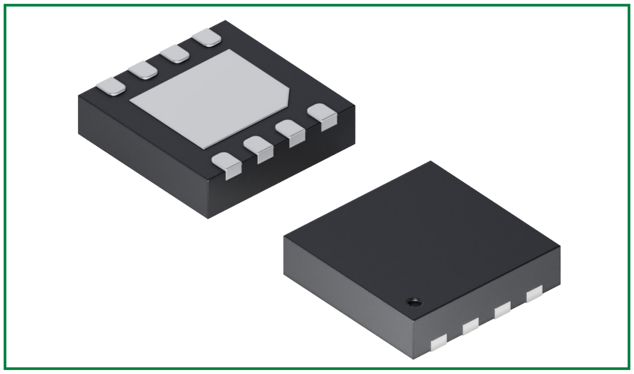
# CPC1601M

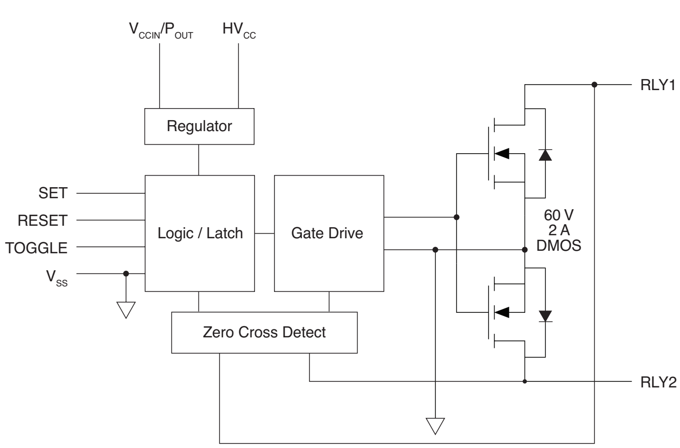
Low Current, 60 V, 2 A
1-Form-A Solid State Latching Relay



## Features

- Small 3×3 mm$^2$ DFN package
- $V_{CCIN}$/$P_{OUT}$ pin Input Current < 1µA
- Single pulse operation On/Off
- Low typical on-resistance of 308 mΩ
- Load Connect RYL1 / RLY2: 60 $V_P$ AC or DC operation
- 2 A continuous load capability AC or DC
- Set/Reset or Toggle operation
- Latching Form-A switch output
- Supply input power voltage: 3 V–5.5 V
- Zero current from system power supply when load biased power mode (load-powered) is used
- Load-harvesting power pin for powering external circuitry up to 10 mW
- Zero current switching in load-powered mode
- No auxiliary power supply needed in load-powered mode e.g. no thermostat common wire "C" lead required
- External galvanic isolation compatible

## CPC1601M Functional Block Diagram




## Description

The CPC1601M is a non-isolated, low operating current, 1-Form-A solid state latching relay, integrated in a small 3×3 mm$^2$ DFN package. The relay can obtain operating power either from the open-circuit load or from system power supply. When powered by the load, the relay consumes no power from the system supply, thus helping to extend battery life. If powered by the load, the relay draws no energy from the system's main power supply, helping to extend battery life. The relay periodically opens, allowing it to harvest power from the open- circuit load voltage. In most applications, this brief interruption is unnoticeable to the load.

Additionally, the CPC1601M includes a power output pin that can supply external circuits with a maximum of 10 mW of power. The CPC1601M can sense whether it is powered by the load or by the system power supply automatically by monitoring the $HV_{CC}$ input pin. The load-powered mode of operation applies to an AC source, such as a 24 $V_{AC}$ transformer secondary voltage.

Galvanic isolation can be achieved by incorporating few passive components into the circuit.

## Applications

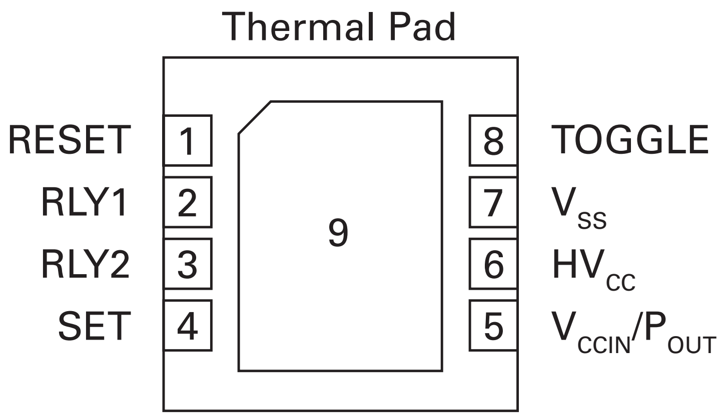
- Thermostats
- HVAC
- Fire alarm panels
- Security systems
- Building automation
- Industrial controls
- Metering
- Electronic switching
- Data acquisition
- Instrumentation

## Ordering Information

| Part Number | Description |
|---|---|
| CPC1601MTR | 8-pin DFN in Tape and Reel; 2000 per reel |

# 1 Specifications

## 1.1 Package Pinout




## 1.2 Pin Description

| Pin | Name | Type | Description |
|---|---|---|---|
| 1 | RESET | Input | Logic input with an active high pulse turns the relay OFF. Connect to ground if using TOGGLE pin. |
| 2 | RLY1 | Bidirectional | Connect to load. |
| 3 | RLY2 | Bidirectional | Connect to load. |
| 4 | SET | Input | Logic input with an active high pulse turns the relay ON. Connect to ground if using TOGGLE pin. |
| 5 | $V_{CCIN}/P_{OUT}$ | Bidirectional | When operating in load-powered mode, $V_{CCIN}/P_{OUT}$ is a 3 V to 5 V output that can be used to power external circuitry. When not operating in load-powered mode, this pin is connected to the system power supply. |
| 6 | $HV_{CC}$ | Input | DC power input to the relay when operating in load-powered mode. Do not connect if CPC1601M is powered by an external supply other than the load supply i.e. battery on $V_{CCIN}/P_{OUT}$ pin. |
| 7 | $V_{SS}$ | Input | Connect to system power supply return. |
| 8 | TOGGLE | Input | Active high pulse alternately turns relay ON and OFF. |
| 9 | Thermal Pad | Input | Thermal Pad should be connected to system power supply return. |

## 1.3 Absolute Maximum Ratings

($T_a = 25\,°C$ unless otherwise noted)

| Parameter | Rating | Units |
|---|---|---|
| Blocking Voltage | 60 | $V_{DC}$ |
| $HV_{CC}$ Supply Voltage | 60 | $V_{DC}$ |
| $V_{CCIN}/P_{OUT}$ Supply Voltage | 6 | $V_{DC}$ |
| Total Power Dissipation [1] | 2 | W |
| ESD Rating, Human Body Model | 2000 | V |
| Operating Temperature, Ambient | −40 to +85 | °C |
| Storage Temperature | −40 to +150 | °C |

[1] *Derate 22 mW/K above 40 °C ambient.*

*Absolute Maximum Ratings are stress ratings. Stresses in excess of these ratings can cause permanent damage to the device. Functional operation of the device at conditions beyond those indicated in the operational sections of this data sheet is not implied.*

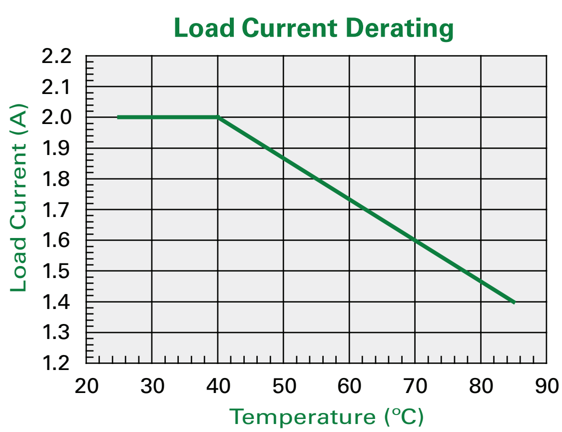
*Typical values are characteristic of the device at +25 °C, and are the result of engineering evaluations. They are provided for information purposes only, and are not part of the manufacturing testing requirements.*

### 1.4 Electrical Characteristics @ 25°C (Unless otherwise noted)

| Parameter | Condition | Symbol | Min | Typ | Max | Units |
|---|---|---|---|---|---|---|
| Load Current, continuous | $T_a \leq 40$°C (see derating curve in 1.5) | $I_L$ | — | — | 2 | A |
| On-Resistance | $T_a$ = +25°C | $R_{ON}$ | — | 308 | 365 | mΩ |
| | $V_{CCIN}$ = 3 V, $I_L$ = 400 mA, +85°C | | — | — | 520 | |
| Off-State Leakage Current | $V_L$ = 60 V | $I_{LEAK}$ | — | — | 1 | µA |
| Switching Speeds | | | | | | |
| Turn-On | SET or TOGGLE pulse applied | $t_{on}$ | — | — | 1 | µs |
| Turn-Off | RESET or TOGGLE pulse applied | $t_{off}$ | — | — | 1 | |
| Output Capacitance | $V_L$ = 20 V, f = 1 MHz | $C_{OUT}$ | — | 98 | — | pF |
| Input Voltage, High (SET, RESET, TOGGLE) | — | $V_{IH}$ | 1.4 | — | — | V |
| Input Voltage, Low (SET, RESET, TOGGLE) | — | $V_{IL}$ | — | — | 0.5 | |
| Input Hysteresis (SET, RESET, TOGGLE) | — | $V_{HYS}$ | — | 0.1 | — | |
| $V_{CCIN}/P_{OUT}$ Supply Output Voltage | Load-powered mode output | $V_{CCOUT}$ | 3 | — | 5 | $V_{DC}$ |
| $V_{CCIN}/P_{OUT}$ Supply Input Voltage | System power | $V_{CCIN}$ | 3 | — | 5.5 | |
| $V_{CCIN}/P_{OUT}$ Supply Input Current | Input voltage = 5 V | $I_{VCC}$ | — | — | 1 | µA |
| $HV_{CC}$ Supply Voltage | Load-powered mode input | $HV_{CC}$ | — | — | 60 | $V_{DC}$ |
| $V_{CCIN}/P_{OUT}$ Supply Output Current | Load-powered mode output | $I_{OCC}$ | — | — | 2 | mA |
| $HV_{CC}$ Supply Current | — | $I_{HVCC}$ | — | — | 250 | µA |
| Load-powered mode Relay OFF Voltage | — | $HV_{CC\_off}$ | — | 10 | — | V |
| Load-powered mode Relay ON Voltage | — | $HV_{CC\_on}$ | — | 20 | — | |

### 1.5 Load Current Derating Curve

Assumes 8-lead 3×3 mm$^2$ DFN with hi-K JEDEC board 22 inch 1 oz Cu and thermal vias connected to Pad.



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# 2 Functional Description

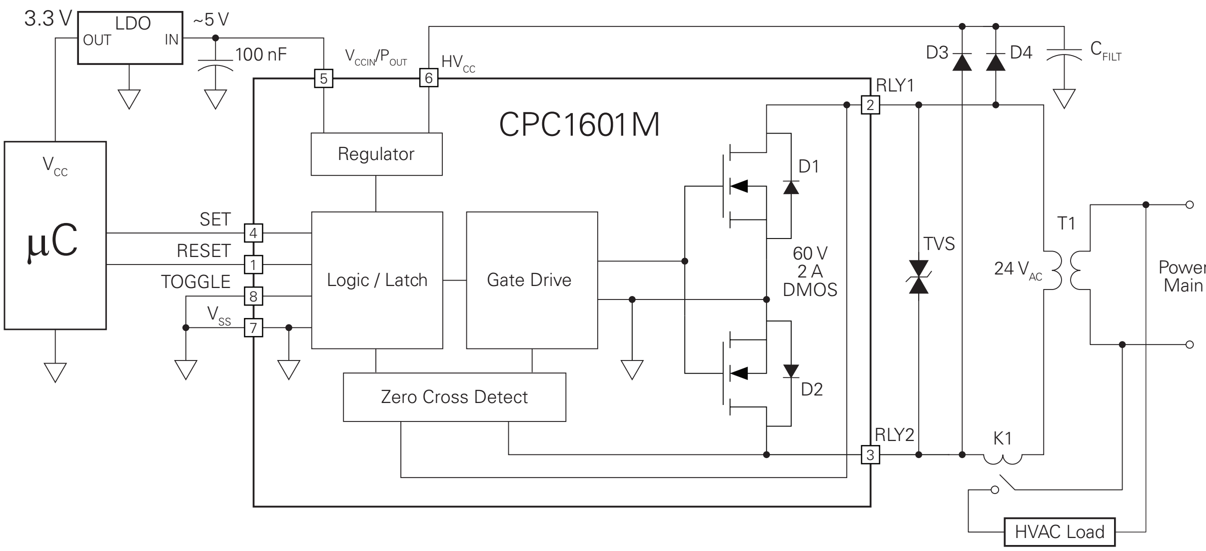



**Figure 1 CPC1601M: Load-powered Mode Application**

## 2.1 Load-powered Mode

Figure 1 illustrates an application in which a thermostat is used to drive a contactor relay (K1) in heating, ventilation, air conditioning (HVAC) systems The contactor is usually a high current electromagnetic relay that switches the HVAC load. In Figure 1, K1 is controlled by turning the CPC1601M relay on and off.

When the CPC1601M is in the OFF mode, the full open-circuit voltage from transformer T1 is seen across the load output pins RLY1 and RLY2. This AC voltage is full-wave rectified by internal DMOS body diodes, denoted by D1 and D2, and external diodes D3 and D4. The full-wave rectified output signal is presented to filter capacitor $C_{FILT}$, which acts as a reservoir capacitor when operating in load-powered mode. Additionally, a voltage output is made available at the $V_{CCIN}/P_{OUT}$ pin where it can be used to power the µC and external circuitry. A low drop regulator (LDO) may not be required if the voltage output is within the operating range of the µC that is used. A transient voltage suppressor diode (TVS) is placed across the load output pins RLY1 and RLY2 to protect the switch output from reverse transients when switching an inductive load.

### 2.1.1 Load-powered Cycle Description:

When the CPC1601M is off, $C_{FILT}$ is fully charged with the voltage described by Equation 1:

*Equation 1:*

$$V(C_{FILT}) = \left(\sqrt{2} \cdot V_{AC}\right) - 2V_F$$

where $V_{AC}$ is the voltage on $C_{FILT}$ and $V_F$ is the forward voltage drop of the diode.

When the relay is commanded to turn on, the load-powered cycle begins. The change in voltage is described by Equation 2 where 'I' represents the current into the $HV_{CC}$ pin and Δt is the desired time between load-powered cycles. It is important to note that the total current also includes any current drawn from the $V_{CCIN}/P_{OUT}$ pin if this pin is connected to external circuitry.

During the load-powered cycle when the relay is off, $C_{FILT}$ is charged to 20 V before the relay turns on. When the relay turns on, the voltage across $C_{FILT}$ starts to drop as $C_{FILT}$ discharges. When the voltage across $C_{FILT}$ reaches approximately 10 V, the relay will turn off at approximately zero current as detected by the zero cross detect circuit. This cycle repeats for as long as the relay remains in the on state.

The maximum relay off voltage is 10 V, and the minimum relay on voltage is 20 V, therefore, ΔV = (20V − 10V) = 10V. By using this ΔV, the designer can trade off load-powered time to size of $C_{FILT}$. The charge time during load-powered cycle mode depends on the source impedance of the load, but is generally a small fraction of an AC cycle. Typical charge times can range from a few hundred µs to around 3 ms for typical loads.

*Equation 2:*

$$\Delta V_{DC} = \frac{I \Delta t}{C_{FILT}}$$

Rearranging Equation 2 to solve for the desired load-powered cycle time:

*Equation 3:*

$$\Delta t = \frac{C_{FILT} \cdot \Delta V}{I}$$

As an example, assume I = 130 µA and $C_{FILT}$ = 2.2 µF, the load-powered cycle time $\Delta t$ will be 169 ms.

### 2.2 Load-powered Mode

In Load-powered mode, the $V_{CCIN}/P_{OUT}$ pin is an output that provides a voltage between 3 V and 5 V and that can be used as an input to an external voltage regulator to power external circuitry. In some cases, the $V_{CCIN}/P_{OUT}$ pin can be used to power user circuitry directly without the use of a regulator, depending on the external circuit requirements. Figure 2 shows a typical loading curve for the $V_{CCIN}/P_{OUT}$ pin.

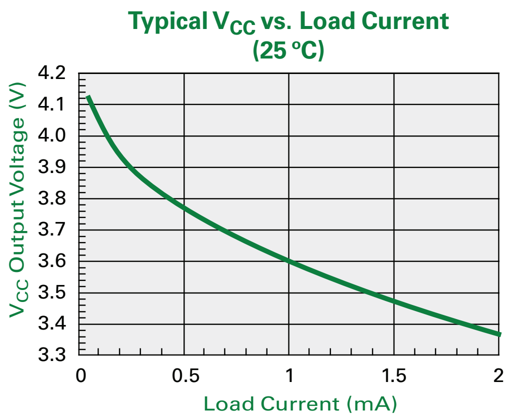



**Figure 2 $V_{CC}$ vs. Load Current**

### 2.3 Load-powered Mode with Zero-Cross Detection Mode

In applications where driving large inductive loads is expected, opening the relay at zero-cross current has the advantage of limiting back EMF that can generate EMI and other noise. This mode of operation can be selected by using the SET, RESET, and TOGGLE pins in a certain sequence as follows:

Referring to Figure 3, RESET must be high for $t_{SU}$ before the TOGGLE input makes the low to high transition that changes the device mode. And RESET must stay high $t_H$ after the rising edge. $t_{SU} = t_H \geq 100\,ns$

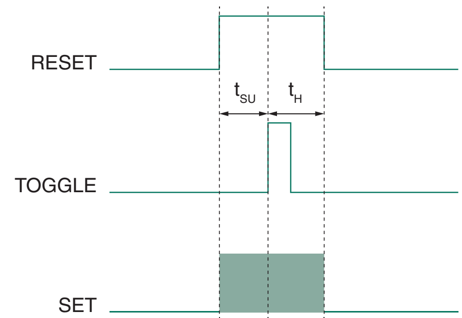



**Figure 3 Zero Crossing Mode Control**

If the SET input is also high for the rising edge of TOGGLE, the zero-crossing mode is enabled in load-powered mode. In this mode, the device will wait after a RESET, or TOGGLE command for the load current to be close to zero before switching the relay into the off state.

If the SET input is low for the rising edge of TOGGLE, the zero-crossing mode is disabled, and the device will operate normally. The off state will trigger immediately with a RESET or TOGGLE command. This is the state after a power-on reset occurs.

## 2.4 System Power Mode

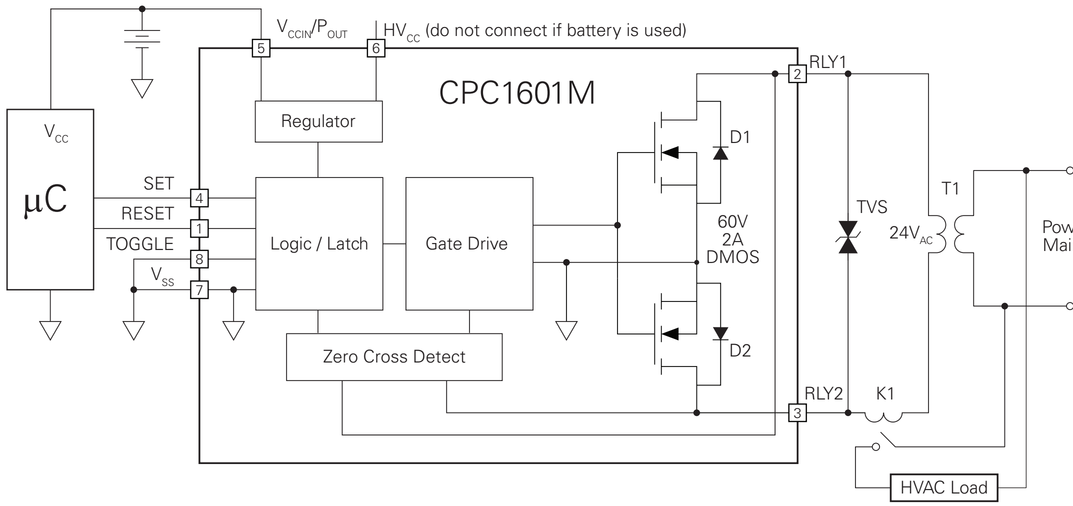



**Figure 4 System Power Mode Application**

In System Power mode of operation, power for the CPC1601M is derived from the power supply and not the load. In a typical thermostat application, the power source is usually a battery. Due to the extremely low power requirements of the CPC1601M, it makes an excellent choice for applications where extending battery life is of utmost importance.

Referring to Figure 4, the CPC1601M $V_{CCIN}/P_{OUT}$ pin is connected to the system battery and the $HV_{CC}$ pin is left open. In this mode the CPC1601M acts as a simple latching relay that can be controlled by using SET and RESET, or in the TOGGLE mode.

## 2.5 Relay Mode Timing

| Function | Conditions | Load-powered Mode | System Power Mode | Load-powered Mode Zero Cross, Current Enabbled |
|---|---|---|---|---|
| SET Activation Time | Positive Edge | < 1 µs | < 1 µs | < 1 µs |
| RESET Deactivation Time | Positive Edge | < 1 µs | < 1 µs | ≤ ½ AC Cycle |

### 2.6 Galvanic Isolation

Some applications may require electrical isolation. This is common in dual transformer HVAC systems where the transformer returns are separate and isolated from each other. The circuit shown in Figure 5 can be used to achieve the required isolation by utilizing capacitive coupling of a PWM signal.

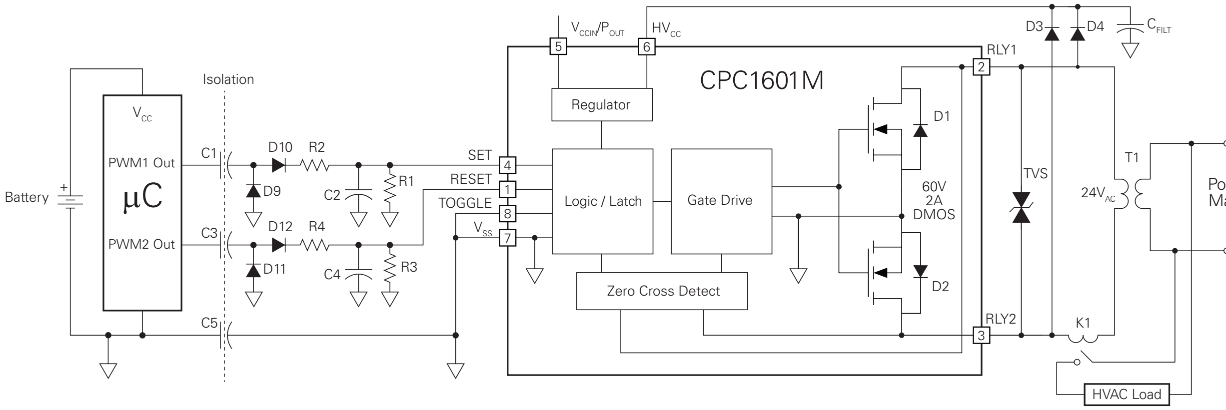



**Figure 5 Application Employing Galvanic Isolation**

Referring to Figure 5, the µC (Micro Controller) generates several multiple cycles of a PWM signal that is capacitively coupled by isolation capacitor C1. This PWM signal is filtered by R2 and C2 thus creating a DC signal that is used to trigger the SET input of the CPC1601M. The RESET circuit is identical to the SET circuit and is driven by another PWM output signal from the µC.

Diode D9 provides a discharge path for C1 when the PWM signal goes low while diode D10 is used to charge C2 and prevent the charge on C2 from discharging through R2. Capacitor C2 holds the charge until the PWM goes low and then discharges through R1 setting the decay time.

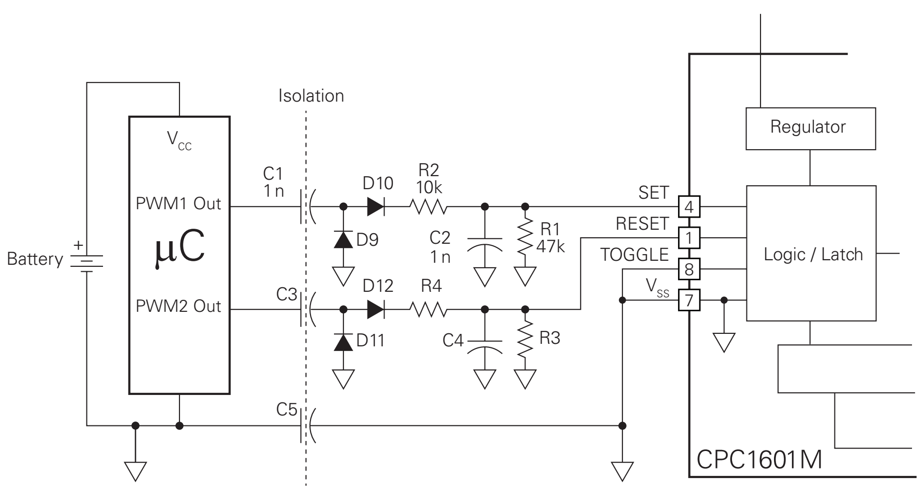



**Figure 6 PWM1 Circuit Example for Galvanic Isolation**

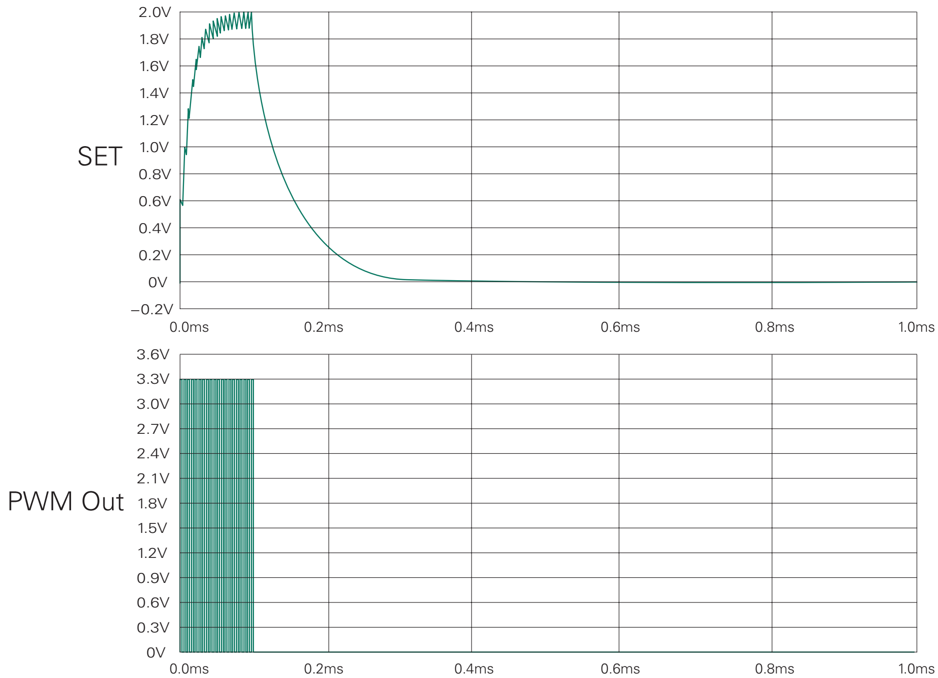



**Figure 7 PWM and SET Waveforms**

Referring to Figure 7, the top trace is the SET input, and the bottom trace is the PWM output of the µC, in this case 20 cycles at 200 kHz. For the values chosen, the SET input rises to approximately 1.9 V noting that the minimum SET on voltage is 1.5 V from the Electrical Specifications table. The component values used in the circuit shown in Figure 6 are the following:

R1 = 47 kΩ

R2 = 10 kΩ

C1 = 1nF

C3 = 0.001 µF

The PWM signal out of the µC is a 200 kHz, 50 % duty cycle square wave. Component values can be modified to suit system requirements.

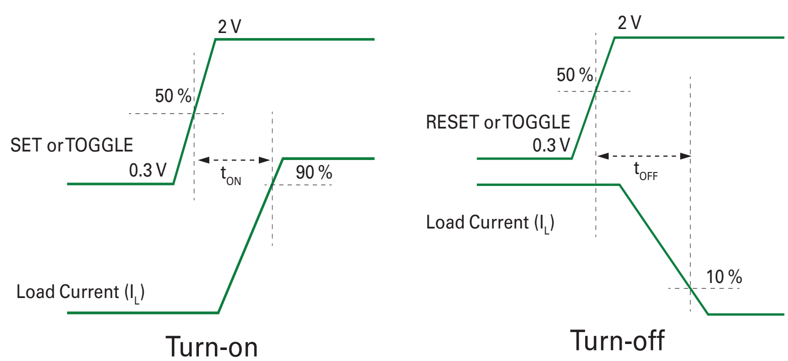



**Figure 8 Switch Timing Waveforms**

# 3 Manufacturing Information

## 3.1 Moisture Sensitivity

All plastic encapsulated semiconductor packages are susceptible to moisture ingression. Littelfuse classifies its plastic encapsulated devices for moisture sensitivity according to the latest revision of the joint industry standard, **IPC/JEDEC J-STD-020**, in force at the time of product evaluation. We test all of our products to the maximum conditions set forth in the standard, and guarantee proper operation of our devices when handled according to the limitations and information in that standard, as well as to any limitations set forth in the information, or standards referenced below.

Failure to adhere to the warnings or limitations as established by the listed specifications could result in reduced product performance, reduction of operable life, and/or reduction of overall reliability.

This product carries a Moisture Sensitivity Level (MSL) classification as shown below, and should be handled according to the requirements of the latest revision of the joint industry standard **IPC/JEDEC J-STD-033**.

| Device | Moisture Sensitivity Level (MSL) Classification |
|---|---|
| CPC1601M | MSL1 |

## 3.2 ESD Sensitivity

This product is ESD Sensitive, and should be handled according to the industry standard **JESD-625**.

## 3.3 Soldering Profile

Provided in the table below is the **IPC/JEDEC J-STD-020** Classification Temperature ($T_C$) and the maximum dwell time ($T_C$ – 5°C). The Classification Temperature sets the Maximum Body Temperature allowed for these devices, during reflow soldering processes.

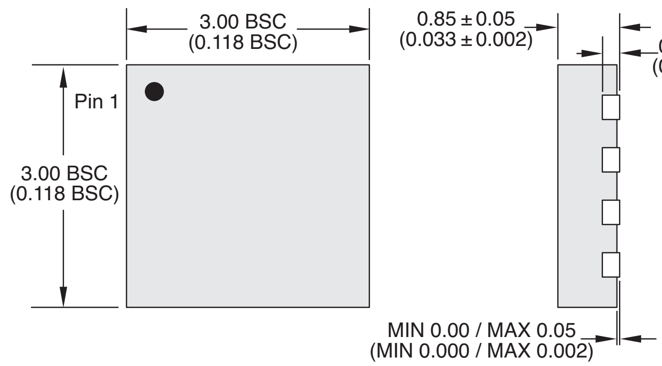
| Device | Classification Temperature ($T_C$) | Dwell Time ($t_P$) | Maximum Reflow Cycles |
|---|---|---|---|
| CPC1601M | 260°C | 30 seconds | 3 |

## 3.4 Board Wash

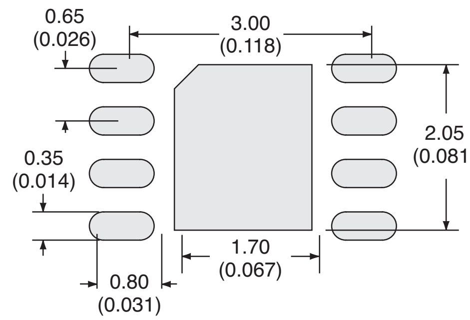
Littelfuse recommends the use of no-clean flux formulations. Board washing to reduce, or remove flux residue following the solder reflow process is acceptable, provided proper precautions are taken to prevent damage to the device. These precautions include, but are not limited to: Using a low pressure wash and providing a follow-up bake cycle sufficient to remove any moisture trapped within the device, due to the washing process. Due to the variability of the wash parameters used to clean the board, determination of the bake temperature and duration necessary to remove the moisture trapped within the package is the responsibility of the user (assembler). Cleaning, or drying methods that employ ultrasonic energy may damage the device and should not be used. Additionally, the device must not be exposed to halide flux or solvents.

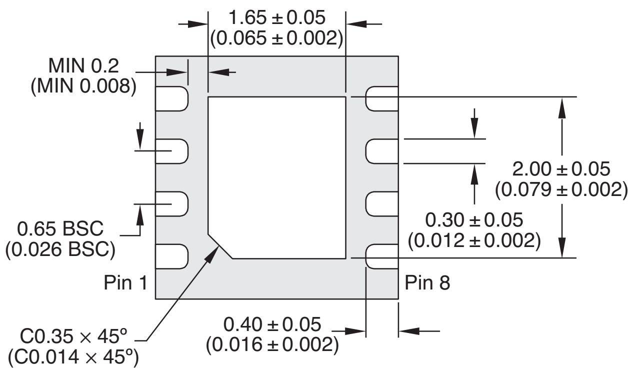
## 3.5 Mechanical Dimensions

### 3.5.1 CPC1601M 8-Pin DFN Package




**Recommended PCB Land Pattern**

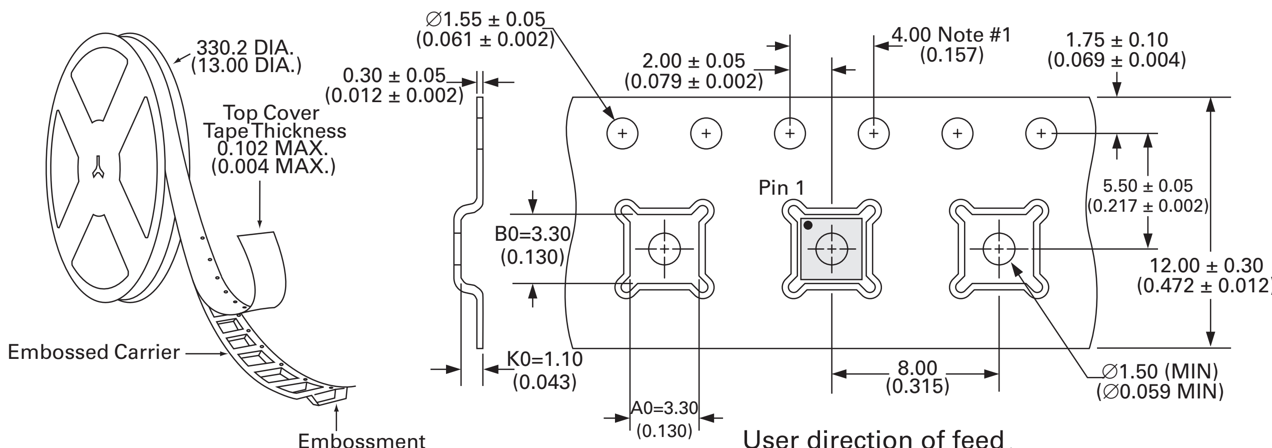



Dimensions
mm
(inches)

NOTES:
1. The exposed metal pad on the back of the package should be connected to GND. Pad is not suitable for carrying current.
2. Terminal width (0.30 ± 0.05) is measured between 0.15 mm and 0.30 mm from the terminal tip.
3. Bilateral coplanarity zone applies to the exposed heat sink slug as well as the terminals.

### 3.5.2 CPC1601M 8-Pin Package Tape and Reel




NOTES:
1. 10 sprocket hole pitch cumulative tolerance ±0.2
2. Camber not to exceed 1 mm in 100 mm
3. Material black Advantek Polystyrene
4. A0 and B0 measured on a plane 0.3 mm above the bottom of the pocket
5. K0 measured from a plane on the inside bottom of the pocket to the top surface of the carrier
6. Pocket position relative to the sprocket hole measured as true position of pocket, not pocket hole
7. Cover tape width 9.3 ± 0.1 mm

Dimensions
mm
(inches)