**General Description**

The MAX17681/MAX17681A is a high-voltage, high-efficiency, iso-buck DC-DC converter designed to provide isolated power up to 5W. The device operates over a wide 4.5V to 42V input and uses primary-side feedback to regulate the output voltage.

The MAX17681/MAX17681A uses peak-current-mode control. The low-resistance, on-chip MOSFETs ensure high efficiency at full load while simplifying the PCB layout.

The MAX17681/MAX17681A devices generate a well regulated primary side voltage which is then scaled by a suitable transformer turns ratio to derive isolated secondary output rails. While both MAX17681 and MAX17681A support primary side overcurrent protection, the MAX17681A is an enhanced design that supports robust secondary-side overcurrent protection as well.

The MAX17681/MAX17681A is available in a compact 10-pin (3mm x 2mm) TDFN package. Simulation models are available.

**Benefits and Features**

- Reduces External Components and Total Cost
  - No Optocoupler
  - Synchronous Primary Operation
  - All-Ceramic Capacitors, Compact Layout
- Reduces Number of DC-DC Regulators to Stock
  - Wide 4.5V to 42V Input
  - 0.9V to 0.96 x \( V_{IN} \) Primary Output Voltage
  - Delivers Up to 5W Output Power
- Reduces Power Dissipation
  - Peak Efficiency > 90%
  - 0.9\( \mu \)A (typ) Shutdown Current
- Operates Reliably in Adverse Industrial Environments
  - Peak and Sink Current-Limit Protection
  - \( \pm 1.7\% \) Feedback Accuracy
  - Programmable EN/UVLO Threshold
  - Adjustable Soft-Start
  - Overtemperature Protection
  - -40°C to +125°C Operation
- Short-Circuit Protection
  - MAX17681A Supports Robust Secondary-Side Short-Circuit Protection
  - MAX17681A Is Recommended for All New Designs

**Applications**

- Isolated Fieldbus Interfaces
- PLC I/O Modules
- Smart Meters
- Isolated Power Supplies in Medical Equipment
- Floating Power Supply Generation

**Application Circuit**

[Application Circuit Diagram]

---

**Ordering Information** appears at end of data sheet.
MAX17681 4.5V to 42V Input, High-Efficiency, Iso-Buck DC-DC Converter

**Absolute Maximum Ratings**

<table>
<thead>
<tr>
<th>Rating</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>VIN to GND</td>
<td>-0.3V to +48V</td>
</tr>
<tr>
<td>EN/UVLO to GND</td>
<td>-0.3V to (VIN + 0.3V)</td>
</tr>
<tr>
<td>LX to PGND</td>
<td>-0.3V to (VIN + 0.3V)</td>
</tr>
<tr>
<td>VCC, FB, RESET, COMP, SS to GND</td>
<td>-0.3V to +6V</td>
</tr>
<tr>
<td>LX Total RMS Current</td>
<td>±1.6A</td>
</tr>
<tr>
<td>Output Short-Circuit Duration</td>
<td>Continuous</td>
</tr>
<tr>
<td>Operating Temperature Range</td>
<td>-40°C to +125°C</td>
</tr>
<tr>
<td>Junction Temperature</td>
<td>+150°C</td>
</tr>
<tr>
<td>Storage Temperature Range</td>
<td>-65°C to +160°C</td>
</tr>
<tr>
<td>Lead Temperature (soldering, 10s)</td>
<td>+300°C</td>
</tr>
<tr>
<td>Soldering Temperature (reflow)</td>
<td>+260°C</td>
</tr>
</tbody>
</table>

Stresses beyond those listed under “Absolute Maximum Ratings” may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

**Package Information**

<table>
<thead>
<tr>
<th>PACKAGE TYPE: 10 TDFN</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>

**THERMAL RESISTANCE, FOUR-LAYER BOARD (Note 1)**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Junction to Ambient (θJA)</td>
<td>67.3°C/W</td>
</tr>
<tr>
<td>Junction to Case (θJC)</td>
<td>18.2°C/W</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.

**Note 1:** Continuous Power Dissipation (T_A = +70°C) (derate 14.9mW/°C above +70°C) (multilayer board) 1188.7mW
## Electrical Characteristics

\((V_{IN} = 24\,V, \, V_{GND} = V_{PGND} = 0\,V, \, C_{VIN} = 2.2\,\mu F, \, C_{VCC} = 1\,\mu F, \, V_{EN} = 1.5\,V, \, C_{SS} = 3300\,pF, \, V_{FB} = 0.98 \times V_{OUT}, \, \text{COMP} = \text{unconnected, \, LX} = \text{unconnected, \, \text{RESET} = \text{unconnected. \, } T_{A} = T_{J} = -40^\circ C \text{ to } +125^\circ C, \, \text{unless otherwise noted. Typical values are at } T_{A} = +25^\circ C. \, \text{All \, voltages are referenced to } GND, \, \text{unless otherwise noted.) (Note 2)}}

<table>
<thead>
<tr>
<th>PARAMETER ((V_{IN}))</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_{IN})</td>
<td>(V_{EN} = 0,V, , \text{shutdown mode})</td>
<td>4.5</td>
<td>42</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>Input Supply Current</td>
<td>(I_{IN-SH})</td>
<td>Normal switching mode, no load</td>
<td>0.9</td>
<td>3.5</td>
<td>1.95</td>
<td>(\mu A)</td>
</tr>
<tr>
<td></td>
<td>(I_{IN-SW})</td>
<td></td>
<td>2.8</td>
<td></td>
<td></td>
<td>mA</td>
</tr>
</tbody>
</table>

| ENABLE/UVLO (EN/UVLO) | \(V_{ENR}\) | \(V_{EN}\) rising | 1.183 | 1.218 | 1.253 | V |
| EN Threshold          | \(V_{ENF}\) | \(V_{EN}\) falling | 1.1 | 1.135 | 1.17 | V |
| EN Input Leakage Current | \(I_{EN}\) | \(V_{EN} = V_{IN} = 42\,V, \, T_{A} = +25^\circ C\) | 8 | 200 |      | \(nA\) |

| LDO | \(V_{CC}\) Output Voltage Range | \(V_{CC}\) | 6\(V < V_{IN} < 12\,V, \, 0\,mA < I_{VCC} < 10\,mA, \, 12\,V < V_{IN} < 42\,V, \, 0\,mA < I_{VCC} < 2\,mA\) | 4.65 | 5 | 5.35 | V |
| VCC Current Limit      | \(I_{VCC-MAX}\) | \(V_{CC} = 4.3\,V, \, V_{IN} = 12\,V\) | 15 | 40 | 80 | mA |
| VCC Dropout            | \(I_{VCC-DO}\) | \(V_{IN} = 4.5\,V, \, I_{VCC} = 5\,mA\) | 4.1|      |     | V |
| VCC UVLO               | \(V_{CC-UVR}\) | \(V_{CC}\) rising | 3.85 | 4 | 4.15 | V |
|                         | \(V_{CC-UVF}\) | \(V_{CC}\) falling | 3.55 | 3.7 | 3.85 | V |

| POWER MOSFETs          | \(R_{DS-ONH}\) | \(I_{LX} = 0.5\,A\) (sourcing) | \(T_{A} = +25^\circ C\) | 0.55 | 0.85 | \(\Omega\) |
| High-Side pMOS On-Resistance | &nbsp; | &nbsp; | \(T_{A} = T_{J} = +125^\circ C\) (Note 3) | &nbsp; | &nbsp; | 1.2 | \(\Omega\) |
|                         | \(R_{DS-ONL}\) | \(I_{LX} = 0.5\,A\) (sinking) | \(T_{A} = +25^\circ C\) | 0.1 | 0.35 | \(\Omega\) |
| Low-Side nMOS On-Resistance | &nbsp; | &nbsp; | \(T_{A} = T_{J} = +125^\circ C\) (Note 3) | &nbsp; | &nbsp; | 0.47 | \(\Omega\) |
| LX Leakage Current      | \(I_{LX_{LKG}}\) | \(V_{EN} = 0\,V, \, T_{A} = +25^\circ C, \, V_{LX} = (V_{PGND} + 1\,V) \text{ to } (V_{IN} - 1\,V)\) | 1 |      |     | \(\mu A\) |

| SOFT-START (SS)        | \(I_{SS}\) | \(V_{SS} = 0.5\,V\) | 4.7 | 5 | 5.3 | \(\mu A\) |

| FEEDBACK (FB)          | \(V_{FB\_REG}\) | \(T_{A} = +25^\circ C\) | 0.884 | 0.9 | 0.916 | V |
| FB Regulation Voltage  | \(I_{FB}\) | \(T_{A} = +25^\circ C\) | 100 |      |     | \(nA\) |

| TRANSCONDUCTANCE AMPLIFIER (COMP) | \(G_{M}\) | \(I_{COMP} = \pm 2.5\,\mu A\) | 510 | 590 | 650 | \(\mu S\) |
| Transconductance        | \(I_{COMP\_SRC}\) | \(19\) | 32 | 55 | \(\mu A\) |
| COMP Source Current     | \(I_{COMP\_SINK}\) | \(19\) | 32 | 55 | \(\mu A\) |
| COMP Sink Current       | \(R_{CS}\) | \(0.45 \, \text{to} \, 0.55\,V/A\) | 0.45 | 0.5 | 0.55 | V/A |

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## Electrical Characteristics (continued)

$(V_{IN} = 24V, V_{GND} = V_{PGND} = 0V, C_{VIN} = 2.2\mu F, C_{VCC} = 1\mu F, V_{EN} = 1.5V, C_{SS} = 3300pF, V_{FB} = 0.98 \times V_{OUT}, COMP = \text{unconnected}, LEX = \text{unconnected}, \text{RESET} = \text{unconnected}. T_A = T_J = -40^\circ C \text{ to } +125^\circ C, \text{unless otherwise noted. Typical values are at } T_A = +25^\circ C. \text{All voltages are referenced to GND, unless otherwise noted.) (Note 2)}$

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SYMBOL</th>
<th>CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Current-Limit Threshold</td>
<td>$I_{\text{PEAK-LIMIT}}$</td>
<td></td>
<td>1.4</td>
<td>1.65</td>
<td>1.9</td>
<td>A</td>
</tr>
<tr>
<td>Runaway Current-Limit Threshold</td>
<td>$I_{\text{RUNAWAY-LIMIT}}$</td>
<td></td>
<td>1.45</td>
<td>1.7</td>
<td>2</td>
<td>A</td>
</tr>
<tr>
<td>Sink Current-Limit Threshold</td>
<td>$I_{\text{SINK-LIMIT}}$</td>
<td></td>
<td>1.05</td>
<td>1.25</td>
<td>1.45</td>
<td>A</td>
</tr>
</tbody>
</table>

### TIMINGS

| Events to Hiccup After Crossing Runaway Current Limit | $V_{\text{OUT-HICF}} \geq V_{SS} > 0.95V$ (soft-start is done) | 67.86 | 70.5 | 73.14 | %     |
| Hiccup Timeout                          | 32768 Cycles                                    |       |      |       |       |
| Minimum On-Time                        | $t_{\text{ON_MIN}}$                              | 200   | 300  | 415   | ns    |
| Maximum Duty Cycle                     | $D_{\text{MAX}}$ $= 0.98 \times V_{\text{FB-REG}}$ | 96.5  | 97.5 | 98.5  | %     |
| LX Dead Time                           |                                                | 12    |      |       | ns    |

### RESET

| RESET Output Level Low               | $I_{\text{RESET}} = 1mA$                      | 0.02  |      |       | V     |
| RESET Output Leakage Current High   | $V_{\text{FB}} = 1.01 \times V_{\text{FB-REG}}, T_A = 25^\circ C$ | 0.45  |      |       | μA    |
| FB Threshold for RESET Falling      | $V_{\text{FB-OKF}} = V_{\text{FB falling}}$   | 90.5  | 92.5 | 94.5  | %     |
| FB Threshold for RESET Rising       | $V_{\text{FB-OKR}} = V_{\text{FB rising}}$    | 93.5  | 95.5 | 97.5  | %     |
| RESET Delay After FB Reaches 95% Regulation | $V_{\text{FB rising}}$ | 1024  |      |       | Cycles |

### THERMAL SHUTDOWN

| Thermal Shutdown Threshold          | Temperature rising                             | 165   |      |       | °C    |
| Thermal Shutdown Hysteresis        |                                                | 10    |      |       | °C    |

**Note 2:** All limits are 100% tested at +25°C. Limits over temperature are guaranteed by design.

**Note 3:** Guaranteed by design, not production tested.
MAX17681
4.5V to 42V Input, High-Efficiency, Iso-Buck DC-DC Converter

Typical Operating Characteristics
(V_{IN} = 24V, V_{GND} = V_{PGND} = 0V, C_{VIN} = 1\mu F, C_{VCC} = 1\mu F, V_{EN} = 1.5V, C_{SS} = 33nF, V_{FB} = 0.98 \times V_{PRI}, T_A = +25^\circ C, unless otherwise noted.)

[Graphs and plots showing efficiency, regulation, voltage, and temperature characteristics.]

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Typical Operating Characteristics (continued)

\( V_{\text{IN}} = 24V, V_{\text{GND}} = V_{\text{PGND}} = 0V, C_{\text{VIN}} = 1\mu F, C_{\text{VCC}} = 1\mu F, V_{\text{EN}} = 1.5V, C_{\text{SS}} = 33nF, V_{\text{FB}} = 0.98 \times V_{\text{PRI}}, T_{A} = +25^\circ C, \) unless otherwise noted.

**FIGURE 9**

APPLICATION CIRCUIT

**LOAD TRANSIENT RESPONSE**, (LOAD CURRENT STEPPED FROM 50mA to 100mA)

\[ V_{\text{OUT}} \] vs. \[ I_{\text{OUT}} \]

**FIGURE 10**

APPLICATION CIRCUIT

**LOAD TRANSIENT RESPONSE**, (LOAD CURRENT STEPPED FROM 20mA to 70mA)

\[ V_{\text{OUT}} \] vs. \[ I_{\text{OUT}} \]

**FIGURE 15**

APPLICATION CIRCUIT

**FULL-LOAD SWITCHING WAVEFORMS**

**FIGURE 16**

APPLICATION CIRCUIT

**SOFT-START**

\[ V_{\text{OUT}} \] vs. \[ I_{\text{OUT}} \]

**FIGURE 17**

APPLICATION CIRCUIT

**SHUTDOWN WITH ENABLE**

\[ V_{\text{OUT}} \] vs. \[ I_{\text{OUT}} \]

**FIGURE 18**

APPLICATION CIRCUIT

**BODE PLOT**

\[ \text{GAIN (dB)} \] vs. \[ \text{PHASE (°)} \]

\( f_{\text{CR}} = 6.7kHz, \text{PHASE MARGIN} = 80° \)

**FIGURE 19**

APPLICATION CIRCUIT

**OVERLOAD PROTECTION FOR MAX17681**

\[ V_{\text{OUT}} \] vs. \[ I_{\text{OUT}} \]

**FIGURE 20**

APPLICATION CIRCUIT

**OVERLOAD PROTECTION FOR MAX17681A**

\[ V_{\text{OUT}} \] vs. \[ I_{\text{OUT}} \]
Pin Configuration

```
TOP VIEW

LX  GND  RESET  COMP  SS
9    8     7      6

MAX17681
MAX17681A
EP

PGND  VIN  EN  UVLO  VCC  FB
5     4     3     2      1

TDFN
3mm x 2mm

*EP = EXPOSED PAD, CONNECTED TO GND
```

Pin Description

<table>
<thead>
<tr>
<th>PIN</th>
<th>NAME</th>
<th>FUNCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>PGND</td>
<td>Power Ground. Connect PGND externally to the power ground plane. Connect GND and PGND pins together at the ground return path of the VCC bypass capacitor.</td>
</tr>
<tr>
<td>2</td>
<td>VIN</td>
<td>Switching Regulator Input. Connect a X7R ceramic capacitor from VIN to PGND for bypassing.</td>
</tr>
<tr>
<td>3</td>
<td>EN/UVLO</td>
<td>Active-High, Enable/Undervoltage-Detection Input. Pull EN/UVLO to GND to disable the regulator output. Connect EN/UVLO to VIN for always-on operation. Connect a resistor-divider between VIN, EN/UVLO, and GND to program the input voltage at which the device is enabled and turns on.</td>
</tr>
<tr>
<td>4</td>
<td>VCC</td>
<td>Internal LDO Output. Bypass VCC to GND with a minimum 1μF capacitor.</td>
</tr>
<tr>
<td>5</td>
<td>FB</td>
<td>Output Feedback Connection. Connect FB to a resistor-divider between VPR1 and GND to set the output voltage. See the Adjusting the Primary Output Voltage section for details.</td>
</tr>
<tr>
<td>6</td>
<td>SS</td>
<td>Soft-Start Input. Connect a ceramic capacitor from SS to GND to set the soft-start time.</td>
</tr>
<tr>
<td>7</td>
<td>COMP</td>
<td>Compensation Input. Connect an RC network from COMP to GND. See the External Loop Compensation section.</td>
</tr>
<tr>
<td>8</td>
<td>RESET</td>
<td>Open-Drain Reset Output. Pull up RESET to an external power supply with an external resistor. RESET pulls low if FB voltage drops below 92.5% of its set value. RESET goes high impedance 1024 clock cycles after FB voltage rises above 95.5% of its set value.</td>
</tr>
<tr>
<td>9</td>
<td>GND</td>
<td>Signal Ground.</td>
</tr>
<tr>
<td>10</td>
<td>LX</td>
<td>Switching Node. Connect LX to the switching side of the transformer. LX is high impedance when the device is in shutdown mode.</td>
</tr>
<tr>
<td>—</td>
<td>EP</td>
<td>Exposed Pad. Connect to the GND pin of the IC. Connect to a large copper plane below the IC to improve heat dissipation capability.</td>
</tr>
</tbody>
</table>
MAX17681
4.5V to 42V Input, High-Efficiency, Iso-Buck DC-DC Converter

Block Diagram

MAX17681
MAX17681A

VCC

EN/UVLO

1.218

POK

CHIPEN

THERMAL
SHUTDOWN

OSCILLATOR

SLOPE

CHIPEN

CW

PWM

CONTROL

LOGIC

SECONDARY
OVER-
CURRENT
PROTECTION
LOGIC

HIGH-SIDE
CURRENT
SENSE

CS

RUNAWAY

HIGH-SIDE
DRIVER

LX

LOW-SIDE
CURRENT
SENSE

SINK LIMIT

LOW-SIDE
DRIVER

LIMIT

PGND

GND

RESET

PWM

SLOPE

CS

5µA

REFERENCE
SWITCHOVER
CIRCUIT

REF

HICCUP

VCC

5.12ms

DELAY

0.8595

FB

* SECONDARY OVER-CURRENT PROTECTION LOGIC ONLY FOR MAX17681A

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**Detailed Description**

The MAX17681/MAX17681A is a high-voltage, high-efficiency, iso-buck DC-DC converter designed to provide isolated power up to 5W. The device operates over a wide 4.5V to 42V input and uses primary side feedback to regulate the output voltage.

The MAX17681/MAX17681A uses peak-current-mode control. The low-resistance, on-chip MOSFETs ensure high efficiency at full load while simplifying the PCB layout. The programmable soft-start feature allows users to reduce input inrush current. The device also incorporates an output enable/undervoltage lockout pin (EN/UVLO) that allows the user to turn on the part at the desired input-voltage level. An open-drain RESET pin provides a delayed power-good signal to the system upon achieving successful regulation of the primary output voltage.

The device operates over the -40°C to +125°C industrial temperature range and is available in a compact 10-pin (3mm x 2mm) TDFN package.

**Linear Regulator (V\(_{CC}\))**

An internal linear regulator (V\(_{CC}\)) provides a 5V nominal supply to power the internal blocks and the low-side MOSFET driver. The output of the V\(_{CC}\) linear regulator should be bypassed with a 1μF ceramic capacitor to GND. The device employs an undervoltage-lockout circuit that disables the internal linear regulator when V\(_{CC}\) falls below 3.7V (typ). The internal V\(_{CC}\) linear regulator can source up to 40mA (typ) to supply the device and to power the low-side gate driver.

**Enable Input (EN/UVLO) and Soft-Start (SS)**

When the EN/UVLO voltage increases above 1.218V (typ), the device initiates a soft-start sequence with the duration of the soft-start being dependent on the value of the capacitor connected from SS to GND. A 5μA current source charges the capacitor and ramps up the SS pin voltage. The SS pin voltage is used as reference for the internal error amplifier. The reference ramp-up allows the output voltage to increase monotonically from zero to the target value.

The EN/UVLO can be used as an input-voltage UVLO-adjustment input. An external voltage-divider between V\(_{IN}\) and EN/UVLO to GND adjusts the input voltage at which the device turns on or turns off. See the Setting the Input Undervoltage Lockout Level section for details. If input UVLO programming is not desired, connect the EN/UVLO to V\(_{IN}\) (see the Electrical Characteristics table for the EN/UVLO rising and falling-threshold voltages). Driving the EN/UVLO low disables both power MOSFETs as well as other internal circuitry and reduces V\(_{IN}\) quiescent current to 0.9μA (typ). The SS capacitor is discharged with an internal pulldown resistor when the EN/UVLO is low. If the EN/UVLO pin is driven from an external signal source, a series resistance of minimum 1kΩ is recommended to be placed between the signal source output and the EN/UVLO pin to reduce voltage ringing on the line.

**Overcurrent Protection/HICCUP Mode**

The MAX17681/MAX17681A are provided with an overcurrent-protection scheme that protects the device under overload and output short-circuit conditions. A cycle-by-cycle peak current limit turns off the high-side MOSFET whenever the switch current exceeds the internal limit of 1.65A (typ). Additionally, the sink current limit turns off the low-side switch when the low side MOSFET negative current exceeds 1.25A (typ). A runaway current limit on the highside MOSFET current at 1.7A (typ) protects the devices under high input voltage, short-circuit conditions.

The MAX17681 enters hiccup mode, either on one occurrence of the runaway current limit or when the primary output voltage (V\(_{PRI}\)) drops to 70.5% (typ) of its nominal value after the soft-start is completed. In the MAX17681, when hiccup is triggered, the converter is protected by suspending switching for a hiccup timeout period of 32,768 clock cycles. Once the hiccup timeout period expires, soft-start is attempted again. This behaviour works well for primary output over-current events. However, when secondary-side overcurrent events occur, additional measures are required for the Iso-Buck topology to enter into hiccup mode reliably, and also support robust output voltage recovery after overcurrent removal. These measures are not supported by MAX17681.
The MAX17681A provides the robust secondary overcurrent protection, and smooth output voltage recovery after removal of overcurrent, by entering into hiccup mode after detecting 16 consecutive negative current limit events. This is supported by implementing a scheme where the primary capacitor voltage is actively discharged during the hiccup timeout period, and soft-starting both primary and secondary-side outputs.

The MAX17681A enters hiccup mode, either on one occurrence of the runaway current limit, when the primary output voltage drops to 71.14% (typ) of its nominal value after the soft-start is completed, or when 16 consecutive negative current limit events occur. When hiccup is triggered, the converter enters a hiccup timeout period of 32,768 clock cycles. During this period, the high side switch is kept off and the low side switch is turned on each cycle until the low side MOSFET negative current reaches 0.6A limit. This mode of operation effectively produces a negative current in the primary capacitor and discharges it towards zero. Once the hiccup timeout period expires, the MAX17681A smoothly soft starts both primary and secondary output voltages.

If the output capacitance is such that it is discharged to zero within one hiccup timeout period, the MAX17681A executes a normal soft-start operation upon exit from the hiccup timeout period. For cases, where the capacitor is sized such that it does not discharge to zero in one hiccup timeout period, during the next soft-start attempt the converter may re-enter the hiccup time period due to one of the event which triggers hiccup mode. Eventually the primary capacitor is completely discharged and the smooth output voltage recovery is ensured.

In summary the MAX17681 provides primary side overcurrent protection, whereas the MAX17681A provides both primary and secondary side over-current protection.

**RESET Output**

The device includes a RESET comparator to monitor the primary output voltage. The open-drain RESET output requires an external pullup resistor. RESET can sink 2mA of current while low. RESET goes high (high-impedance) 1024 switching cycles after the primary output increases above 95.5% of the nominal regulated voltage. RESET goes low when the primary output voltage drops to below 92.5% of the nominal regulated voltage. In MAX17681A, when the secondary output is shorted, the primary output voltage is discharged as well during the hiccup period. So, in this case, even for a fault on the isolated output, the RESET can be used as an indicator. RESET also goes low during thermal shutdown. RESET is valid when the device is enabled and $V_{IN}$ is above 4.5V.

**Thermal-Overload Protection**

Thermal-overload protection limits total power dissipation in the device. When the junction temperature of the device exceeds +165°C, an on-chip thermal sensor shuts down the device, allowing the device to cool. The thermal sensor turns the device on again after the junction temperature cools by 10°C. Carefully evaluate the total power dissipation (see the Power Dissipation section) to avoid unwanted triggering of the thermal-overload protection in normal operation.
Applications Information

Operation of the Iso-Buck Converter

The iso-buck is a synchronous-buck-converter-based topology, useful for generating isolated outputs at low power level without using an optocoupler. Figure 1 shows the basic circuit of an iso-buck converter, consists of a half-bridge transformer driver and secondary side filter.

Figure 2 shows the equivalent circuit when the high-side switch (QHS) is ON. During this time, the primary current ramps up and stores energy in the transformer magnetizing inductance \( L_{PRI} \) and the primary capacitor \( C_{PRI} \). The secondary side diode is reverse-biased and the load current is supplied by the secondary-side filter capacitor \( C_{OUT} \).

Figure 3 shows the equivalent circuit when the low-side switch (QLS) is on. During this time, the secondary diode gets forward-biased. The primary current ramps down and releases stored energy in the transformer magnetizing inductance and the primary capacitor to the load. Operating waveforms of the converter are shown in Figure 4. Neglecting diode drop \( V_D \), transformer resistances, and leakage inductance, the output voltage \( V_{OUT} \) is proportional to the primary output voltage \( V_{PRI} \) and is regulated by the MAX17681/MAX17681A control loop.
Primary Output Voltage Selection
Primary output voltage is regulated by the MAX17681/MAX17681A control loop. The primary output voltage can be calculated by using the equation:

\[ V_{PRI} = D_{MAX} \times V_{IN_{MIN}} \]

where \( D_{MAX} \) is the maximum duty cycle of the converter and \( V_{IN_{MIN}} \) is the minimum input voltage. Maximum duty cycle should be in the range of 0.4 to 0.6 for ideal iso-buck operation.

Adjusting the Primary Output Voltage
The primary output voltage is set with a resistor-divider from primary output to FB to GND (see Figure 5). Choose R2 in the range of 10k to 49.9k and calculate R1 using the equation:

\[ R1 = R2 \times \left( \frac{V_{PRI}}{0.9} - 1 \right) \]

Turns Ratio Selection
Neglecting diode drop \( V_D \), transformer resistances, and leakage inductance, the iso-buck output voltage \( V_{OUT} \) is proportional to the primary output voltage \( V_{PRI} \). The turns ratio (K) is given by the equation:

\[ K = \frac{N_{SEC}}{N_{PRI}} = \frac{V_{OUT} + V_D}{V_{PRI}} \]

Turns ratio can be adjusted to match with the readily available off-the-shelf transformer turns ratio by adjusting the primary output voltage.

Winding Peak and RMS Currents
Windings peak and RMS current ratings should be specified for selecting the iso-buck transformer. Primary and secondary winding peak currents are given by the equations:

\[ I_{HS\_AVG} = I_{PRI} \left[ \frac{\sum_i n_i I_{OUT_i} \times K_i}{n} \right] \]

\[ I_{PK\_PRI} = I_{HS\_AVG} + \frac{\Delta I}{2} \]

\[ I_{PK\_SEC_i} = I_{OUT_i} \left( 1 - D \right) \]

\[ D = \frac{V_{PRI}}{V_{IN}} \]

where \( n \) is the total number of isolated outputs, \( i \) is the individual isolated output, \( I_{PRI} \) is the primary load current, \( I_{OUT_i} \) is the individual secondary load current, \( K_i \) is the individual secondary turns ratio, \( D \) is the duty cycle, and \( \Delta I \) is the primary ripple current.

Primary RMS current is the sum of the high-side and low-side switch RMS currents.

High-side switch RMS current:

\[ I_{HS\_RMS} = \sqrt{D \times \left( I_{HS\_AVG}^2 + \frac{\Delta I^2}{12} \right)} \]

Primary Inductance Selection
Primary inductance value determines the ripple current in the transformer. The required primary inductance is given by the equation:

\[ L_{PRI} = 7 \times V_{PRI} \]

where \( L_{PRI} \) is the primary inductance in \( \mu \)H and \( V_{PRI} \) is the primary output voltage.

The primary ripple current can be calculated using the equation:

\[ \Delta I = \frac{V_{PRI} \times \left( 1 - \frac{V_{PRI}}{V_{IN}} \right)}{f_{SW} \times L_{PRI}} \]

where \( L_{PRI} \) is the primary inductance in \( \mu \)H, \( f_{SW} \) is the switching frequency in Hz, \( V_{PRI} \) is the primary output voltage, \( V_{IN} \) is the input voltage.
Low-side switch RMS current:

\[ I_{LS\_RMS} = \left( \frac{1}{(1-D)} \times \left( I_{PK\_PRI} - \frac{1}{(1-D)} \times \sum_{i=1}^{n} I_{OUTi} \times K_i \right) - \frac{\Delta I}{2} \right)^2 + \frac{\Delta I^2}{12} \]

Primary winding RMS current:

\[ I_{PRI\_RMS} = \sqrt{I_{HS\_RMS}^2 + I_{LS\_RMS}^2} \]

Secondary winding RMS current is given by the equation:

\[ I_{SEC\_RMSi} = \frac{I_{OUTi}}{\sqrt{(1-D)}} \]

Leakage Inductance

Transformer leakage inductance (L\text{LEAK}) plays a key role in determining the output voltage regulation. For better output voltage regulation, leakage inductance should be reduced to less than 1% of the primary inductance value. Higher leakage inductance also limits the amount of power delivered to the output.

Primary Negative Peak Current

The primary current can go negative when the low side switch is turned on. Steady-state primary negative peak current should be verified not to exceed -1A. The primary negative peak current can be calculated using the equation:

\[ I_{NEGPK\_PRI} = I_{PK\_PRI} - \frac{1}{(1-D)} \times \sum_{i=1}^{n} I_{OUTi} \times K_i \] - \Delta I

Specifying the Iso-Buck Transformer

An off-the-shelf transformer or coupled inductor can be used as an Iso-buck transformer. If readily not available, use the table below to specify the Iso-buck transformer parameters to transformer vendors.

Primary Output Capacitor Selection

X7R ceramic output capacitors are preferred due to their stability over temperature in industrial applications. The minimum required output capacitance is given by the equation:

\[ C_{PRI} = \frac{I_{HS\_AVG} \times D_{MAX}}{f_{SW} \times 0.01 \times V_{PRI}} \]

\[ D_{MAX} = \frac{V_{PRI}}{V_{IN\_MIN}} \]

Where \( I_{OUT} \) is the load current, \( K \) is the turns ratio, \( f_{SW} \) is the switching frequency, \( V_{PRI} \) is the primary output voltage, \( V_{IN\_MIN} \) is the minimum input voltage.

Secondary Output Capacitor Selection

A secondary side capacitor supplies load current when the high-side switch is on. The required output capacitance to support 1% steady state ripple is given by the equation:

\[ C_{OUT} = \frac{I_{OUT} \times D_{MAX}}{f_{SW} \times 0.01 \times V_{OUT}} \]

It should be noted that dielectric materials used in ceramic capacitors exhibit capacitance loss due to DC bias levels and should be appropriately derated to ensure the required output capacitance is obtained in the application.

### Table 1. Specifying Iso-Buck Transformer

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SYMBOL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Inductance</td>
<td>( L_{PRI} )</td>
</tr>
<tr>
<td>Leakage Inductance</td>
<td>( L_{LEAK} )</td>
</tr>
<tr>
<td>Primary Ripple Current</td>
<td>( \Delta I )</td>
</tr>
<tr>
<td>Primary Peak Current</td>
<td>( I_{PK_PRI} )</td>
</tr>
<tr>
<td>Primary RMS Current</td>
<td>( I_{PRI_RMS} )</td>
</tr>
<tr>
<td>Secondary Peak Current</td>
<td>( I_{PK_SEC} )</td>
</tr>
<tr>
<td>Secondary RMS Current</td>
<td>( I_{SEC_RMS} )</td>
</tr>
<tr>
<td>Working Voltage</td>
<td>VAC, VDC</td>
</tr>
<tr>
<td>Insulation Level</td>
<td>VAC, VDC</td>
</tr>
</tbody>
</table>
Input Capacitor Selection
Ceramic input capacitors are recommended for the IC. The input capacitor reduces peak current drawn from the power source and reduces noise and voltage ripple on the input caused by the switching circuitry. In applications where the source is located distant from the device input, an electrolytic capacitor should be added in parallel to the input ceramic capacitor to provide necessary damping for potential oscillations caused by the longer input power path and input ceramic capacitor. The required input capacitance can be calculated using the equation:

\[
C_{\text{IN}} = \frac{I_{\text{HS_AVG}} \times D_{\text{MAX}} \times (1 - D_{\text{MAX}})}{f_{\text{SW}} \times \Delta V_{\text{IN}}}
\]

\[
D_{\text{MAX}} = \frac{V_{\text{PRI}}}{V_{\text{IN_MIN}}}
\]

\(\Delta V_{\text{IN}}\) is the input voltage ripple, normally 2% of the minimum input voltage, \(D_{\text{MAX}}\) is the maximum duty cycle, and \(f_{\text{SW}}\) is the switching frequency of operation.

Secondary Diode Selection
A secondary rectifier diode should be rated to carry peak secondary current and to withstand reverse voltage when the high-side switch is on. A Schottky diode with less forward-voltage drop should be selected for better output voltage regulation.

The peak current rating of the diode is given by:

\[
I_{\text{PK_Diode}} = \frac{I_{\text{OUT}}}{(1 - D)}
\]

The peak reverse voltage rating of the diode is given by:

\[
V_{\text{DIODE}} = 2 \times \left( (V_{\text{IN_MAX}} - V_{\text{PRI}}) \times K + V_{\text{OUT}} \right)
\]

Power dissipated in the diode can be calculated using the equation:

\[
P_{\text{DIODE}} = V_{D} \times I_{\text{OUT}}
\]

Minimum Load Requirements
Under light-load conditions, the iso-buck converter output voltage increases excessively due to the transformer leakage inductance and parasitic capacitance. Normally, a minimum load of 10% to 20% of the full load is sufficient to keep the converter output voltage regulation within ±5%. The output voltage regulation should be verified after testing prototype.

A resistor connected in series with a Zener diode (See R4, Z1 in Figure 9) can be used as an overvoltage protection circuit to limit the overvoltage under absolute no load conditions. The Zener diode threshold can be selected as 15% higher than the nominal regulated output voltage \(V_{\text{OUT}}\). The series resistor, R1, value can be in the range of 30Ω to 60Ω.

Soft-Start Capacitor Selection
The MAX17681/MAX17681A implements adjustable soft-start operation to reduce inrush current. A capacitor connected from the SS pin to GND programs the soft-start period.

The soft-start time (\(t_{\text{SS}}\)) is related to the capacitor connected at SS (\(C_{\text{SS}}\)) by the following equation:

\[
C_{\text{SS}} = 5.55 \times t_{\text{SS}}
\]

where \(t_{\text{SS}}\) is in milliseconds and \(C_{\text{SS}}\) is in nanofarads.

Setting the Input Undervoltage Lockout Level
The device offers an adjustable input undervoltage-lockout level. Set the voltage at which the device turns on with a resistive voltage-divider connected from \(V_{\text{IN}}\) to GND (see Figure 6). Connect the center node of the divider to EN/UVLO.

Choose R1 to be 3.3MΩ max and then calculate R2 as follows:

\[
R2 = \frac{R1 \times 1.218}{(V_{\text{INU}} - 1.218)}
\]

where \(V_{\text{INU}}\) is the voltage at which the device is required to turn on.

![Figure 6. Adjustable EN/UVLO Network](image-url)
External Loop Compensation

The MAX17681/MAX17681A uses peak current-mode control scheme and needs only a simple RC network to have a stable control loop. The compensation network is shown in Figure 7. The following equations can be used for calculating the compensation components:

\[
R_{COMP} = \frac{6000 \times f_C \times \left( \frac{C_{OUT} \times (1-D)}{K^2 + C_PRI} \right) \times V_{PRI}}{}
\]

where \( R_{COMP} \) is in \( \Omega \), and the maximum limit for \( R_{COMP} \) is 12k\( \Omega \). \( f_C \) is bandwidth of the converter in Hz. Choose \( f_C \) in the range of 2kHz to 10kHz.

\[
C_{COMP} = \frac{5}{\pi \times f_C \times R_{COMP}}
\]

\[
C_P = \frac{1}{2\pi \times 50000 \times R_{COMP}}
\]

Power Dissipation

Ensure that the junction temperature of the device does not exceed +125°C under the operating conditions specified for the power supply. At a particular operating condition, the power losses that lead to temperature rise of the device can be estimated as follows:

\[
P_{LOSS} = P_{OUT} \times \left( \frac{1}{\eta} - 1 \right) \times \left( I_{PRI_{RMS}}^2 \times R_{PRI} \right) - \left( I_{SEC_{RMS}}^2 \times R_{SEC} \right) \times (V_D \times I_{OUT})
\]

where \( P_{OUT} \) is the output power, \( \eta \) is the efficiency of power conversion, \( R_{PRI} \) is the primary resistance of the transformer, \( R_{SEC} \) is the secondary resistance of the transformer and \( V_D \) is the diode drop.

The junction temperature \( T_J \) of the device can be estimated at any ambient temperature \( T_A \) from the following equation:

\[
T_J = T_A + (\theta_{JA} \times P_{LOSS})
\]

where \( \theta_{JA} \) is the junction-to-ambient thermal impedance of the package.

PCB Layout Guidelines

Careful PCB layout is critical to achieve clean and stable operation. For a sample layout that ensures first-pass success, refer to the MAX17681/MAX17681A evaluation kit layouts available at www.maximintegrated.com. Follow these guidelines for good PCB layout:

1) All connections carrying pulsed currents must be very short and as wide as possible. The loop area of these connections must be made very small to reduce stray inductance and radiated EMI.

2) A ceramic input filter capacitor should be placed close to the \( V_{IN} \) pin of the device. The bypass capacitor for the \( V_{CC} \) pin should also be placed close to the \( V_{CC} \) pin. External compensation components should be placed close to the IC and far from the LX node. The feedback trace should be routed as far as possible from the LX node.

3) Signal and power grounds must be kept separate. They should be connected together at a point where switching noise is minimum, typically the return terminal of the \( V_{CC} \) bypass capacitor. The ground plane should be kept continuous as much as possible.

4) Multiple thermal vias that connect to a large ground plane should be provided under the exposed pad of the device, for efficient heat dissipation.

Figure 8 show the recommended component placement for the MAX17681/MAX17681A iso-buck converter.
Figure 8. Recommended Component Placement

4.5V to 42V Input, High-Efficiency, Iso-Buck DC-DC Converter

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Typical Application Circuits

Figure 9. Low-Profile 24V to 24V, 100mA Isolated Output Application Circuit

Figure 10. 24V to ±15V, 75mA Isolated Output Application Circuit
Typical Application Circuits (continued)

![Application Circuit Diagram]

Figure 11. 24V to 3.3V/80mA Non-Isolated and ±16V,65mA Isolated Output Application circuit

Ordering Information

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<th>PART</th>
<th>TEMP RANGE</th>
<th>PIN-PACKAGE</th>
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<tbody>
<tr>
<td>MAX17681ATB+</td>
<td>-40°C to +125°C</td>
<td>10L TDFN-EP*</td>
</tr>
<tr>
<td>MAX17681AATB+</td>
<td>-40°C to +125°C</td>
<td>10L TDFN-EP*</td>
</tr>
</tbody>
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+Denotes a lead (Pb)-free/RoHS-compliant package.
*EP = Exposed pad.

Chip Information

PROCESS: BiCMOS
## Revision History

<table>
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<tr>
<th>REVISION NUMBER</th>
<th>REVISION DATE</th>
<th>DESCRIPTION</th>
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<tr>
<td>0</td>
<td>9/14</td>
<td>Initial release</td>
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<tr>
<td>1</td>
<td>10/15</td>
<td>Equation updated</td>
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<td>2</td>
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<td>Added MAX17681A to Ordering Information table</td>
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<td>4</td>
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<td>Reversed Ordering Information footnote and updated Benefits and Features section</td>
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