# MIC2171

## 100 kHz, 2.5A Switching Regulator

### Features

- 2.5A, 65V Internal Switch Rating
- 3V to 40V Input Voltage Range
- Current Mode Operation, 2.5A Peak
- Internal Cycle-by-Cycle Current Limit
- Twice the Frequency of the LM2577
- Low External Electronic Components Count
- Suitable for Most Switching Topologies
- 7 mA Quiescent Current (Operating)
- Fits LT1171/LM2577 TO-220 and TO-263 Sockets

### Applications

- Laptop/Palmtop Computers
- Battery Operated Equipment
- Handheld Instruments
- Off-Line Converter up to 50W (Requires External Power Switch)
- Predriver for Higher Power Capability

### General Description

The MIC2171 is a complete 100 kHz SMPS current-mode controller with an internal 65V 2.5A power switch.

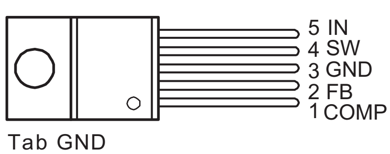
Although primarily intended for voltage step-up applications, the floating switch architecture of the MIC2171 makes it practical for step-down, inverting, and Cuk configurations, as well as isolated topologies.

Operating from 3V to 40V, the MIC2171 draws only 7 mA of quiescent current, making it attractive for battery-operated applications.

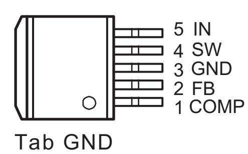
The MIC2171 is available in a 5-pin TO-220 or TO-263 package that allows –40°C to +85°C ambient temperature operation.

### Package Types

**5-Pin TO-220 (T)**

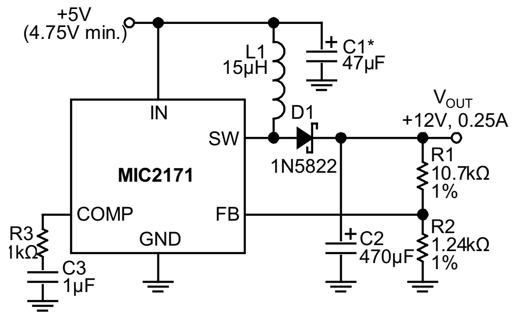



**5-Pin TO-263 (U)**



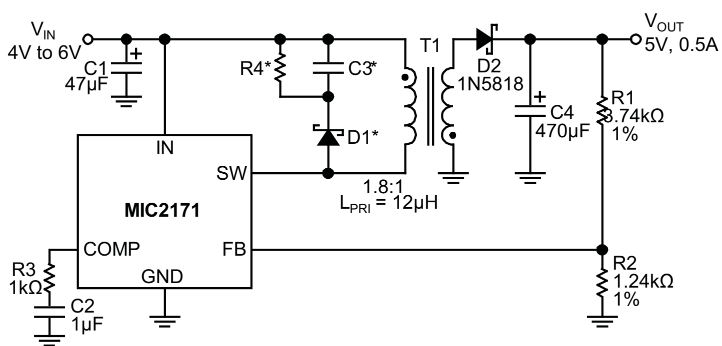
## Typical Application Circuits

**5V to 12V Boost Converter**



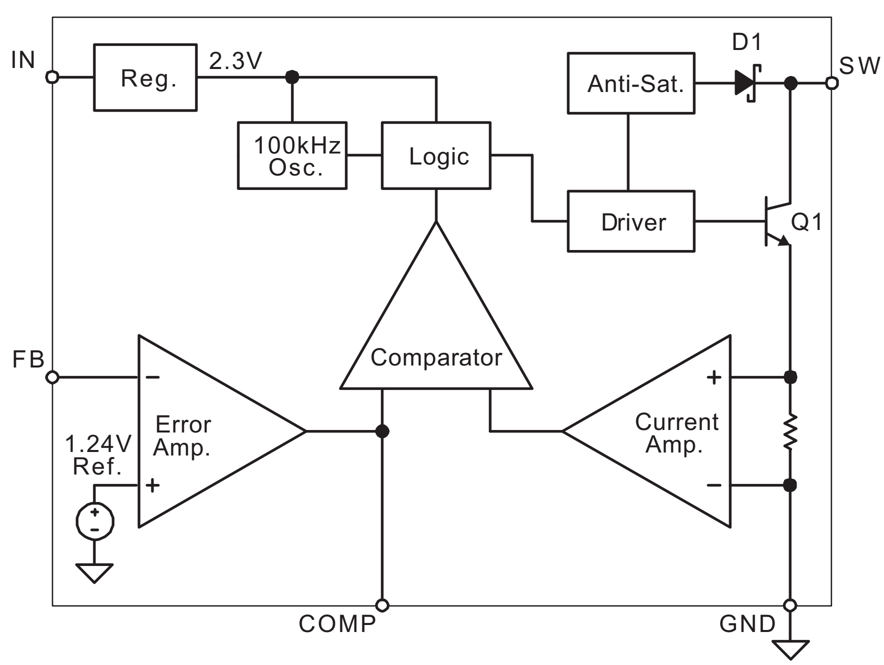

* Locate near MIC2171 when supply leads > 2”

**5V Flyback Converter**




* Optional voltage clipper (may be req’d if T1 leakage inductance too high)

## Functional Block Diagram



# 1.0 ELECTRICAL CHARACTERISTICS

## Absolute Maximum Ratings †

Supply Voltage ($V_{IN}$) ........ 40V
Switch Voltage ($V_{SW}$) ........ 65V
Feedback Voltage ($V_{FB}$) (transient, 1 ms) ........ ±15V
Storage Temperature ($T_S$) ........ –65°C to +150°C
Lead Temperature (soldering 10 sec.) ........ 300°C

## Operating Ratings ‡

Operating Ambient Temperature Range ($T_A$) ........ –40°C to +85°C
Thermal Resistance
TO-220-5 ($\theta_{JA}$) ........ 45°C/W
TO-263-5 ($\theta_{JA}$) ........ 45°C/W

**† Notice:** Stresses above those listed under “Absolute Maximum Ratings” may cause permanent damage to the device. This is a stress rating only and functional operation of the device at those or any other conditions above those indicated in the operational sections of this specification is not intended. Exposure to maximum rating conditions for extended periods may affect device reliability. Specifications are for packaged product only.

**‡ Notice:** The device is not guaranteed to function outside its operating ratings.

## ELECTRICAL CHARACTERISTICS

**Electrical Characteristics:** $V_{IN}$ = 5V; $T_A$ = 25°C, unless otherwise specified. **Bold** values indicate –40°C ≤ $T_A$ ≤ 85°C. Note 1, Note 2

<table>
<tr><th>Parameter</th><th>Symbol</th><th>Min.</th><th>Typ.</th><th>Max.</th><th>Units</th><th>Conditions</th></tr>
<tr><td colspan="7">Reference</td></tr>
<tr><td rowspan="2">Feedback Voltage</td><td rowspan="2">$V_{FB}$</td><td>1.220</td><td>1.240</td><td>1.264</td><td rowspan="2">V</td><td rowspan="2">$V_{COMP}$ = 1.24V</td></tr>
<tr><td>1.214</td><td>—</td><td>1.274</td></tr>
<tr><td>Feedback Voltage Line Regulation</td><td>$\Delta V_{FB(LINE)}$</td><td>—</td><td>0.6</td><td>—</td><td>%/V</td><td>3V ≤ $V_{IN}$ ≤ 40V, $V_{COMP}$ = 1.24V</td></tr>
<tr><td rowspan="2">Feedback Bias Current</td><td rowspan="2">$I_{FB}$</td><td>—</td><td>310</td><td>750</td><td rowspan="2">nA</td><td rowspan="2">$V_{FB}$ = 1.24V</td></tr>
<tr><td>—</td><td>—</td><td>1100</td></tr>
<tr><td colspan="7">Error Amplifier</td></tr>
<tr><td rowspan="2">Transconductance</td><td rowspan="2">$g_m$</td><td>3.0</td><td>3.9</td><td>6.0</td><td rowspan="2">µA/mV</td><td rowspan="2">$\Delta I_{COMP}$ = ±25 µA</td></tr>
<tr><td>2.4</td><td>—</td><td>7.0</td></tr>
<tr><td>Voltage Gain</td><td>$A_V$</td><td>400</td><td>800</td><td>2000</td><td>V/V</td><td>0.9V ≤ $V_{COMP}$ ≤ 1.4V</td></tr>
<tr><td rowspan="2">Output Current</td><td rowspan="2">$I_{COMP}$</td><td>125</td><td>175</td><td>350</td><td rowspan="2">µA</td><td rowspan="2">$V_{COMP}$ = 1.5V</td></tr>
<tr><td>100</td><td>—</td><td>400</td></tr>
<tr><td rowspan="2">Output Swing</td><td>$V_{COMP(MAX)}$</td><td>1.8</td><td>2.1</td><td>2.3</td><td rowspan="2">V</td><td>High Clamp, $V_{FB}$ = 1V</td></tr>
<tr><td>$V_{COMP(MIN)}$</td><td>0.25</td><td>0.35</td><td>0.52</td><td>Low Clamp, $V_{FB}$ = 1.5V</td></tr>
<tr><td rowspan="2">Compensation Pin Threshold</td><td rowspan="2">$V_{COMP\_TH}$</td><td>0.8</td><td>0.9</td><td>1.08</td><td rowspan="2">V</td><td rowspan="2">Duty Cycle = 0</td></tr>
<tr><td>0.6</td><td>—</td><td>1.25</td></tr>
<tr><td colspan="7">Output Switch</td></tr>
<tr><td rowspan="2">ON Resistance</td><td rowspan="2">$R_{SW(ON)}$</td><td>—</td><td>0.37</td><td>0.5</td><td rowspan="2">Ω</td><td rowspan="2">$I_{SW}$ = 2A, $V_{FB}$ = 0.8V</td></tr>
<tr><td>—</td><td>—</td><td>0.55</td></tr>
<tr><td rowspan="3">Current Limit</td><td rowspan="3">$I_{CLIM}$</td><td>2.5</td><td>3.6</td><td>5.0</td><td rowspan="3">A</td><td>Duty Cycle = 50%, $T_J$ ≥ 25°C</td></tr>
<tr><td>2.5</td><td>4.0</td><td>5.5</td><td>Duty Cycle = 50%, $T_J$ < 25°C</td></tr>
<tr><td>2.5</td><td>3.0</td><td>5.0</td><td>Duty Cycle = 80%, Note 3</td></tr>
</table>

## ELECTRICAL CHARACTERISTICS (CONTINUED)

**Electrical Characteristics:** $V_{IN}$ = 5V; $T_A$ = 25°C, unless otherwise specified. **Bold** values indicate –40°C ≤ $T_A$ ≤ 85°C. Note 1, Note 2

| Parameter | Symbol | Min. | Typ. | Max. | Units | Conditions |
|---|---|---|---|---|---|---|
| Breakdown Voltage | $V_{BR}$ | **65** | 75 | — | V | 3V ≤ $V_{IN}$ ≤ 40V, $I_{SW}$ = 5 mA |
| **Oscillator** | | | | | | |
| Frequency | $f_O$ | 88 | 100 | 112 | kHz | — |
| | | **85** | — | **115** | | — |
| Maximum Duty Cycle | $\delta_{max}$ | 80 | 90 | 95 | % | — |
| **Input Supply Voltage** | | | | | | |
| Minimum Operating Voltage | $V_{IN(MIN)}$ | — | 2.7 | **3.0** | V | — |
| Quiescent Current | $I_Q$ | — | 7 | 9 | mA | 3V ≤ $V_{IN}$ ≤ 40V, $V_{COMP}$ = 0.6V, $I_{SW}$ = 0A |
| Supply Current Increase | $\Delta I_{IN}$ | — | 9 | 20 | mA | $\Delta I_{SW}$ = 2A, $V_{COMP}$ = 1.5V, during $t_{ON}$ |

**Note 1:** Exceeding the absolute maximum rating may damage the device.

**2:** Devices are ESD sensitive. Handling precautions recommended.

**3:** For duty cycles (δ) between 50% and 95%, minimum guaranteed switch current is given by $I_{CLIM}$ = 1.66 (2 – δ) Amp.

## TEMPERATURE SPECIFICATIONS (Note 1)

| Parameters | Symbol | Min. | Typ. | Max. | Units | Conditions |
|---|---|---|---|---|---|---|
| **Temperature Ranges** | | | | | | |
| Operating Ambient Temperature | $T_A$ | –40 | — | +85 | °C | — |
| Operating Junction Temperature | $T_J$ | –40 | — | +125 | °C | — |
| Maximum Junction Temperature | $T_{J(MAX)}$ | — | — | +150 | °C | — |
| Storage Temperature | $T_S$ | –65 | — | +150 | °C | — |
| Lead Temperature | $T_{LEAD}$ | — | — | +300 | °C | Soldering, 10 sec. |
| **Package Thermal Resistances** | | | | | | |
| Thermal Resistance 5-Pin TO-220-5 | $\theta_{JA}$ | — | 45 | — | °C/W | Note 2 |
| Thermal Resistance 5-Pin TO-263-5 | $\theta_{JA}$ | — | 45 | — | | Note 3 |

**Note 1:** The maximum allowable power dissipation is a function of ambient temperature, the maximum allowable junction temperature and the thermal resistance from junction to air (i.e., $T_A$, $T_J$, $\theta_{JA}$). Exceeding the maximum allowable power dissipation will cause the device operating junction temperature to exceed the maximum +125°C rating. Sustained junction temperatures above +125°C can impact the device reliability.

**2:** Mounted vertically, no external heat sink, 1/4 inch leads soldered to PC board containing approximately 4 inch squared copper area surrounding leads.

**3:** All ground leads soldered to approximately 2 inches squared of horizontal PC board copper area.

## 2.0 TYPICAL PERFORMANCE CURVES

| | |
|---|---|
| **Note:** | The graphs and tables provided following this note are a statistical summary based on a limited number of samples and are provided for informational purposes only. The performance characteristics listed herein are not tested or guaranteed. In some graphs or tables, the data presented may be outside the specified operating range (e.g., outside specified power supply range) and therefore outside the warranted range. |

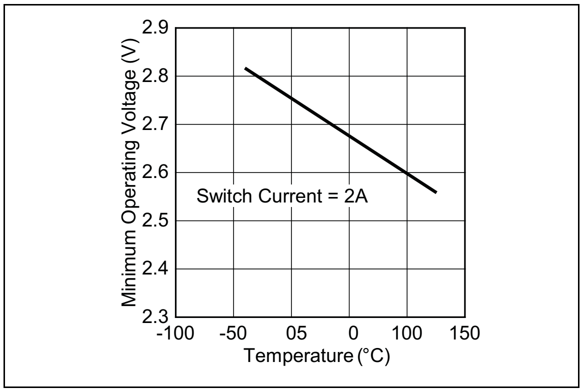



*FIGURE 2-1: Minimum Operating Voltage vs. Temperature.*

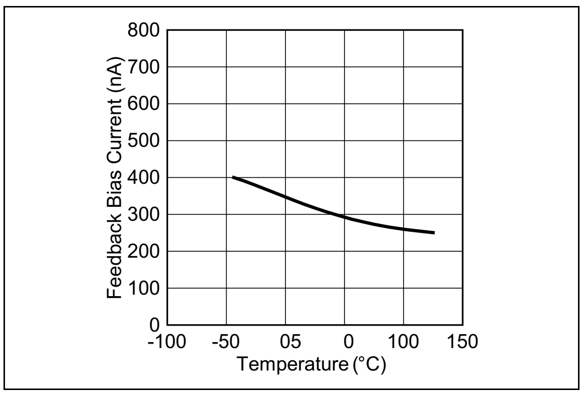



*FIGURE 2-2: Feedback Bias Current vs. Temperature.*

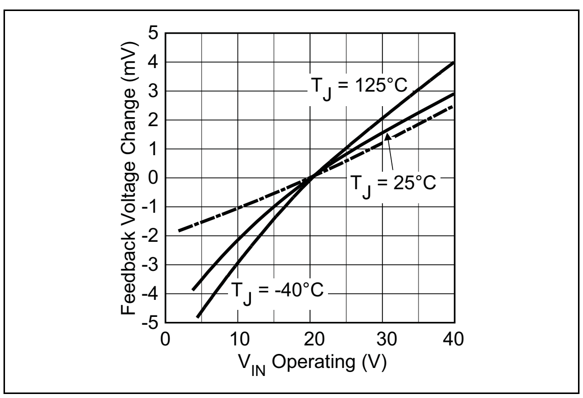



*FIGURE 2-3: Feedback Voltage Line Regulation.*

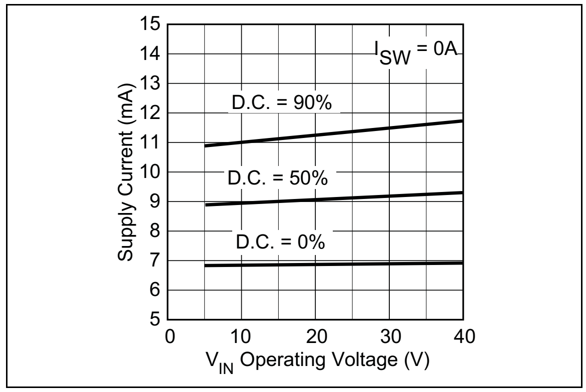



*FIGURE 2-4: Supply Current vs. Operating Voltage.*

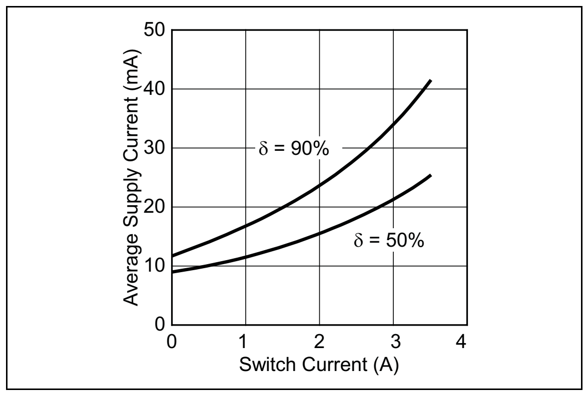



*FIGURE 2-5: Supply Current vs. Switch Current.*

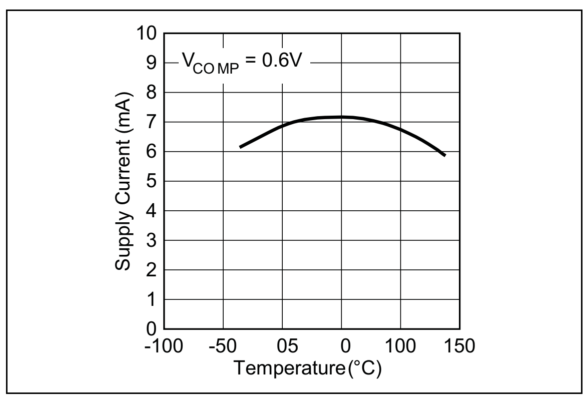



*FIGURE 2-6: Supply Current vs. Temperature.*

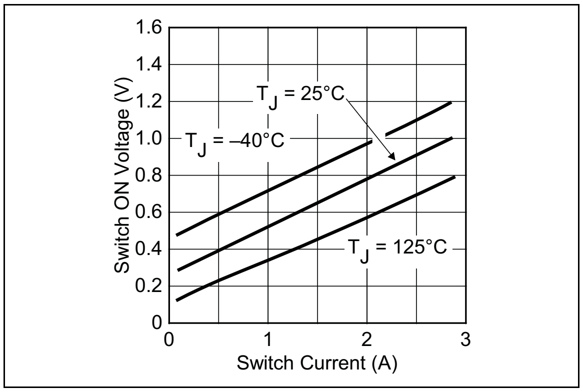



***FIGURE 2-7:*** *Switch ON Voltage vs. Switch Current.*

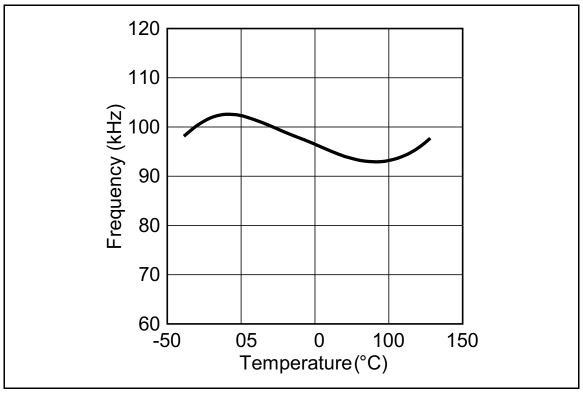



***FIGURE 2-8:*** *Oscillator Frequency vs. Temperature.*

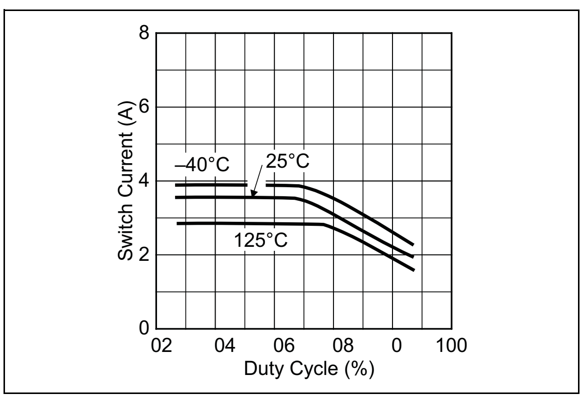



***FIGURE 2-9:*** *Current Limit vs. Duty Cycle.*

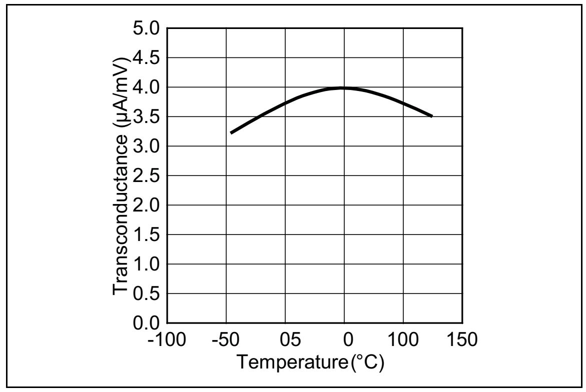



***FIGURE 2-10:*** *Error Amplifier Gain vs. Temperature.*

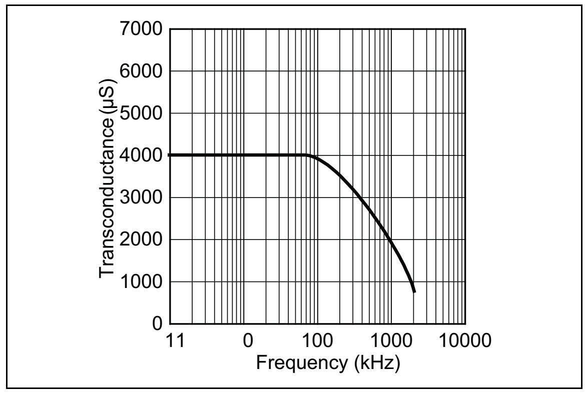



***FIGURE 2-11:*** *Error Amplifier Gain vs. Frequency.*

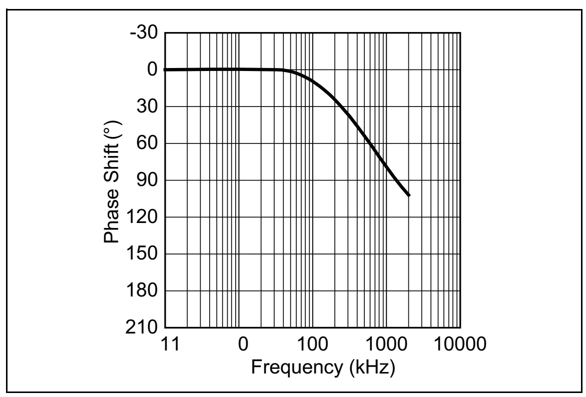



***FIGURE 2-12:*** *Error Amplifier Phase vs. Frequency.*

## 3.0 PIN DESCRIPTIONS

The descriptions of the pins are listed in Table 3-1.

**TABLE 3-1: PIN FUNCTION TABLE**

| Pin Number | Pin Name | Description |
|---|---|---|
| 1 | COMP | Frequency Compensation: Output of transconductance-type error amplifier. Primary function is for loop stabilization. Can also be used for output voltage soft-start and current limit tailoring. |
| 2 | FB | Feedback: Inverting input of error amplifier. Connect to external resistive divider to set switching regulator output voltage. |
| 3 | GND | Ground: Connect directly to the input filter capacitor for proper operation (see applications info). |
| 4 | SW | Power Switch Collector: Collector of NPN switch. Connect to external inductor or input voltage depending on circuit topology. |
| 5 | IN | Supply Voltage: 3.0V to 40V |

# 4.0 FUNCTIONAL DESCRIPTION

Refer to Functional Block Diagram section.

## 4.1 Internal Power

The MIC2171 operates when $V_{IN}$ is ≥ 2.6V. An internal 2.3V regulator supplies biasing to all internal circuitry, including a precision 1.24V band gap reference.

## 4.2 PWM Operation

The 100 kHz oscillator generates a signal with a duty cycle of approximately 90%. The current-mode comparator output is used to reduce the duty cycle when the current amplifier output voltage exceeds the error amplifier output voltage. The resulting PWM signal controls a driver which supplies base current to the output transistor Q1.

## 4.3 Current Mode Advantages

The MIC2171 operates in current mode rather than voltage mode. There are three distinct advantages to this technique. Feedback loop compensation is greatly simplified because inductor current sensing removes a pole from the closed loop response. Inherent cycle-by-cycle current limiting greatly improves the power switch reliability and provides automatic output current limiting. Finally, current-mode operation provides automatic input voltage feed forward which prevents instantaneous input voltage changes from disturbing the output voltage setting.

## 4.4 Anti-Saturation

The anti-saturation diode (D1) increases the usable duty cycle range of the MIC2171 by eliminating the base to collector stored charge which would delay Q1's turnoff.

## 4.5 Compensation

Loop stability compensation of the MIC21712 can be accomplished by connecting an appropriate RC network from either COMP to circuit ground (Typical Application Circuits) or from COMP to FB.

The error amplifier output (COMP) is also useful for soft start and current limiting. Because the error amplifier output is a transconductance type, the output impedance is relatively high, which means the output voltage can be easily clamped or adjusted externally.

## 5.0 APPLICATIONS INFORMATION

### 5.1 Soft-Start

A diode coupled capacitor from COMP to circuit ground slows the output voltage rise at turn on (Figure 5-1).

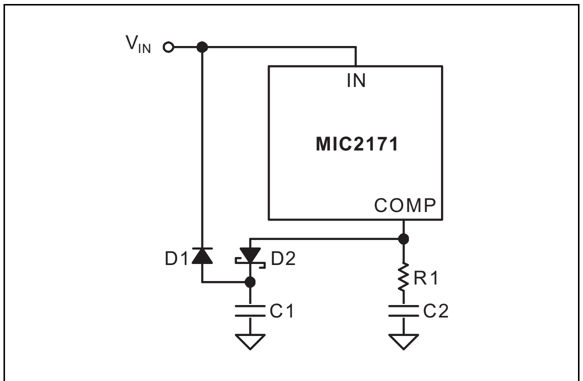



*FIGURE 5-1: Soft-Start.*

The additional time it takes for the error amplifier to charge the capacitor corresponds to the time it takes the output to reach regulation. Diode D1 discharges C1 when $V_{IN}$ is removed.

### 5.2 Current Limit

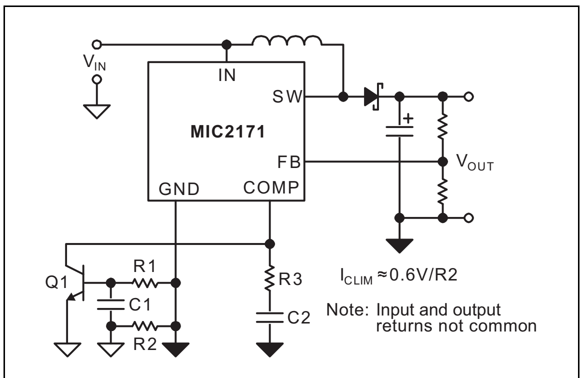



*FIGURE 5-2: Current Limit.*

The maximum current limit of the MIC2171 can be reduced by adding a voltage clamp to the COMP output (Figure 5-2). This feature can be useful in applications requiring either a complete shutdown of Q1's switching action or a form of current fold back limiting. This use of the COMP output does not disable the oscillator, amplifiers or other circuitry, therefore the supply current is never lower than approximately 5 mA.

### 5.3 Thermal Management

For the best reliability, MIC2171 should avoid prolonged operation with junction temperatures near the rated maximum.

Firstly, the junction temperature is determined by calculating the power dissipation of the device. For the MIC2171, the total power dissipation is the sum of the device operating losses and power switch losses.

The device operating losses are the DC losses associated with biasing all of the internal functions plus the losses of the power switch driver circuitry. The DC losses are calculated based on the supply voltage ($V_{IN}$) and device supply current ($I_Q$). The MIC2171 supply current is almost constant regardless of the supply voltage (see Section 1.0, Electrical Characteristics). The driver section losses (not including the switch) are a function of supply voltage, power switch current, and duty cycle.

**EQUATION 5-1:**

$$P_{(BIAS+DRIVER)} = (V_{IN} \times I_Q) + V_{IN} \times V_{CLIM} \times \frac{\Delta I_{IN}}{\Delta I_{SW}} \times \delta$$

Where:

$P_{(BIAS + DRIVER)}$ = Device operating losses

$V_{IN}$ = Supply Voltage

$I_Q$ = Quiescent supply current

$I_{CLIM}$ = Power switch current limit

$\Delta I_{IN}$ = Maximum supply current increase

$\Delta I_{SW}$ = Switch current increase

As a practical example, refer to Typical Application Circuits

$V_{IN}$ = 5V

$I_Q$ = 0.007A

$I_{CLIM}$ = 2.21A

$\delta$ = 66.2% (0.662)

Then,

$P_{(BIAS + DRIVER)}$ = 5 x 0.007 + (5 x 2.21 x 0.02 x 0.662)/2

$P_{(BIAS + DRIVER)}$ = 0.108W

Power switch dissipation calculations are greatly simplified by making two assumptions which are usually fairly accurate. First, the majority of losses in the power switch are due to on-time conduction losses. To find these losses, assign a resistance value to the collector/emitter terminals of the device using the saturation voltage versus collector current curves (see Section 2.0, Typical Performance Curves). Power switch losses are calculated by modeling the switch as a resistor with the switch duty cycle modifying the average power dissipation.

**EQUATION 5-2:**

$$P_{SW} = (I_{SW})^2 \times R_{SW} \times \delta$$

Where:

δ = Duty cycle

For boost converter,

$$\delta = \frac{V_{OUT} + V_F - V_{IN(MIN)}}{V_{OUT} + V_F}$$

Where:

$V_{IN(MIN)}$ = $V_{IN} - V_{SW}$
$V_{SW}$ = $I_{CLIM}$ x $R_{SW}$
$V_{OUT}$ = Output voltage
$V_F$ = D1 forward voltage drop at $I_{OUT}$

From the Typical performance Characteristics:

$R_{SW} = 0.37\Omega$

Then:

$P_{SW} = (2.21)^2 \times 0.37 \times 0.662$

$P_{SW} = 1.2W$

$P_{(TOTAL)} = 1.2 + 0.1$

$P_{(TOTAL)} = 1.3W$

The junction temperature for any semiconductor is calculated using the following:

**EQUATION 5-3:**

$$T_J = T_A + P_{(TOTAL)} \times \theta_{JA}$$

Where:

$T_J$ = Junction temperature
$T_A$ = Ambient temperature (maximum)
$P_{(TOTAL)}$ = Total power dissipation
$\theta_{JA}$ = Junction to ambient thermal resistance

For the practical example:

$T_A = 70°C$

$\theta_{JA} = 45°C/W$ (for TO-220)

Then:

$T_J = 70 + (1.3 \times 45)$

$T_J = 128.5°C$

This junction temperature is below the rated maximum of 150°C.

## 5.4 Grounding

Refer to Figure 5-3. Heavy lines indicate high-current ground paths.

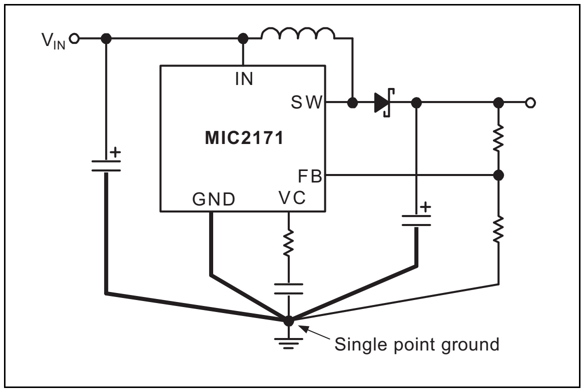



*FIGURE 5-3: Single Point Ground.*

A single point ground is strongly recommended for proper operation.

The signal ground, compensation network ground, and feedback network connections are sensitive to minor voltage variations. The input and output capacitor grounds and power ground tracks will exhibit voltage drop when carrying large currents. Keep the sensitive circuit ground traces separate from the power ground traces. Small voltage variations applied to the sensitive circuits can prevent the MIC2171 or any switching regulator from functioning properly.

## 5.5 Boost Conversion

Refer to the Typical Application Circuits for a typical boost conversion application where a +5V logic supply is available and a +12V at 0.25A output is required.

The first step in designing a boost converter is determining whether inductor L1 will cause the converter to operate in either continuous or discontinuous conduction mode. Discontinuous conduction mode is preferred because the feedback control of the converter is simpler.

When L1 discharges its current completely during the MIC2171 off-time, it is operating in discontinuous conduction mode.

L1 is operating in continuous conduction mode if it does not discharge completely before the MIC2171 power switch is turned on again.

### 5.5.1 DISCONTINUOUS CONDUCTION MODE DESIGN

Given the maximum output current, solve Equation 5-4 to determine whether the device can operate in discontinuous conduction mode without triggering the internal device current limit.

**EQUATION 5-4:**

$$I_{OUT} \leq \frac{\left(\frac{I_{CLIM}}{2}\right) \times V_{IN(MIN)}}{V_{OUT}}$$

$$\delta = \frac{V_{OUT} + V_F - V_{IN(MIN)}}{V_{OUT} + V_F}$$

Where:

| | |
|---|---|
| $I_{CLIM}$ = | Internal switch current limit |
| $I_{CLIM}$ = | 1.25A when $\delta$ < 50% |
| $I_{CLIM}$ = | 1.67 (2 – $\delta$) when $\delta \geq$ 50% |
| $I_{OUT}$ = | Maximum output current |
| $V_{IN(MIN)}$ = | Minimum input voltage = $V_{IN} - V_{SW}$ |
| $\delta$ = | Duty cycle for boost converter in CRM |
| $V_{OUT}$ = | Required output voltage |
| $V_F$ = | Diode forward voltage drop |

For the example in the Typical Application Circuits:

$I_{OUT}$ = 0.25A

$I_{CL}$ = 1.67 (2 – 0.662) = 2.24A

$V_{IN(MIN)}$ = 4.18V

$\delta$ = 0.662

$V_{OUT}$ = 12.0V

$V_F$ = 0.36V (@ 0.26A, 70°C)

Then:

**EQUATION 5-5:**

$$I_{OUT} \leq \frac{\left(\frac{2.235}{2}\right) \times 4.178}{12}$$

$$I_{OUT} \leq 0.389A$$

This value is greater than the 0.25A output current requirement, so one can proceed to find the inductance value of L1 for discontinuous operation at $P_{OUT}$.

**EQUATION 5-6:**

$$\frac{V_{IN} \times \delta}{I_{CLIM} \times f_{SW}} \leq L1 \leq \frac{(V_{IN})^2 \times \delta}{2 \times P_{OUT} \times f_{SW}}$$

Where:

| | |
|---|---|
| $P_{OUT}$ = | 12 x 0.25 = 3W |
| $f_{SW}$ = | $1.10^5$ Hz (100 kHz) |

For our practical example:

**EQUATION 5-7:**

$$\frac{4.178 \times 0.662}{2.235 \times 1 \times 10^5} \leq L1 \leq \frac{(4.178)^2 \times 0.662}{2 \times 3.0 \times 1 \times 10^5}$$

$$12.38\mu H \leq L1 \leq 19.26\mu H \quad \text{(Use 15 µH)}$$

Equation 5-8 solves for L1's maximum current value.

**EQUATION 5-8:**

$$I_{L1(PEAK)} = \frac{V_{IN} \times t_{ON}}{L1}$$

Where:

| | |
|---|---|
| $t_{ON}$ = | $\delta / f_{SW} = 6.62 \times 10^{-6}$ sec. |

**EQUATION 5-9:**

$$I_{L1(PEAK)} = \frac{4.178 \times 6.62 \times 10^{-6}}{15 \times 10^{-6}} = 1.096A$$

$$I_{L1(PEAK)} = 1.84A$$

Use a 15 µH inductor with a peak current rating greater than 2A.

## 5.6 Flyback Conversion

Flyback converter topology may be used in low power applications where voltage isolation is required or whenever the input voltage can be less than or greater than the output voltage. As with the step-up converter, the inductor (transformer's primary winding) current can be continuous or discontinuous. In this particular case, discontinuous operation is recommended.

The Typical Application Circuits shows a practical flyback converter design using the MIC2171.

### 5.6.1 SWITCH OPERATION

During Q1's on time (Q1 is the internal NPN transistor, see the Functional Block Diagram, energy is stored in T1's primary inductance. During Q1's off time, stored energy is partially discharged into C4 (output filter capacitor). Careful selection of a low ESR capacitor for C4 may provide satisfactory output voltage ripple making additional filter stages unnecessary.

C1's value (input capacitor) may be reduced or it can be eliminated if the MIC2171 is located near a low impedance voltage source

### 5.6.2 OUTPUT DIODE

The output diode allows T1 to store energy in its primary inductance (D2 blocked/reverse biased) and release energy into C4 (D2 forward biased); the low forward voltage drop of a Schottky diode minimizes power loss in D2.

### 5.6.3 FREQUENCY COMPENSATION

A simple frequency compensation network consisting of R3 and C2 prevents output oscillations.

High impedance output stages (transconductance type) in the MIC2171 often permit simplified loop stability solutions to be connected to circuit ground, although a more conventional technique of connecting the components from the error amplifier output to its inverting input is also possible.

### 5.6.4 VOLTAGE CLIPPER

Extra care must be taken to minimize T1's leakage inductance, otherwise it may be necessary to add the voltage clipper consisting of D1, R4, and C3 in order to avoid second breakdown (failure) of the MIC2171's internal power switch.

### 5.6.5 DISCONTINUOUS CONDUCTION MODE DESIGN

When designing a discontinuous conduction mode flyback converter, first determine whether the device can safely handle the peak primary current demand drawn by the output power. Equation 5-10 finds the maximum duty cycle required for a given input voltage and output power. If the duty cycle is greater than 0.8, discontinuous operation cannot be used.

**EQUATION 5-10:**

$$\delta \geq \frac{2 \times P_{OUT}}{I_{CLIM}(V_{IN(MIN)} - V_{SW})}$$

Where:

| | |
|---|---|
| $P_{OUT}$ = | 5.0V × 0.5A = 2.5W |
| $V_{IN}$ = | 4.0V to 6.0V |
| $I_{CLIM}$ = | 1.25A when δ < 50%<br>1.67 (2 – δ) when δ ≥ 50% |

Then:

$V_{IN(MIN)} = V_{IN} – (I_{CLIM} \times R_{SW})$

$V_{IN(MIN)} = 4V – 0.78V$

$V_{IN(MIN)} = 3.22V$

δ ≥ 0.74 (76%), less than 0.8, so discontinuous is permitted. A few iterations of Equation 5-10 may be required if the duty cycle is found to be greater than 50% since the $I_{CLIM}$ is a function of duty cycle when δ > 50%.

The next step is to calculate the maximum transformer turns ratio **a**, or $N_{PRI}/N_{SEC}$, that will guarantee a safe operation of the MIC2171's power switch.

**EQUATION 5-11:**

$$a \leq \frac{V_{CE} \times F_{CE} - V_{IN(MAX)}}{V_{SEC}}$$

Where:

| | |
|---|---|
| a = | Maximum transformer turn ratio |
| $V_{CE}$ = | Power switch collector to emitter maximum voltage |
| $F_{CE}$ = | Safety derating factor (0.8 for most commercial and industrial applications) |
| $V_{IN(MAX)}$ = | Maximum input voltage |
| $V_{SEC}$ = | Transformer secondary voltage ($V_{OUT} + V_F$) |

For the practical example:

$V_{CE}$ = 65V max. for the MIC2171

$F_{CE}$ = 0.8

$V_{SEC}$ = 5.6V

Then:

**EQUATION 5-12:**

$$a \leq \frac{65 \times 0.8 - 6.0}{5.6}$$

$$a \leq 8.2 \quad (N_{PRI}/N_{SEC})$$

Next, calculate the maximum primary inductance required to store the needed output energy with the power switch duty cycle of 76%.

**EQUATION 5-13:**

$$\frac{V_{IN(MIN)} \times \delta}{I_{CLIM} \times f_{SW}} \leq L_{PRI} \leq \frac{0.5 \times f_{SW} \times V_{IN(MIN)}^2 \times t_{ON}^2}{P_{OUT}}$$

Where:

| | |
|---|---|
| $L_{PRI}$ = | Maximum primary inductance |
| $f_{SW}$ = | Device switching frequency (100 kHz) |
| $V_{IN(MIN)}$ = | Minimum input voltage |
| $t_{ON}$ = | Power switch on time |

Then:

**EQUATION 5-14:**

$$\frac{3.22 \times 0.76}{2.1 \times 1 \times 10^5} \le L_{PRI} \le \frac{0.5 \times 1 \times 10^5 \times 3.22^2 \times (7.6 \times 10^{-6})^2}{2.5}$$

$$(11.65\mu H \le L_{PRI} \le 12\mu H)$$

Use a 12 µH primary inductance to overcome circuit inefficiencies.

To complete the design, the inductance value of the secondary winding must be calculated, so it will ensure that the energy stored in the transformer during the power switch on time will be completed discharged into the output during the off time; this is necessary when operating in discontinuous mode.

**EQUATION 5-15:**

$$L_{SEC} \le \frac{0.5 \times f_{SW} \times V_{SEC}^2 \times t_{OFF}^2}{P_{OUT}}$$

Where:

| | |
|---|---|
| $L_{SEC}$ = | Maximum secondary inductance |
| $t_{OFF}$ = | Power switch off time |

Then:

**EQUATION 5-16:**

$$L_{SEC} \le \frac{0.5 \times 1 \times 10^5 \times 5.6^2 (2.4 \times 10^{-6})^2}{2.5}$$

$$L_{SEC} \le 3.6\mu H$$

Finally, recalculate the transformer turns ratio to ensure that it is less than the value found earlier by using Equation 5-11.

**EQUATION 5-17:**

$$a \le \sqrt{\frac{L_{PRI}}{L_{SEC}}}$$

Then:

**EQUATION 5-18:**

$$a \le \sqrt{\frac{12}{3.6}} = 1.83$$

This ratio is less than the ratio calculated in Equation 5-11. When selecting the transformer, it is necessary to know the primary peak current which must be handled without saturating the transformer core.

**EQUATION 5-19:**

$$I_{PEAK(PRI)} = \frac{V_{IN(MIN)} \times t_{ON}}{L_{PRI}}$$

So:

**EQUATION 5-20:**

$$I_{PEAK(PRI)} = \frac{3.22 \times 7.6 \times 10^{-6}}{12 \times 10^{-6}}$$

$$I_{PEAK(PRI)} = 2.04A$$

Now find the minimum reverse voltage requirement for the output rectifier. This rectifier must have an average current rating greater than the maximum output current of 0.5A.

**EQUATION 5-21:**

$$V_{BR} \ge \frac{V_{IN(MAX)} + (V_{OUT} \times a)}{F_{BR} \times a}$$

Where:

| | |
|---|---|
| $V_{BR}$ = | Output rectifier maximum peak reverse voltage rating |
| a = | Transformer turns ratio (1.8) |
| $F_{BR}$ = | Reverse voltage safety derating factor (0.8) |

Then:

**EQUATION 5-22:**

$$V_{BR} \geq \frac{6.0 + (5.0 \times 1.8)}{0.8 \times 1.8}$$

$$V_{BR} \geq 10.4V$$

A 1N5817 dioded will safely handle voltage and current requirements provided in this example.

## 5.7 Forward Converters

The MIC2171 can be used in several circuit configurations to generate an output voltage which is lower than the input voltage (buck or step-down topology). Figure 5-4 shows the MIC2171 in a voltage step-down application. Because of the internal architecture of these devices, more external components are required to implement a step-down regulator than with other devices offered by Microchip (refer to the LM257x or LM457x family of buck switchers). However, for step-down conversion requiring a transformer (forward), the MIC2171 is a good choice.

A 12V to 5V step-down converter using transformer isolation (forward) is shown in Figure 5-4. Unlike the isolated flyback converter which stores energy in the primary inductance during the controller's on-time and releases it to the load during the off-time, the forward converter transfers energy to the output during the on-time, using the off-time to reset the transformer core. In the application depicted in Figure 5-4, the transformer core is reset by the tertiary winding, discharging T1's peak magnetizing current through D2.

For most forward converters, the duty cycle is limited to 50%, allowing the transformer flux to reset with only two times the input voltage appearing across the power switch. Although during normal operation this circuit's duty cycle is well below 50%, the MIC2171 has a maximum duty cycle capability of 90%. If 90% was required during operation (start-up and high load currents), a complete reset of the transformer during the off-time would require the voltage across the power switch to be ten times the input voltage. This would limit the input voltage to 6V or less for forward converter applications.

To prevent core saturation, the application presented in this section uses a duty cycle limiter consisting of Q1, C4 and R3. Whenever the MIC2171 exceeds a duty cycle of 50%, T1's reset winding current turns Q1 on; this action reduces the duty cycle of the MIC2171 until T1 is able to reset during each cycle.

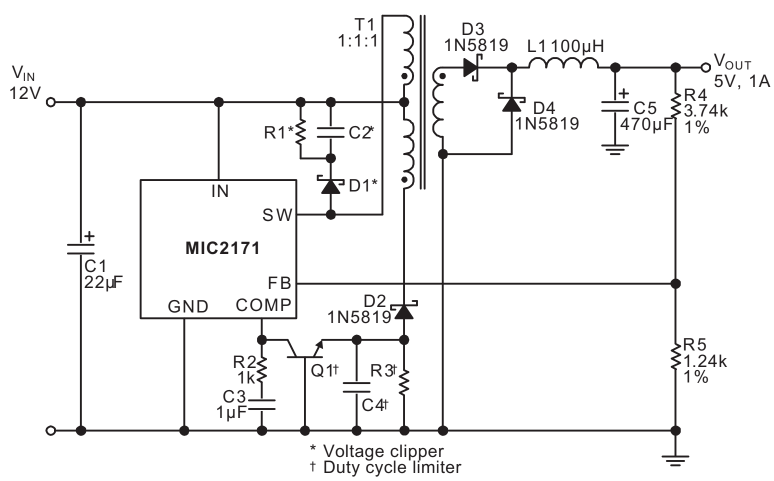



***FIGURE 5-4:*** *12V to 5V Forward Converter.*

## 5.8 Output Voltage Setting

The MC2171 requires a resistor divider connected from the output to ground with the middle point connected to the FB pin to set the desired output voltage. The output voltage is set by Equation 5-23.

**EQUATION 5-23:**

$$V_{OUT} = V_{REF}\left(\frac{R1}{R2} + 1\right)$$

Where:

| | |
|---|---|
| $V_{REF}$ = | 1.24V internal reference voltage |
| R1 = | Upper feedback resistor |
| R2 = | Lower feedback resistor |

A typical value of R1 can be in the range of 3kΩ to 15kΩ. If R1 is too large, it may allow noise to be introduced into the voltage feedback loop. If R1 is too small in value, it will decrease the efficiency of the switching regulator, especially at light loads. Once R1 is selected, R2 can be calculated using Equation 5-24.

**EQUATION 5-24:**

$$R2 = \frac{V_{REF} \times R1}{V_{OUT} - V_{REF}}$$

## 6.0 PACKAGING INFORMATION

### 6.1 Package Marking Information

| 5-Lead TO-220* | Example |
|---|---|
| XXX<br>XXXXXX<br>WNNNP | MIC<br>2171WT<br>1947P |

| 5-Lead TO-263* | Example |
|---|---|
| XXX<br>XXXXXX<br>WNNNP | MIC<br>2171WU<br>2000P |

| | | |
|---|---|---|
| **Legend:** | XX...X | Product code or customer-specific information |
| | Y | Year code (last digit of calendar year) |
| | YY | Year code (last 2 digits of calendar year) |
| | WW | Week code (week of January 1 is week '01') |
| | NNN | Alphanumeric traceability code |
| | (e3) | Pb-free JEDEC® designator for Matte Tin (Sn) |
| | * | This package is Pb-free. The Pb-free JEDEC designator ((e3)) can be found on the outer packaging for this package. |
| | ●, ▲, ▼ | Pin one index is identified by a dot, delta up, or delta down (triangle mark). |

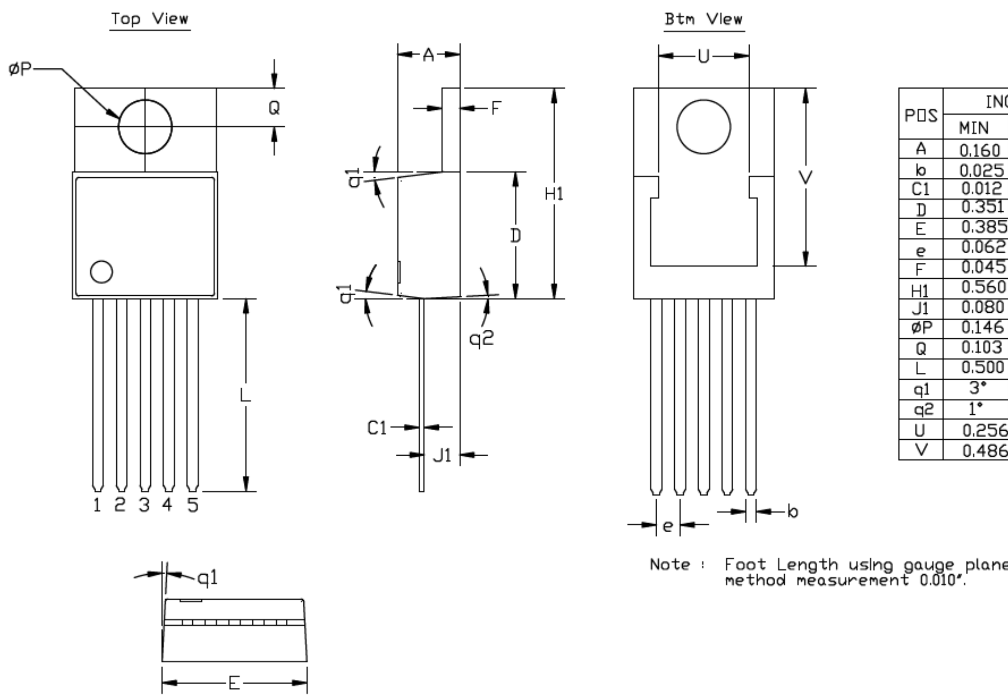
**Note**: In the event the full Microchip part number cannot be marked on one line, it will be carried over to the next line, thus limiting the number of available characters for customer-specific information. Package may or may not include the corporate logo.

Underbar (_) and/or Overbar (‾) symbol may not be to scale.

## 5-Lead TO-220 Package Outline and Recommended Land Pattern

**TITLE**
5 LEAD TO220 PACKAGE OUTLINE & RECOMMENDED LAND PATTERN

| | | | |
|---|---|---|---|
| **DRAWING #** | TO220-5LD-PL-1 | **UNIT** | INCH |
| **Lead Frame** | Copper Alloy | **Lead Finish** | Matte Tin |




| POS | INCH MIN | INCH MAX |
|---|---|---|
| A | 0.160 | 0.190 |
| b | 0.025 | 0.040 |
| C1 | 0.012 | 0.022 |
| D | 0.351 | 0.361 |
| E | 0.385 | 0.420 |
| e | 0.062 | 0.072 |
| F | 0.045 | 0.055 |
| H1 | 0.560 | 0.619 |
| J1 | 0.080 | 0.120 |
| øP | 0.146 | 0.156 |
| Q | 0.103 | 0.113 |
| L | 0.500 | 0.580 |
| q1 | 3° | 10° |
| q2 | 1° | 7° |
| U | 0.256 Ref. | |
| V | 0.486 Ref. | |

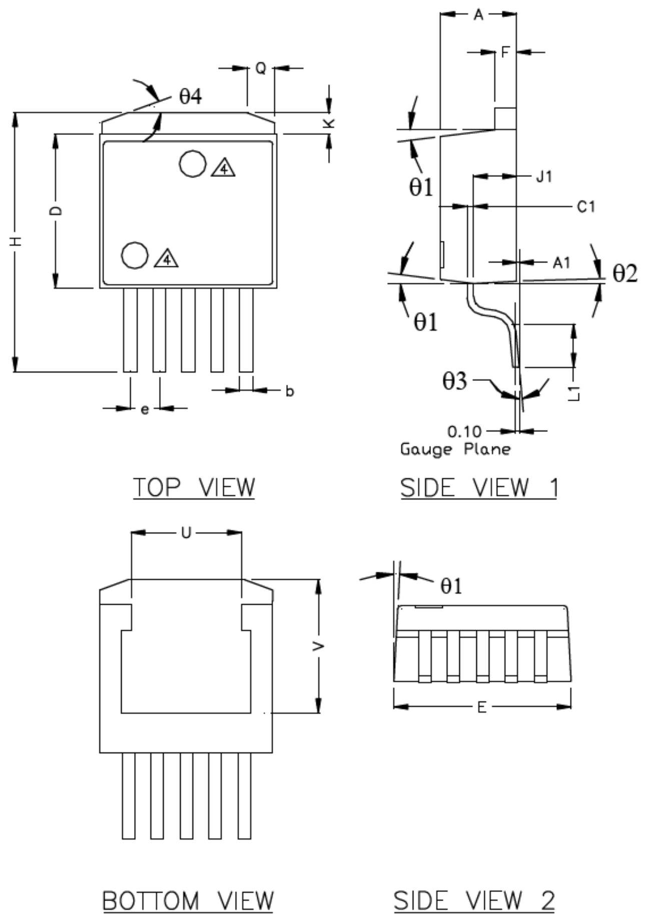
Note: For the most current package drawings, please see the Microchip Packaging Specification located at http://www.microchip.com/packaging.

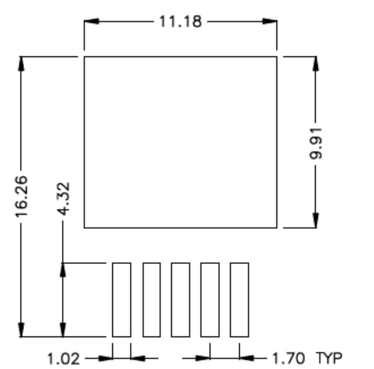
## 5-Lead TO-263 Package Outline and Recommended Land Pattern

**TITLE**
5 LEAD T0263 PACKAGE OUTLINE & RECOMMENDED LAND PATTERN

| DRAWING # | T0263-5LD-PL-1 | UNIT | INCH/MM |
|---|---|---|---|




| POS | INCH | | MM | |
|---|---|---|---|---|
| | MIN | MAX | MIN | MAX |
| A | 0.170 | 0.181 | 4.318 | 4.597 |
| A1 | 0.000 | 0.012 | 0.000 | 0.305 |
| b | 0.026 | 0.036 | 0.660 | 0.914 |
| C1 | 0.012 | 0.023 | 0.305 | 0.584 |
| D | 0.330 | 0.361 | 8.392 | 9.169 |
| E | 0.396 | 0.420 | 10.058 | 10.668 |
| e | 0.062 | 0.072 | 1.575 | 1.829 |
| F | 0.045 | 0.055 | 1.143 | 1.397 |
| H | 0.575 | 0.625 | 14.605 | 15.875 |
| J1 | 0.080 | 0.120 | 2.032 | 3.048 |
| K | 0.045 | 0.066 | 1.143 | 1.676 |
| L1 | 0.090 | 0.110 | 2.286 | 2.794 |
| θ1 | 3° | 10° | 3° | 10° |
| θ2 | 1° | 7° | 1° | 7° |
| θ3 | 0° | 8° | 0° | 8° |
| θ4 | 18° | 22° | 18° | 22° |
| Q | 0.055 | 0.075 | 1.397 | 1.905 |
| U | 0.256 Ref. | | 6.502 Ref. | |
| V | 0.305 Ref. | | 7.747 Ref. | |




RECOMMENDED LAND PATTERN
(UNIT : mm)

NOTE:
1. PACKAGE OUTLINE EXCLUSIVE OF MOLD FLASH & METAL BURR.
2. PACKAGE OUTLINE INCLUSIVE OF PLATING THICKNESS.
3. FOOT LENGTH USING GAUGE PLANE METHOD MEASUREMENT 0.010"
4. PACKAGE TOP MARK MAY BE IN TOP CENTER OR LOWER LEFT CORNER
5. ALL DIMENSIONS ARE IN INCHES/MILLIMETERS.

Note: For the most current package drawings, please see the Microchip Packaging Specification located at http://www.microchip.com/packaging.

# APPENDIX A: REVISION HISTORY

## Revision A (May 2022)

- Converted Micrel document MIC2171 to Microchip data sheet DS20006355A.
- Minor text changes throughout.

NOTES:

## PRODUCT IDENTIFICATION SYSTEM

To order or obtain information, e.g., on pricing or delivery, contact your local Microchip representative or sales office.

| PART NO. | X | XX | –XX |
|---|---|---|---|
| Device | Ambient Temperature Range | Package Option | Media Type |

| | | |
|---|---|---|
| **Device:** | MIC2171: 100 kHz, 2.5A Switching Regulator | |
| **Ambient Temperature Range:** | W = | –40°C to +85°C |
| **Package:** | T = | 5-Lead TO-220 (RoHS Compliant) |
| | U = | 5-Lead TO-263 (RoHS Compliant) |
| **Media Type:** | <blank> = | 50/Tube (TO-220 Package) |
| | <blank> = | 50/Tube (TO-263 Package) |
| | TR = | 750/Reel |

**Examples:**

a) MIC2171WT: 100 kHz, 2.5A Switching Regulator, –40°C to +85°C Ambient Temperature Range, 5-Lead TO-220 Package, 50/Tube

b) MIC2171WU: 100 kHz, 2.5A Switching Regulator, –40°C to +85°C Ambient Temperature Range, 5-Lead TO-263 Package, 50/Tube

c) MIC2171WU-TR: 100 kHz, 2.5A Switching Regulator, –40°C to +85°C Ambient Temperature Range, 5-Lead TO-263 Package, 750/Reel

**Note 1:** Tape and Reel identifier only appears in the catalog part number description. This identifier is used for ordering purposes and is not printed on the device package. Check with your Microchip Sales Office for package availability with the Tape and Reel option.

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