Ultra-Low Quiescent Current, Linear Regulator

Revision History

<table>
<thead>
<tr>
<th>REVISION NUMBER</th>
<th>REVISION DATE</th>
<th>DESCRIPTION</th>
<th>PAGES CHANGED</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>11/14</td>
<td>Initial release</td>
<td>—</td>
</tr>
<tr>
<td>1</td>
<td>3/16</td>
<td>Updated Electrical Characteristics table and Typical Operating Characteristics section</td>
<td>1–4, 6, 7</td>
</tr>
<tr>
<td>2</td>
<td>3/17</td>
<td>Updated maximum input voltage range</td>
<td>1–6</td>
</tr>
<tr>
<td>3</td>
<td>9/17</td>
<td>Updated title, Electrical Characteristics table, and the Benefits and Features and Available Output Current Calculation sections. Replaced Note 1 for the Absolute Maximum Ratings section</td>
<td>1–9</td>
</tr>
<tr>
<td>3.1</td>
<td></td>
<td>Closed the parentheses for the Typical Operating Characteristics global characteristics</td>
<td>4–5</td>
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</tbody>
</table>

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