General Description
The MAX16141, an ideal diode controller, provides system protection against a variety of system faults, such as reverse-current, overcurrent, input overvoltage/undervoltage, and overtemperature conditions. The wide operating voltage range of 3.5V to 36V, combined with 5μA (typ) of shutdown current, make the MAX16141 ideal for automotive applications. An integrated charge pump drives the gate of the back-to-back external nFETs 9V above the source connection, minimizing power loss between the source and the load.

A fast-acting comparator allows the MAX16141 to block reverse-current flow within 1μs (max) of the input falling below the output voltage. An external current-sense resistor between RS and OUT provides overload monitoring capability. Two input pins, OVSET and UVSET, provide set points to protect against input overvoltage and undervoltage events using a simple resistive-divider.

During startup, the MAX16141 monitors the voltage drop across the external nFETs (VIN - VOUT) to ensure VOUT is greater than 0.9 x VIN. Once the startup event is complete, the MAX16141 is ready to protect against systems faults. During normal operation, some systems experience brownouts or short interruptions of power. To ensure smooth system recovery from these interruptions, the MAX16141 includes a secondary power input (VCC) to keep critical circuits alive. When the main input power recovers, the MAX16141 enables the gate in fast mode (70μs, typ) to charge the output capacitor.

Additional features include a low-power mode that allows the MAX16141 to source limited power to the load, an internal switch that helps save power during shutdown mode, and a fault output that asserts during fault conditions.

The MAX16141 is available in a 4mm x 4mm x 0.75mm, 16-pin TQFN package and operates over the automotive temperature range of -40°C to +125°C.

Benefits and Features
- Wide Voltage Range
  - 3.5V to 36V Operating Voltage Range
  - -36V to +60V Protection Voltage Range
- Eliminates Discrete Diode Power Dissipation
- Low-Power Shutdown Reduces Battery Drain
  - 5μA (Typ) Shutdown Current
  - Term Switch Isolates UVLO and OVLO Circuitry in Shutdown
- Isolates Failed Supply from Load
  - Bidirectional Current Blocking On Open
  - Bidirectional Voltage Blocking On Open
- Current Protection
  - Factory Adjustable Overcurrent Trip Thresholds
  - Factory Adjustable Reverse-Current Trip Thresholds
- Resistor Adjustable Overvoltage and Undervoltage Trip Thresholds
- Automotive Qualified
  - Operates Down to +3.5V, Riding Out Cold-Crank Conditions
  - -40°C to +125°C Operating Temperature Range
- N-Channel MOSFET Gate Driver of VIN + 8V
- Fault Output
  - UVLO, OVLO, Overcurrent, Reverse-Current, and Thermal Shutdown

Applications
- Automotive Power Systems
- Network/Telecom Power Systems
- RAID Systems
- Servers
- PoE Systems

Ordering Information appears at end of data sheet.
MAX16141
3.5V to 36V Ideal Diode Controller
with Voltage and Current Circuit Breaker

Simplified Block Diagram

[Diagram of MAX16141 showing various components such as CHARGE PUMP, OSC, SR CTRL, OC COMP, VREG_IN, SHDN SIGNAL, SLEEP SIGNAL, UVLO, RV COMP, POK COMP, VREG, AND BG, UVSET, OVSET, TERM, SLEEP, GND, GFC, GRC, FAULT, THERMAL SHDN, FALL TIME CTRL, RISE TIME CTRL, FAULT DRIVE, UVSET, VREG, AND BG, UVLO, LATCH/ AUTO-RETRY DIGITAL, OTP+ TEST MODES, TER, M, SLEEP MODE, TERM, SLEEP SIGNAL, IN, SRC, GATE, RS, OUT, Vcc, MAX16141, and various other labels and connections between components.]
MAX16141

3.5V to 36V Ideal Diode Controller
with Voltage and Current Circuit Breaker

**Absolute Maximum Ratings**

VIN to GND ................................................................. -36V to +60V
VCC, SHDN, FAULT, RS OUT to GND ................ -0.3V to +60V
RS, OUT to GND ................................................................. -0.3V to +60V
VIN to VCC, VIN to SHDN, VIN to TERM ............ -45V to +60V
SRC, GATE to GND ................................................................. -36V to +50V
SRC to GATE, VIN to VOUT, RS to OUT ............ -36V to +36V
TERM to VCC ................................................................. -15V to +1V
SLEEP, OVSET, UVSET, GRC, GFC, to GND ......... -0.3V to +6V
Continuous Sink/Source Current (all pins except FAULT) ........................................ 20mA
Continuous Sink/Source Current (FAULT) ........ 5mA
Continuous Power Dissipation (TQFN 16-Pin) ... 2000mW
Operating Temperature Range ....................... -40°C to +125°C
Junction Temperature ..................................................... +150°C
Storage Temperature Range ......................... -60°C to +150°C
Lead Temperature (soldering 10s) .................. +300°C
Soldering Temperature (reflow) .................... +260°C

**Package Information**

16-TQFN

<table>
<thead>
<tr>
<th>Package Code</th>
<th>T1644+4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outline Number</td>
<td>21-0139</td>
</tr>
<tr>
<td>Land Pattern Number</td>
<td>90-0070</td>
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</table>

Thermal Resistance, Single-Layer Board:

Junction to Ambient (θJA) | 59.30 |
Junction to Case (θJC)   | 6 |

Thermal Resistance, Four-Layer Board:

Junction to Ambient (θJA) | 40 |
Junction to Case (θJC)   | 6 |

For the latest package outline information and land patterns (footprints), go to [www.maximintegrated.com/packages](http://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](http://www.maximintegrated.com/thermal-tutorial).
### MAX16141

**3.5V to 36V Ideal Diode Controller**

**with Voltage and Current Circuit Breaker**

### Electrical Characteristics

(V\textsubscript{IN} = 12V, C\textsubscript{GATE-SRC} = 7nF, C\textsubscript{VCC} = 0.33\mu F, T\textsubscript{A} = -40°C to +125°C, unless otherwise noted. Typical values are at T\textsubscript{A} = +25°C. All specs are subject to change.)

<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>Input Voltage Range</td>
<td>V\textsubscript{IN} and V\textsubscript{CC}</td>
<td>Operating range</td>
<td>3.5</td>
<td>36</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>Input Protection Voltage Range</td>
<td>V\textsubscript{IN}</td>
<td></td>
<td>-36</td>
<td>+60</td>
<td></td>
<td>V</td>
</tr>
</tbody>
</table>

### INPUT SUPPLY CURRENT

<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>Input Supply Current</td>
<td>I\textsubscript{IN}</td>
<td>V\textsubscript{SHDN} = high, V\textsubscript{IN} = V\textsubscript{SRC} = V\textsubscript{OUT} = 12V</td>
<td>2.0</td>
<td>3.8</td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td>Input Supply Current</td>
<td>I\textsubscript{IN}</td>
<td>V\textsubscript{SHDN} = high, V\textsubscript{IN} = V\textsubscript{SRC} = V\textsubscript{OUT} = 36V</td>
<td>2.1</td>
<td>4.0</td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td>Sleep Mode Supply Current</td>
<td>I\textsubscript{SLEEP}</td>
<td>Internal PFET on, charge pump off</td>
<td>10</td>
<td>15</td>
<td></td>
<td>\mu A</td>
</tr>
<tr>
<td>SRC Input Current</td>
<td>I\textsubscript{SRC}</td>
<td>V\textsubscript{IN} = 12V, SHDN = high</td>
<td>1</td>
<td>2</td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td>Undervoltage Lockout</td>
<td>UVLO</td>
<td>V\textsubscript{IN} rising</td>
<td>3.3</td>
<td></td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>OVSET/UVSET Input Current</td>
<td></td>
<td>V\textsubscript{IN} rising</td>
<td>100</td>
<td></td>
<td></td>
<td>nA</td>
</tr>
<tr>
<td>OVSET/UVSET Threshold</td>
<td></td>
<td>V\textsubscript{IN} rising</td>
<td>0.485</td>
<td>0.5</td>
<td>0.515</td>
<td>V</td>
</tr>
<tr>
<td>OVSET Threshold Hysteresis</td>
<td>\textsubscript{V_{OV,HYS}}</td>
<td>OTP configuration-dependent</td>
<td>0.05 x \textsubscript{V_{OV,TH}}</td>
<td></td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>UVSET Threshold Hysteresis</td>
<td>\textsubscript{V_{UV,HYS}}</td>
<td>OTP configuration-dependent</td>
<td>0.05 x \textsubscript{V_{UV,TH}}</td>
<td></td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>TERM On-Resistance</td>
<td>\textsubscript{R_{TERM}}</td>
<td></td>
<td>0.7</td>
<td>1.3</td>
<td></td>
<td>k\Omega</td>
</tr>
<tr>
<td>Startup Response Time</td>
<td>t\textsubscript{SU}</td>
<td></td>
<td>450</td>
<td></td>
<td></td>
<td>\mu s</td>
</tr>
<tr>
<td>OVSET to GATE Prop Delay</td>
<td></td>
<td>V\textsubscript{OVSET} rising from (V\textsubscript{TH,OV} - 100mV) to (V\textsubscript{TH,OV} + 100mV)</td>
<td>10</td>
<td></td>
<td></td>
<td>\mu s</td>
</tr>
<tr>
<td>UVSET to GATE Prop Delay</td>
<td></td>
<td>V\textsubscript{UVSET} falling from (V\textsubscript{UV,TH} + 100mV) to (V\textsubscript{UV,TH} - 100mV)</td>
<td>20</td>
<td></td>
<td></td>
<td>\mu s</td>
</tr>
<tr>
<td>OVSET to FAULT Prop Delay</td>
<td>t\textsubscript{OV}</td>
<td>V\textsubscript{OVSET} rising from (V\textsubscript{OV,TH} - 100mV) to (V\textsubscript{OV,TH} + 100mV)</td>
<td>0.3</td>
<td></td>
<td></td>
<td>\mu s</td>
</tr>
</tbody>
</table>

### GATE OUTPUT 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>GATE Output Voltage High Above V\textsubscript{SRC}</td>
<td>V\textsubscript{GS}</td>
<td>V\textsubscript{IN} = V\textsubscript{SRC} = V\textsubscript{OUT} = 3.5V, I\textsubscript{GATE} = -1\mu A</td>
<td>5</td>
<td>6.3</td>
<td>8</td>
<td>V</td>
</tr>
<tr>
<td>GATE Output Voltage High Above V\textsubscript{SRC}</td>
<td>V\textsubscript{GS}</td>
<td>V\textsubscript{IN} = V\textsubscript{SRC} = V\textsubscript{OUT} = 12V, I\textsubscript{GATE} = -1\mu A</td>
<td>8</td>
<td>9</td>
<td>11</td>
<td>V</td>
</tr>
<tr>
<td>GATE Output Voltage High Above V\textsubscript{SRC}</td>
<td>V\textsubscript{GS}</td>
<td>V\textsubscript{IN} = V\textsubscript{SRC} = V\textsubscript{OUT} = 24V, I\textsubscript{GATE} = -1\mu A</td>
<td>7</td>
<td>8.5</td>
<td>11</td>
<td>V</td>
</tr>
<tr>
<td>GATE Output Voltage High Above V\textsubscript{SRC}</td>
<td>V\textsubscript{GS}</td>
<td>V\textsubscript{IN} = V\textsubscript{SRC} = V\textsubscript{OUT} = 36V, I\textsubscript{GATE} = -1\mu A</td>
<td>6.25</td>
<td>8</td>
<td>11</td>
<td>V</td>
</tr>
</tbody>
</table>
## Electrical Characteristics (continued)

(V\text{IN} = 12V, C_{GATE-SRC} = 7nF, C_{VCC} = 0.33\mu F, T_A = -40°C to +125°C, unless otherwise noted. Typical values are at T_A = +25°C. All specs are subject to change.)

<table>
<thead>
<tr>
<th>PARAMETER</th>
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<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>GATE Charge Pump Current</td>
<td>I_{GATE}</td>
<td>( V_{IN} = V_{GATE} = V_{SRC} = 12V )</td>
<td>1200</td>
<td>μA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SHDN, SLEEP Logic-High Input Voltge</td>
<td>V_{IH}</td>
<td></td>
<td>1.4</td>
<td>V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SHDN, SLEEP Logic-Low Input Voltage</td>
<td>V_{IL}</td>
<td></td>
<td>0.4</td>
<td>V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SHDN Input Pulse Width</td>
<td>t_{PW_{-}SHDN}</td>
<td>Pulse on SHDN pin less than 6µS will filter out (same as the MAX16126)</td>
<td>6</td>
<td>µs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SHDN Input Pulldown Current</td>
<td>I_{SPD}</td>
<td></td>
<td>0.1</td>
<td>1.2</td>
<td>μA</td>
<td></td>
</tr>
<tr>
<td>FAULT Ouput Voltage Low</td>
<td>V_{OL}</td>
<td>FAULT sinking 1mA</td>
<td>0.4</td>
<td>V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FAULT Leakage Current</td>
<td>I_{IL}</td>
<td>( V_{FAULT} = 12V )</td>
<td>0.5</td>
<td>μA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OUT Input Resistance</td>
<td>R_{OUT}</td>
<td></td>
<td>4</td>
<td>MΩ</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### REVERSE CURRENT THRESHOLD

| Reverse-Current Threshold        | V_{(OUT-IN)} | MAX16141_A                  | 7    | 10   | 14   | mV    |
| Reverse Current-Blocking Response Time | I_{REV} | Overdrive Threshold Voltage = 40mV | 0.3  | 1    | µs   |       |
| Fast Reverse Recovery Turn-On Time (Note 2) | I_{REV_{-}FAST} | Gate rise from GND to V_{SRC} + 3.5V, \( C_{GS} = 7nF \) (Note 1) | 100Ω from GATE to gate of the MOSFETs | 70    | µs   |       |

### OVERCURRENT THRESHOLDS

| Overcurrent Threshold (Note 2)   | V_{(RS-OUT)} | MAX16141A                  | 22.5 | 25   | 27.5 | mV    |
| Overcurrent Response Time        | \( V_{RS-OUT} \) | Comparator overdrive = 40mV, Response time is measured from overcurrent event to FAULT pulling low | 0.5  | µs   |      |       |
| Thermal Shutdown                 | T_{SHDN} | \( +145 \) °C             |      |      |      | °C    |
| Thermal Shudown Hysteresis       | T_{SHDN_{-}HYS} |                              | 15   | °C   |      |       |
| Power OK Threshold               | V_{OUT rising} | \( 0.9V \times \frac{V_{IN}}{V_{OUT}} \) | V    |      |      |       |
| Power OK Threshold               | V_{OUT falling} | \( 0.87 \times \frac{V_{IN}}{V_{OUT}} \) | V    |      |      |       |
### Electrical Characteristics (continued)

(V\textsubscript{IN} = 12V, C\textsubscript{GATE\textendash}SRC = 7nF, C\textsubscript{VCC} = 0.33μF, T\textsubscript{A} = -40°C to +125°C, unless otherwise noted. Typical values are at T\textsubscript{A} = +25°C. All specs are subject to change.)

<table>
<thead>
<tr>
<th>PARAMETER</th>
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<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>GATE RAMP RATE CONTROL CURRENT</td>
<td>Gate Rise Time</td>
<td>R\textsubscript{GRC} = 10kΩ, gate rising from ground to SRC + 3.5V</td>
<td>10</td>
<td></td>
<td></td>
<td>ms</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R\textsubscript{GRC} = 20kΩ, gate rising from ground to SRC + 3.5V</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>R\textsubscript{GRC} = 40kΩ, gate rising from ground to SRC + 3.5V</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>GATE RAMP DOWN</td>
<td>R\textsubscript{GFC} = 20kΩ, GATE is falling from (V\textsubscript{SRC} + 8V) to V\textsubscript{SRC}</td>
<td>200</td>
<td></td>
<td></td>
<td>μs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R\textsubscript{GFC} = 10kΩ, Gate falling form (V\textsubscript{SRC} + 8V) to V\textsubscript{SRC}</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>GATE Pulldown Current</td>
<td>Active during reverse bias detection to achieve 1μs (max) response time</td>
<td>0.280</td>
<td></td>
<td></td>
<td>A</td>
</tr>
</tbody>
</table>

**Note 1:** Tested with MOSFETs, NVD6824NL.

**Note 2:** Guaranteed by design and bench characterization.

**Note 3:** Specifications with minimum and maximum limits are 100% production tested at T\textsubscript{A} = +25°C and are guaranteed over the operating temperature range by design and characterization. Actual typical values may vary and are not guaranteed.
Typical Operating Characteristics

\( V_{IN} = V_{CC} = 12V, \ C_{VCC} = 0.33\mu F, \ T_A = -40^\circ C \) to \( +125^\circ C \), unless otherwise noted.
Typical Operating Characteristics (continued)

\[ V_{IN} = V_{CC} = 12V, \ C_{VCC} = 0.33\mu F, \ T_{A} = -40^\circ C \text{ to } +125^\circ C, \text{ unless otherwise noted.} \]
MAX16141 3.5V to 36V Ideal Diode Controller with Voltage and Current Circuit Breaker

Pin Configuration

Pin Description

<table>
<thead>
<tr>
<th>PIN</th>
<th>NAME</th>
<th>FUNCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>IN</td>
<td>Sense Input. Bypass IN with a 0.1μF ceramic capacitor to GND.</td>
</tr>
<tr>
<td>2</td>
<td>VCC</td>
<td>Auxiliary Power Input. VCC provides power to the MAX16141 during short interruption of power at IN. Connect VCC to IN through a diode. Bypass VCC to ground with a 0.1μF capacitor.</td>
</tr>
<tr>
<td>3</td>
<td>SHDN</td>
<td>Active-Low Shutdown Input. Drive SHDN low to drive GATE low and TERM to high-impedance state. Drive SHDN high for normal operation.</td>
</tr>
<tr>
<td>4</td>
<td>TERM</td>
<td>UVSET/OVSET Voltage-Divider Termination Output. TERM is internally connected to VCC through a switch. Connect TERM to the high-side of the UVSET/OVSET resistive-divider network for undervoltage and overvoltage settings.</td>
</tr>
<tr>
<td>5</td>
<td>OVSET</td>
<td>Overvoltage Threshold Adjustment Input. Connect a resistive-divider from TERM to OVSET and GND to set the overvoltage threshold.</td>
</tr>
<tr>
<td>6</td>
<td>UVSET</td>
<td>Undervoltage Threshold Adjustment Input. Connect a resistive-divider from TERM to UVSET and GND to set the undervoltage threshold.</td>
</tr>
</tbody>
</table>
### Pin Description (continued)

<table>
<thead>
<tr>
<th>PIN</th>
<th>NAME</th>
<th>FUNCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>GND</td>
<td>Ground</td>
</tr>
<tr>
<td>8</td>
<td>GRC</td>
<td>Gate Rise Control Input. Connect a resistor from GRC to ground to set the gate rise time. See Electrical Characteristics for appropriate resistor values.</td>
</tr>
<tr>
<td>9</td>
<td>GFC</td>
<td>Gate Fall Control Input. A resistor from GFC to ground allows the MAX16141 to disable the gate slower in the event of an overvoltage fault. See Electrical Characteristics for appropriate resistor values.</td>
</tr>
<tr>
<td>10</td>
<td>N.C.</td>
<td>No Connect. Connect to ground.</td>
</tr>
<tr>
<td>11</td>
<td>SLEEP</td>
<td>Active-Low Sleep Mode input. In the sleep mode, the gate drive is disabled and power to the load flows through an internal low-power switch and the body diode of the ORing FET.</td>
</tr>
<tr>
<td>12</td>
<td>FAULT</td>
<td>Active-Low, Open-Drain Fault Output. FAULT requires a pullup resistor.</td>
</tr>
<tr>
<td>13</td>
<td>OUT</td>
<td>Load Current/Output Voltage Sense Input. OUT is internally connected to a current-sense comparator input and a voltage comparator. During normal operation the MAX16141 monitors the overcurrent conditions using a sense resistor between RS and OUT. During the reverse-voltage condition, the MAX16141 enters a fault mode when the voltage between OUT and IN exceeds the set threshold.</td>
</tr>
<tr>
<td>14</td>
<td>RS</td>
<td>Current Sense Positive Input. RS is internally connected to the positive input of a current-sense resistor. Connect a sense resistor between RS and OUT to set the overload threshold.</td>
</tr>
<tr>
<td>15</td>
<td>SRC</td>
<td>Source Input. Connect SRC to the common source connection of the external n-channel MOSFETs. An external zener diode between SRC and GATE protects the gates of the external MOSFETs.</td>
</tr>
<tr>
<td>16</td>
<td>GATE</td>
<td>Gate-Driven Output. Connect GATE to the gates of the external n-channel MOSFETs. GATE is the charge-pump output during normal operation. GATE is quickly pulled low during a fault condition or when SHDN is pulled low.</td>
</tr>
</tbody>
</table>
**Detailed Description**

**Device Operation**

The MAX16141 is an ideal diode controller featuring several system-level protections, such as reverse-current, overcurrent, overvoltage, undervoltage, and overtemperature faults. The MAX16141 consumes only 5μA (typ) in shutdown mode. During a reverse-voltage condition, $V_{OUT} > V_{IN}$, the MAX16141 disables the gate within 1μs (max) of $V_{IN}$ falling below $V_{OUT}$ by the factory-set threshold.

An internal charge pump drives the gate 9V above the source voltage to fully turn on two external back-to-back N-channel FETs, minimizing power dissipation and voltage drop across the FETs. The MAX16141 monitors the load current using a sense resistor between $RS$ and $OUT$ and protects against reverse current flow when $V_{IN}$ falls below $V_{OUT}$. This device features gate ramp rate control to provide correct operation in a variety of situations. For example, the ramp-up during power-up can be adjusted to avoid excessive inrush current. In the case of an overvoltage fault, the ramp down rate is slow enough to avoid large inductive transients when interrupting high fault currents. On the other hand, the gate drive responds quickly to transient shorts of the input to ground, thereby preventing discharge of the load-side capacitance. When the input recovers, the gate drive ramps up quickly enough to provide power to the load before the load voltage can drop excessively.

**Power-Up**

At power-up, the MAX16141 monitors the output and releases the gate after 450μs of startup delay ($t_{SU}$). During power-up, the gate’s rise time is determined by value of resistor connected between $GRC$ and $GND$, while $FAULT$ remains low and goes high-impedance when the output voltage is greater than 90% of $V_{IN}$ if no fault condition is present.

**Undervoltage Protection**

The MAX16141 monitors the input voltage for undervoltage fault. An external resistive divider connected between $TERM$, $UVSET$, and $GND$ (TERM is connected to $V_{CC}$ through a switch when $SHDN$ is high). When the input voltage falls below the undervoltage threshold ($V_{CC} = V_{IN} < V_{UVTH} - V_{HYS}$), the MAX16141 pulls the gate voltage low, turning off the external MOSFETs, and $FAULT$ asserts. When the input voltage rises above the undervoltage threshold ($V_{CC} = V_{IN} > V_{UVTH}$), $GATE$ goes high after a 450μs startup delay (typ).

**Overvoltage Protection**

The MAX16141 detects an overvoltage conditions using an external resistive divider connected between TERM, $OVSET$, and $GND$ (TERM is connected to $V_{CC}$ through a switch when $SHDN$ is high). When the input voltage exceeds the programmed overvoltage threshold, the MAX16141 isolates the load from the input and disables $GATE$ low with a slow falling ramp rate, as selected by the resistor value between $GFC$ and ground. See Electrical Characteristics for $GATE$’s fall times versus resistor values. During the overvoltage fault condition, $GATE$ latches low and $FAULT$ stays asserted.

**Overvoltage/Undervoltage Threshold Hysteresis**

The MAX16141 offers 6 factory-set overvoltage/undervoltage threshold hysteresis options. See Figure 5 for available options.

**Overcurrent Protection**

The MAX16141 detects an overcurrent fault condition using a sense resistor between $RS$ and $OUT$. When the load current exceeds the factory-set threshold, the MAX16141 isolates the load from the input and disables $GATE$ low with a slow falling ramp rate, as selected by the resistor value between $GFC$ and ground. See Electrical Characteristics table for $GATE$’s fall times versus resistor values. During the overcurrent fault condition, $GATE$ enters the 300ms auto-retry mode while $FAULT$ stays asserted. Upon on the termination of overcurrent fault condition, the MAX16141 pulls the gate voltage high and allow the fault to deassert.

The MAX16141 offers 4 factory-set overcurrent threshold options. See Figure 5 for available options.

**Ideal Diode Reverse-Current Protection**

The MAX16141 detects reverse-current condition using a comparator that monitors the differential voltage between $IN$ and $OUT$. When $V_{IN}$ falls below $V_{OUT}$ by the factory-set thresholds, the MAX16141 disables the gate drive within 1μs (max) to minimize load discharge into the source. The gate drive is enabled once the input rises above the output voltage by 50mV. The MAX16141 offers 4 factory-set reverse-current threshold options. See Figure 5 for available options.
Reverse-Voltage Protection
The MAX16141 integrates reverse-voltage protection, preventing damage to the downstream circuitry caused by battery reversal or negative transients. The devices can withstand reverse voltage to -36V without damage to themselves or the load. During a reverse-voltage condition, the two external n-channel MOSFETs are turned off, protecting the load. Connect a 0.1µF ceramic capacitor from IN to GND. During normal operation, both MOSFETs are turned on and have a minimal forward voltage drop, providing lower power dissipation and a much lower voltage drop than a reverse-battery protection diode.

Thermal Shutdown Protection
The MAX16141 includes thermal shutdown protection that turns off the external MOSFETs if the internal die temperature exceeds +145°C ($T_J$). By ensuring good thermal coupling between the MOSFETs and the MAX16141, the thermal shutdown can turn off the MOSFETs if they overheat. When the junction temperature exceeds $T_J = +145°C$ (typ), the internal thermal sensor signals the shutdown logic, pulling the GATE voltage low and allowing the device to cool. The MAX16141 isolates the load from the input by pulling the gate to ground with a slow falling ramp rate to prevent transient overshoots beyond the input protection voltage and asserts FAULT. When $T_J$ drops by 15°C (typ), GATE goes high with a slow rising ramp rate and the MOSFETs turn back on. Do not exceed the absolute maximum junction-temperature rating of $T_J = +150°C$.

GATE Ramp-Up Control
To ensure proper power-up, the MAX16141 offers 3 different gate rise-times set with a resistor connected from GRC to GND. See Electrical Characteristics table for more detail. The gate’s controlled rise-time ensures soft-start with limited inrush current and is active during power-up, when exiting shutdown, recovering from undervoltage, overvoltage, and thermal faults.

Note: The values in the EC table are determined based on a 7nF gate-to-source capacitance. Depending on the gate-to-source capacitance, the rise time of the gate will be different.

GATE Ramp-Down Control
The MAX16141 controls the gate fall time using a resistor from GFC to ground. The gate’s fall-time control remains active during overvoltage, undervoltage, overcurrent and thermal fault is detected. The gate’s fall-time control is not active when the MAX16141 enters shutdown mode or detects reverse current fault condition. See Electrical Characteristics table for more detail.

Sleep Mode
The MAX16141 features a low-power mode using an active-low logic input (SLEEP). In sleep mode, the MAX16141 consumes about 10µA (typ) of current while sources up to 400µA (typ) to the load. During sleep mode, the gate drive remains disabled and the MAX16141 provides power to the load through the body diode of the MOSFET that is connected to SRC and an internal switch. See Figure 1 for more detail.

Figure 1. Sleep Mode Operation
**Gate Charge Pump**

An internal charge pump generates the GATE-to-SRC voltage to enhance the external MOSFETs. After the input voltage exceeds the input undervoltage threshold, the charge pump turns on after a 450µs startup delay. During a fault condition, GATE is disabled with a 280mA pulldown current.

**TERM Connection**

The TERM connection has an internal switch to VCC. In shutdown (SHDN = low), this switch is open. By connecting the voltage threshold resistive divider to TERM instead of directly to VCC, power dissipation in the resistive divider can be eliminated and the supply current in shutdown mode reduced.

During shutdown mode, the (VCC - VTERM) can be as high 60V but (VTERM - VCC) must be limited to < 1V due to parasitic diode.

**FAULT Output**

FAULT is an open-drain output that indicates fault conditions. During startup, FAULT is initially low and goes high-impedance when VOUT is greater than 90% of VIN if no fault conditions are present. FAULT asserts low during shutdown mode, reverse-current, overcurrent, overvoltage, thermal shutdown, or undervoltage faults, or when VOUT falls below 90% of VIN.

**Auto-Retry**

The MAX16141 enters auto-retry mode of 300ms during overcurrent, output short-circuit and thermal shutdown faults only. In auto-retry mode, the gate drive is enabled every 300ms (typ) to check if the fault condition is removed or not. If the fault is active, the gate will be pulled low after a short duration of 20ms (typ). If the fault condition is removed, the gate will stay on and the MAX16141 resume normal operation. During these fault conditions, FAULT asserts low and deasserts once the fault conditions are removed.

**Applications Information**

**Setting Overvoltage/Undervoltage Threshold**

The MAX16141 features window-detection threshold comparators. The noninverting input of the undervoltage comparator shares the same reference voltage connected to the inverting input of the overvoltage comparator. This configuration allows using three-resistor network to set both undervoltage and overvoltage thresholds. The top of the resistive divider network connects to TERM. See Figure 2. When the input voltage falls outside the set window-threshold, the gate voltage is disabled and the n-channel MOSFETs are turned off. Use the equations below to set the thresholds:

\[
V_{\text{UVTH}} = \left( V_{\text{TH}} - V_{\text{TH,HYS}} \right) \frac{R_{\text{TOTAL}}}{R_2 + R_3},
\]

\[
V_{\text{OVTH}} = \left( V_{\text{TH}} \right) \frac{R_{\text{TOTAL}}}{R_3}.
\]

Where \(V_{\text{UVTH}}\) and \(V_{\text{OVTH}}\) are the undervoltage and overvoltage thresholds respectively, \(R_{\text{TOTAL}} = R_1 + R_2 + R_3\), \(V_{\text{TH}}\) is the 0.5V OVSET and UVSET threshold, and the \(V_{\text{TH,HYS}}\) is the hysteresis.

Use the steps below to determine values for R1, R2, and R3.

1) Choose a value for \(R_{\text{TOTAL}}\), the sum of R1, R2, and R3.

2) Calculate R3 based on \(R_{\text{TOTAL}}\) and the desired overvoltage threshold point, OVTH:

\[
R_3 = \left( \frac{V_{\text{TH}} \times R_{\text{TOTAL}}}{V_{\text{OVTH}}} \right).
\]

3) Calculate R2 based on \(R_{\text{TOTAL}}\), R3 and the desired undervoltage threshold point, UVTH:

\[
R_2 = \left( \frac{V_{\text{TH}} - V_{\text{TH,HYS}} \times R_{\text{TOTAL}}}{V_{\text{UVTH}}} \right) - R_3
\]

4) Calculate R1 based on \(R_{\text{TOTAL}}\), R2 and R3:

\[
R_1 = R_{\text{TOTAL}} - R_2 - R_3
\]
The MAX16141 offers factory threshold hysteresis for undervoltage and overvoltage threshold settings.

**Reverse-Voltage Protection**
Traditionally, discrete diodes have been used to block reverse current flow and prevent output capacitor discharge. However, for high-current applications, ideal diode controllers (FET-based solutions) are more appealing due to their low power dissipation. But, unlike a discrete diode that blocks reverse current instantaneously, a typical ideal diode controller reacts much more slowly. To prevent heavy discharge of the load-side capacitor in the case of a fault that shorts the input to ground, the MAX16141 disables the gate drive within 1µs (max) of detection of the reverse-voltage condition. See Figure 3.

![Figure 2. UVSET and OVSET Thresholds Setting](image)

![Figure 3. Reverse-Voltage Fault](image)
The MAX16141 protects against negative input voltage down to -36V. High leakage current of the back-to-back MOSFETs and diode (D1) between IN and VCC can cause OUT and VCC pins to drop below their minimum ABS max ratings. For proper protection against negative input voltage, low leakage MOSFETs and diode is recommended.

**Overcurrent Threshold Setting**

Use the formula below to set the overcurrent threshold:

\[ I_{OC} = \frac{V_{RS-OUT}}{R_{SENSE}} \]

where,

- \( V_{RS-OUT} \) is the overcurrent threshold voltage in Volts
- \( R_{SENSE} \) is the resistor in Ohms connected between RS and OUT.

**Short Power Interruptions**

In an automotive environment, systems usually experience brief power interruptions where the main supply is shorted to ground. The power interruption may last for several seconds; and the only source of power to system load is the output capacitance. To ensure fast recovery, an auxiliary input (VCC) helps keep the MAX16141 standby mode for 100µs (typ). When the main supply input (IN) recovers, the MAX16141 initiates a fast recovery mode that allows the gate to reach its peak voltage within 70µs (typ). See **Figure 4** for more detail. Therefore, brief power supply interruptions will not affect operation of the load, as long as the load-side capacitance is sufficiently large to power the load during the interruption.

Since VCC provides power to the MAX16141 when the main supply is shorted to ground, a low-leakage diode such as CMPD4150 from VIN to VCC and a bulk capacitance is required to keep the MAX16141 in standby mode. See **Typical Application Circuit** for proper connection. The size of the bulk capacitance is dictated by the expected duration of the power interruption and supply current of the MAX16141. Below is a simple bulk capacitance calculation for 100µs power interruption and 1V drop in VCC voltage.

\[ C_{VCC} = \left( \frac{I_{CC} \times 100 \times 10^{-6}}{\Delta V_{CC}} \right) \]

Where \( C_{VCC} \) is the bulk capacitance at VCC, \( I_{CC} \) is the supply current in amper, and \( \Delta V_{CC} \) is the desired droop in VCC in volts.

\[ \left( 3 \times 10^{-3} \text{ (A)} \times 100 \times 10^{-6} \text{ (s)} \right) \div 1\text{V} \approx 0.33\mu\text{F} \]

**Note:** If the input voltage sags slowly and the output follows, the differential voltage between the input and output may always be less than factory-set threshold. In this case, the reverse-current fault may not occur. Instead, an undervoltage fault may eventually be detected; causing the gate drive to be disabled.

---

**Figure 4. Short Power Interruption and Recover**

[Diagram showing voltage waveform changes during power interruption and recovery]
MOSFET Selection

MOSFET selection is critical to design a proper protection circuit. Several factors must be considered: the gate capacitance, the drain-to-source voltage rating, the on-resistance (R\text{DS}(\text{ON}))\text{, the peak power dissipation capability, and the average power dissipation limit. In general, both MOSFETs should have the same part number. For size-constrained applications, a dual MOSFET can conserve board area. Select the drain-to-source voltage so that the MOSFETs can handle the highest voltage that might be applied to the circuit. Gate capacitance is not as critical, but it does determine the maximum turn-on and turn-off time. MOSFETs with more gate capacitance tend to respond more slowly.}

MOSFET Power Dissipation

The R\text{DS}(\text{ON}) must be low enough to limit the MOSFET power dissipation during normal operation. Power dissipation (per MOSFET) during normal operation can be calculated using this formula:

\[ P = I_{\text{LOAD}}^2 \times R_{\text{DS}(\text{ON})} \]

where \( P \) is the power dissipated in each MOSFET and \( I_{\text{LOAD}} \) is the average load current.

During a fault condition in switch mode, the MOSFETs turn off and do not dissipate power. Limiter mode imposes the worst-case power dissipation. The average power can be computed using the following formula:

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

where \( P \) is the average power dissipated in both MOSFETs, \( I_{\text{LOAD}} \) is the average load current, \( V_{\text{IN}} \) is the input voltage, and \( V_{\text{OUT}} \) is the average limited voltage on the output. In limiter mode, the output voltage is a sawtooth wave with characteristics determined by the R\text{DS}(\text{ON}) of the MOSFETs, the output load current, the output capacitance, the gate charge of the MOSFETs, and the GATE charge-pump current.

Since limiter mode can involve high switching currents when the GATE is turning on at the start of a limiting cycle (especially when the output capacitance is high), it is important to ensure the circuit does not violate the peak power rating of the MOSFETs. Check the pulse power ratings in the MOSFET data sheet.

MOSFET Gate Protection

To protect the gate of the MOSFETs, connect a Zener clamp diode from the gate to the source. The cathode connects to the gate, and the anode connects to the source. Choose the Zener clamp voltage to be above 10V and below the MOSFET V\text{GS} maximum rating.
### Typical Application Circuit

[Diagram of the MAX16141 circuit diagram showing components such as R1, R2, R3, D1, CVCC, CAN CTRL, EN, and connections to the MAX16141 chip with labels for GND, VIN, GATE, SRC, RS, OUT, VCC, SHDN, UVSET, RSENSE, GRC, GFC, and PHASE.]
### MAX16141

3.5V to 36V Ideal Diode Controller with Voltage and Current Circuit Breaker

#### Ordering Information

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<tr>
<td>MAX16141AAF/V+T</td>
<td>-40°C to +125°C</td>
<td>16-TQFN</td>
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+ Denotes a lead(Pb)-free/RoHS-compliant package.

T Denotes tape-and-reel.

/V denotes automotive qualified parts.

**Note:** See the Figure 5 for overcurrent, reverse-current, overvoltage, and undervoltage hysteresis options. Contact factory for availability of variants not listed in the Ordering Information table (10k units minimum order quantity).
**Revision History**

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<th>REVISION DATE</th>
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<td>Updated Electrical Characteristics table, Detailed Description section, Ordering Information table, and Applications Information section</td>
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