Features
- Temperature Proportional Fan Speed for Acoustic Control and Longer Fan Life
- Efficient PWM Fan Drive
- 3.0V to 5.5V Supply Range:
  - Fan Voltage Independent of TC648 Supply Voltage
  - Supports any Fan Voltage
- Over-temperature Fault Detection
- Automatic Shutdown Mode for “Green” Systems
- Supports Low Cost NTC/PTC Thermistors
- Space Saving 8-Pin MSOP Package

Applications
- Power Supplies
- Computers
- Portable Computers
- Telecom Equipment
- UPSs, Power Amps
- General Purpose Fan Speed Control

Available Tools
- Fan Controller Demonstration Board (TC642DEMO)
- Fan Controller Evaluation Kit (TC642EV)

Package Types

<table>
<thead>
<tr>
<th>SOIC/PDIP/MSOP</th>
</tr>
</thead>
<tbody>
<tr>
<td>V\text{IN}</td>
</tr>
<tr>
<td>C\text{F}</td>
</tr>
<tr>
<td>V\text{AS}</td>
</tr>
<tr>
<td>G\text{ND}</td>
</tr>
<tr>
<td>V\text{DD}</td>
</tr>
<tr>
<td>V\text{OUT}</td>
</tr>
<tr>
<td>\text{OTF}</td>
</tr>
<tr>
<td>\text{NC}</td>
</tr>
</tbody>
</table>

General Description
The TC648 is a switch mode, fan speed controller for use with brushless DC fans. Temperature proportional speed control is accomplished using pulse width modulation (PWM). A thermistor (or other voltage output temperature sensor) connected to the \text{V\text{IN}} input furnishes the required control voltage of 1.25V to 2.65V (typical) for 0% to 100% PWM duty cycle. The TC648 can be configured to operate in either auto-shutdown or minimum speed mode. In auto-shutdown mode, fan operation is automatically suspended when measured temperature (\text{V\text{IN}}) is lower than a user programmed minimum setting (\text{V\text{AS}}). The fan is automatically restarted, and proportional speed control restored, when \text{V\text{IN}} exceeds \text{V\text{AS}} (plus hysteresis). Operation in minimum speed mode is similar to auto-shutdown mode, with the exception that the fan is operated at a user programmed minimum setting when the measured temperature is low. An integrated Start-up Timer ensures reliable motor start-up at turn-on, and when coming out of shutdown or auto-shutdown mode.

The over-temperature fault output (\text{OTF}) is asserted when the PWM reaches 100% duty cycle, indicating a possible thermal runaway situation.

The TC648 is available in the 8-pin plastic DIP, SOIC and MSOP packages and is available in the industrial and extended commercial temperature ranges.
Functional Block Diagram

TC648

- VIN
- VDD
- OTF
- VSHDN
- VDD
- NC
- VOUT
- PWM
- SHDN
- VAS
- CF
- GND

- OTF
- Control Logic
- Start-up Timer

Clock Generator
1.0 **ELECTRICAL CHARACTERISTICS**

**Absolute Maximum Ratings**

Supply Voltage ......................................................... 6V
Input Voltage, Any Pin... (GND – 0.3V) to (VDD + 0.3V)

**Package Thermal Resistance:**
- PDIP (R\textsubscript{\theta JA}) ............................................. 125°C/W
- SOIC (R\textsubscript{\theta JA}) ............................................ 155°C/W
- MSOP (R\textsubscript{\theta JA}) .......................................... 200°C/W

Specified Temperature Range .......... -40°C to +125°C
Storage Temperature Range .......... -65°C to +150°C

*Stresses above 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 above those indicated in the operation sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

### DC ELECTRICAL SPECIFICATIONS

#### Electrical Characteristics:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
<th>Test Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>V\textsubscript{DD}</td>
<td>Supply Voltage</td>
<td>3.0</td>
<td>—</td>
<td>5.5</td>
<td>V</td>
<td>Pins 6, 7 Open, C\textsubscript{F} = 1 µF, V\textsubscript{IN} = V\textsubscript{C(MAX)}</td>
</tr>
<tr>
<td>I\textsubscript{DD}</td>
<td>Supply Current, Operating</td>
<td>—</td>
<td>0.5</td>
<td>1.0</td>
<td>mA</td>
<td></td>
</tr>
<tr>
<td>I\textsubscript{DD(SHDN)}</td>
<td>Supply Current, Shutdown/ Auto-shutdown Mode</td>
<td>—</td>
<td>25</td>
<td>—</td>
<td>µA</td>
<td>Pins 6, 7 Open; C\textsubscript{F} = 1 µF, V\textsubscript{IN} = 0.35V</td>
</tr>
<tr>
<td>I\textsubscript{IN}</td>
<td>V\textsubscript{IN}, V\textsubscript{AS} Input Leakage</td>
<td>-1.0</td>
<td>—</td>
<td>+1.0</td>
<td>µA</td>
<td>Note 1</td>
</tr>
<tr>
<td>V\textsubscript{OUT}</td>
<td>Output Rise Time</td>
<td>—</td>
<td>50</td>
<td>µsec</td>
<td></td>
<td>I\textsubscript{OH} = 5 mA, Note 1</td>
</tr>
<tr>
<td>I\textsubscript{F}</td>
<td>V\textsubscript{OUT} Fall Time</td>
<td>—</td>
<td>50</td>
<td>µsec</td>
<td></td>
<td>I\textsubscript{OL} = 1 mA, Note 1</td>
</tr>
<tr>
<td>I\textsubscript{OL}</td>
<td>Sink Current at V\textsubscript{OUT} Output</td>
<td>1.0</td>
<td>—</td>
<td>—</td>
<td>mA</td>
<td>V\textsubscript{OL} = 10% of V\textsubscript{DD}</td>
</tr>
<tr>
<td>I\textsubscript{OH}</td>
<td>Source Current at V\textsubscript{OUT} Output</td>
<td>5.0</td>
<td>—</td>
<td>—</td>
<td>mA</td>
<td>V\textsubscript{OH} = 80% of V\textsubscript{DD}</td>
</tr>
<tr>
<td>V\textsubscript{TH(SENSE)}</td>
<td>SENSE Input Threshold Voltage with Respect to GND</td>
<td>50</td>
<td>70</td>
<td>90</td>
<td>mV</td>
<td>Note 1</td>
</tr>
<tr>
<td>V\textsubscript{OL}</td>
<td>Output Low Voltage</td>
<td>—</td>
<td>—</td>
<td>0.3</td>
<td>V</td>
<td>I\textsubscript{OL} = 2.5 mA</td>
</tr>
<tr>
<td>V\textsubscript{IN}, V\textsubscript{AS} Inputs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V\textsubscript{C(MAX)}, V\textsubscript{OFF}</td>
<td>Voltage at V\textsubscript{IN} for 100% Duty Cycle and Overtemp. Fault</td>
<td>2.5</td>
<td>2.65</td>
<td>2.8</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>V\textsubscript{C(SPAN)}</td>
<td>V\textsubscript{C(MAX)} - V\textsubscript{C(MIN)}</td>
<td>1.3</td>
<td>1.4</td>
<td>1.5</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>V\textsubscript{AS}</td>
<td>Auto-shutdown Threshold</td>
<td>V\textsubscript{C(MAX)} - V\textsubscript{C(SPAN)}</td>
<td>—</td>
<td>V\textsubscript{C(MAX)}</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>V\textsubscript{SHDN}</td>
<td>Voltage Applied to V\textsubscript{IN} to Ensure Reset/Shutdown</td>
<td>—</td>
<td>—</td>
<td>V\textsubscript{DD} x 0.13</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>V\textsubscript{REL}</td>
<td>Voltage Applied to V\textsubscript{IN} to Release Reset Mode</td>
<td>V\textsubscript{DD} x 0.19</td>
<td>—</td>
<td>—</td>
<td>V</td>
<td>V\textsubscript{DD} = 5V</td>
</tr>
<tr>
<td>V\textsubscript{HYST}</td>
<td>Hysteresis on V\textsubscript{SHDN}, V\textsubscript{REL}</td>
<td>—</td>
<td>0.01 x V\textsubscript{DD}</td>
<td>—</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>V\textsubscript{HAS}</td>
<td>Hysteresis on Auto-shutdown Comparator</td>
<td>—</td>
<td>70</td>
<td>—</td>
<td>mV</td>
<td></td>
</tr>
</tbody>
</table>

**Note 1:** Ensured by design, not tested.
### DC ELECTRICAL SPECIFICATIONS (CONTINUED)

**Electrical Characteristics:** Unless otherwise specified, $T_{\text{MIN}} \leq T_A \leq T_{\text{MAX}}$, $V_{\text{DD}} = 3.0\text{V}$ to $5.5\text{V}$

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
<th>Test Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_{\text{OSC}}$</td>
<td>PWM Frequency</td>
<td>26</td>
<td>30</td>
<td>34</td>
<td>Hz</td>
<td>$C_F = 1.0 \ \mu\text{F}$</td>
</tr>
<tr>
<td>$I_{\text{STARTUP}}$</td>
<td>Start-up Timer</td>
<td>—</td>
<td>32/F</td>
<td>—</td>
<td>Sec</td>
<td>$C_F = 1.0 \ \mu\text{F}$</td>
</tr>
</tbody>
</table>

**Note 1:** Ensured by design, not tested.
2.0 PIN DESCRIPTIONS

The descriptions of the pins are listed in Table 2-1.

TABLE 2-1: PIN FUNCTION TABLE

<table>
<thead>
<tr>
<th>Pin No.</th>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>V IN</td>
<td>Analog Input</td>
</tr>
<tr>
<td>2</td>
<td>C F</td>
<td>Analog Output</td>
</tr>
<tr>
<td>3</td>
<td>V AS</td>
<td>Analog Input</td>
</tr>
<tr>
<td>4</td>
<td>GND</td>
<td>Ground Terminal</td>
</tr>
<tr>
<td>5</td>
<td>NC</td>
<td>No Internal Connection</td>
</tr>
<tr>
<td>6</td>
<td>OTF</td>
<td>Digital (Open Collector) Output</td>
</tr>
<tr>
<td>7</td>
<td>V OUT</td>
<td>Digital Output</td>
</tr>
<tr>
<td>8</td>
<td>V DD</td>
<td>Power Supply Input</td>
</tr>
</tbody>
</table>

2.1 Analog Input (V IN)

The thermistor network (or other temperature sensor) connects to the V IN input. A voltage range of 1.25V to 2.65V (typical) on this pin drives an active duty cycle of 0% to 100% on the V OUT pin (see Section 5.0, “Typical Applications”, for more details).

2.2 Analog Output (C F)

C F is the positive terminal for the PWM ramp generator timing capacitor. The recommended C F is 1 µF for 30 Hz PWM operation.

2.3 Analog Input (V AS)

An external resistor divider connected to the V AS input sets the auto-shutdown threshold. Auto-shutdown occurs when V IN \( \leq \) V AS. During shutdown, supply current falls to 25 µA (typical). The fan is automatically restarted when V IN \( \geq \) (V AS +V HAS) (see Section 5.0, “Typical Applications” for more details).

2.4 Ground (GND)

GND denotes the ground Terminal.

2.5 No Connect

No internal connection.

2.6 Digital Output (OTF)

OTF goes low to indicate an over-temperature condition. This occurs when the voltage at V IN > V OTF (see Section 1.0, “Electrical Characteristics”). An over-temperature indication is a non-latching condition.

2.7 Digital Output (V OUT)

V OUT is an active high complimentary output that drives the base of an external NPN transistor (via an appropriate base resistor) or the gate of an N-channel MOSFET. This output has asymmetrical drive (see Section 1.0, “Electrical Characteristics”).

2.8 Power Supply Input (V DD)

V DD may be independent of the fan’s power supply (see Section 1.0, “Electrical Characteristics”).
3.0 DETAILED DESCRIPTION

3.1 PWM

The PWM circuit consists of a ramp generator and threshold detector. The frequency of the PWM is determined by the value of the capacitor connected to the CF pin. A frequency of 30 Hz is recommended for most applications (CF = 1 µF). The PWM is also the time base for the Start-up Timer (see Section 3.3, “Start-up Timer”). The PWM voltage control range is 1.25V to 2.65V (typical) for 0% to 100% output duty cycle.

3.2 VOUT Output

The VOUT pin is designed to drive a low cost transistor or MOSFET as the low side power switching element in the system. Various examples of driver circuits will be shown throughout this data sheet. This output has asymmetric complementary drive and is optimized for driving NPN transistors or N-channel MOSFETs. Since the system relies on PWM rather than linear control, the power dissipation in the power switch is kept to a minimum. Generally, very small devices (TO-92 or SOT packages) will suffice.

3.3 Start-Up Timer

To ensure reliable fan start-up, the Start-up Timer turns the VOUT output on for 32 cycles of the PWM whenever the fan is started from the off state. This occurs at power-up and when coming out of shutdown or auto-shutdown mode. If the PWM frequency is 30 Hz (CF = 1 µF), the resulting start-up time will be approximately one second.

3.4 Over-Temperature Fault (OTF) Output

OTF is asserted when the PWM control voltage applied to VIN becomes greater than that needed to drive 100% duty cycle (see Section 1.0, “Electrical Characteristics”). This indicates that the fan is at maximum drive, and the potential exists for system overheating. Either heat dissipation in the system has gone beyond the cooling system’s design limits, or some subtle fault exists (such as fan bearing failure or an airflow obstruction). This output may be treated as a “System Overheat” warning and used to trigger system shutdown or some other corrective action. OTF will become inactive when VIN < VOTF.

3.5 Auto-Shutdown Mode

If the voltage on VIN becomes less than the voltage on VAS, the fan is automatically shut off (auto-shutdown mode). The TC648 exits auto-shutdown mode when the voltage on VIN becomes higher than the voltage on VAS by VHAS (the auto-shutdown hysteresis voltage (see Figure 3-1)). The Start-up Timer is triggered and normal operation is resumed upon exiting auto-shutdown mode. The VAS input should be grounded if auto-shutdown mode is not used.

3.6 Shutdown Mode (Reset)

If an unconditional shutdown and/or device reset is desired, the TC648 may be placed in shutdown mode by forcing VIN to a logic low (i.e., VIN < VSHDN) (see Figure 3-1). In this mode, all functions cease and the OTF output is unconditionally inactive. The TC648 should not be shut down unless all heat producing activity in the system is at a negligible level. The TC648 exits shutdown mode when VIN becomes greater than VREL, the release voltage. Entering shutdown mode also performs a complete device reset. Shutdown mode resets the TC648 into its power-up state. OTF is unconditionally inactive in shutdown mode. Upon exiting shutdown mode (VIN > VREL), the Start-up Timer will be triggered and normal operation will resume, assuming VIN > VAS + VHAS.

Note: If VIN < VAS when the device exits shutdown mode, the fan will not restart as it will be in auto-shutdown mode.

If VIN is not greater than (VAS + VHAS) upon exiting shutdown mode, the fan will not be restarted. To ensure that a complete reset takes place, the user’s circuitry must ensure that VIN > (VAS + VHAS) when the device is released from shutdown mode. A recommended algorithm for management of the TC648 by a host microcontroller or other external circuitry is given in Section 5.0, “Typical Applications”. A small amount of hysteresis, typically one percent of VDD (50 mV at VDD = 5.0V), is designed into the VSHDN/VREL threshold. The levels specified for VSHDN and VREL in Section 1.0, “Electrical Characteristics”, include this hysteresis plus adequate margin to account for normal variations in the absolute value of the threshold and hysteresis.

CAUTION: Shutdown mode is unconditional. That is, the fan will remain off as long as the VIN pin is being held low or VIN < VAS + VHAS.
4.0 SYSTEM BEHAVIOR

The flowcharts describing the TC648’s behavioral algorithms are shown in Figure 4-1. They can be summarized as follows:

4.1 Power-Up

1. Assuming the device is not being held in shutdown or auto-shutdown mode (VIN > VAS)...........
2. Turn VOUT output on for 32 cycles of the PWM clock. This ensures that the fan will start from a dead stop.
3. Branch to Normal Operation.
4. End.

4.2 Normal Operation

Normal Operation is an endless loop which may only be exited by entering shutdown or auto-shutdown mode. The loop can be thought of as executing at the frequency of the oscillator and PWM.

1. Drive VOUT to a duty cycle proportional to VIN on a cycle by cycle basis.
2. If an over-temperature fault occurs, (VIN > VOTF), activate OTF; release OTF when VIN < VOTF.
3. Is the TC648 in shutdown or auto-shutdown mode?
   If so....
   a. VOUT duty cycle goes to zero.
   b. OTF is disabled.
   c. Exit the loop and wait for VIN > (VAS + VHAS), then execute Power-up sequence.
4. End.
FIGURE 4-1: TC648 Behavioral Algorithm Flowcharts.
5.0 TYPICAL APPLICATIONS

Designing with the TC648 involves the following:

1. The temperature sensor network must be configured to deliver 1.25V to 2.65V on V_IN for 0% to 100% of the temperature range to be regulated.
2. The auto-shutdown temperature must be set with a voltage divider on V_AS (if used).
3. The output drive transistor and base resistor must be selected.
4. If reset/shutdown capability is desired, the drive requirements of the external signal or circuit must be considered.

The TC642 demonstration and prototyping board (TC642DEMO) and the TC642 Evaluation Kit (TC642EV) provide working examples of TC648 circuits and prototyping aids. The TC642DEMO is a printed circuit board optimized for small size and ease of inclusion into system prototypes. The TC642EV is a larger board intended for benchtop development and analysis. At the very least, anyone contemplating a design using the TC648 should consult the documentation for both the TC642EV (DS21403) and TC642DEMO (DS21401). Figure 5-1 shows the base schematic for the TC642DEMO.

An Excel-based spreadsheet is also available for designing the thermistor network for the TC64X fan controllers. This file (TC64X Therm) is available for downloading from the Microchip website at www.microchip.com.

**NOTES:**
* See cautions regarding latch-up considerations in Section 5.0, "Typical Applications".
** Optional. See Section 5.0, "Typical Applications", for details.

**FIGURE 5-1:** Typical Application Circuit.
5.1 Temperature Sensor Design

The temperature signal connected to \( V_{IN} \) must output a voltage in the range of 1.25V to 2.65V (typical) for 0% to 100% of the temperature range of interest. The circuit in Figure 5-2 illustrates a convenient way to provide this signal using a temperature dependent voltage divider circuit.

![Temperature Sensing Circuit](image)

**FIGURE 5-2:** Temperature Sensing Circuit.

RT\(_1\) is a conventional NTC thermistor and R\(_1\) and R\(_2\) are standard resistors. The supply voltage (V\(_{DD}\)) is divided between R\(_2\) and the parallel combination of RT\(_1\) and R\(_1\). For convenience, the parallel combination of RT\(_1\) and R\(_1\) will be referred to as R\(_{TEMP}\). The resistance of the thermistor at various temperatures is obtained from the manufacturer’s specifications. Thermistors are often referred to in terms of their resistance at 25°C.

Generally, the thermistor shown in Figure 5-2 is a nonlinear device with a negative temperature coefficient (also called an NTC thermistor). In Figure 5-2, R\(_1\) is used to linearize the thermistor temperature response and R\(_2\) is used to produce a positive temperature coefficient at the \( V_{IN} \) node. As an added benefit, this configuration produces an output voltage delta of 1.4V, which is well within the range of the \( V_{C(SPAN)} \) specification of the TC648. A 100 kΩ NTC thermistor is selected for this application in order to keep I\(_{DIV}\) to a minimum.

For the voltage range at \( V_{IN} \) to be equal to 1.25V to 2.65V, the temperature range of this configuration is 0°C to 50°C. If a different temperature range is required from this circuit, R\(_1\) should be chosen to equal the resistance value of the thermistor at the center of this new temperature range. It is suggested that a maximum temperature range of 50°C be used with this circuit due to thermistor linearity limitations. With this change, R\(_2\) is adjusted according to the following equations:

\[
\frac{V_{DD} \times R_2}{R_{TEMP}(T_1) + R_2} = V(T_1)
\]

\[
\frac{V_{DD} \times R_2}{R_{TEMP}(T_2) + R_2} = V(T_2)
\]

Where \( T_1 \) and \( T_2 \) are the chosen temperatures and \( R_{TEMP} \) is the parallel combination of the thermistor and \( R_1 \).

These two equations facilitate solving for the two unknown variables, \( R_1 \) and \( R_2 \). More information about thermistors may be obtained from AN679, “Temperature Sensing Technologies”, and AN685, “Thermistors in Single Supply Temperature Sensing Circuits”, which can be downloaded from Microchip’s web site at www.microchip.com.

5.2 Minimum Speed Mode

The TC648 is configured for minimum speed mode by grounding V\(_{AG} \) and designing the temperature sensor network such that \( V_{IN} \) operates the fan at relatively constant, minimum speed when the thermistor is at minimum temperature. Figure 5-3 shows operation in minimum speed mode. The 0% and 100% fan speeds correspond to \( V_{IN} \) values of 1.25V and 2.65V, typical. Minimum system temperature (\( T_{MIN} \)) is defined as the lowest measured temperature at which proportional fan speed control is required by the system. The fan operates at minimum speed for all temperatures below \( T_{MIN} \) and at speeds proportional to the measured temperature between \( T_{MIN} \) and \( T_{MAX} \).

![Minimum Fan Speed Mode Operation](image)

**FIGURE 5-3:** Minimum Fan Speed Mode Operation.

Temperature sensor design consists of a two-point calculation: one at \( T_{MIN} \) and one at \( T_{MAX} \). At \( T_{MIN} \), the ohmic value of the thermistor must be much higher than that of \( R_1 \) so that minimum speed is determined primarily by the values of \( R_3 \) and \( R_2 \). At \( T_{MAX} \), the ohmic value of the thermistor must result in a \( V_{IN} \) of 2.65V nominal. The design procedure consists of initially choosing \( R_1 \) to be 10 times smaller than the
thermistor resistance at $T_{\text{MIN}}$. $R_2$ is then calculated to deliver the desired speed at $T_{\text{MIN}}$. The values for $R_1$, $R_2$ and $RT_1$ are then checked at $T_{\text{MAX}}$ for 2.65V nominal. It may be necessary to adjust the values of $R_1$ and $R_2$ after the initial calculation to obtain the desired results. The design equations are:

\[
R_1 = (0.1)(RT_{1\text{MIN}})
\]

Where: $RT_1 =$ Thermistor resistance at $T_{\text{MIN}}$

\[
R_2 = \frac{(RT_{1\text{MIN}})(R_1)(V_{\text{MIN}})}{(RT_{1\text{MIN}} + R_1)(V_{\text{DD}} - V_{\text{MIN}})}
\]

Where $V_{\text{MIN}} =$ the value of $V_{\text{IN}}$ required for minimum fan speed. $V_{\text{DD}} =$ Power Supply Voltage

\[
V_{\text{MAX}} = \frac{(RT_{1\text{MIN}})(R_1)(V_{\text{MIN}})}{R_2(R_1 + RT_{1\text{MAX}})(V_{\text{DD}})}
\]

Where $RT_{1\text{MAX}} =$ thermistor resistance at $T_{\text{MAX}}$. $V_{\text{MAX}} =$ the value of $V_{\text{IN}}$ required for maximum fan speed.

Because the thermistor characteristics are fixed, it may not be possible, in certain applications, to obtain the desired values of $V_{\text{MIN}}$ and $V_{\text{MAX}}$ using the above equations. In this case, the circuit in Figure 5-4 can be used. Diode $D_1$ clamps $V_{\text{IN}}$ to the voltage required to sustain minimum speed. The calculations of $R_1$ and $R_2$ for the temperature sensor are identical to the equation on the previous page.

### 5.3 Auto-Shutdown Temperature Design

A voltage divider on $V_{\text{AS}}$ sets the temperature at which the part is automatically shut down if the sensed temperature at $V_{\text{IN}}$ drops below the set temperature at $V_{\text{AS}}$ (i.e. $V_{\text{IN}} < V_{\text{AS}}$).

As with the $V_{\text{IN}}$ input, 1.25V to 2.65V corresponds to the temperature range of interest from $T_1$ to $T_2$, respectively. Assuming that the temperature sensor network designed previously is linearly related to temperature, the shutdown temperature $T_{\text{AS}}$ is related to $T_2$ and $T_1$ by:

\[
\frac{2.65 - 1.25V}{T_2 - T_1} = \frac{V_{\text{AS}} - 1.25}{T_{\text{AS}} - T_1}
\]

\[
V_{\text{AS}} = \left(\frac{1.4V}{T_2 - T_1}\right)(T_{\text{AS}} - T_1) + 1.25
\]

For example, if 1.25V and 2.65V at $V_{\text{IN}}$ corresponds to a temperature range of $T_1 = 0°C$ to $T_2 = 125°C$, and the auto-shutdown temperature desired is 25°C, then the $V_{\text{AS}}$ voltage is:

\[
V_{\text{AS}} = \frac{1.4V}{(125 - 0)}(25 - 0) + 1.25 = 1.53V
\]

The $V_{\text{AS}}$ voltage may be set using a simple resistor divider, as shown in Figure 5-5.
Per Section 1.0, "Electrical Characteristics", the leakage current at the V_{AS} pin is no more than 1 µA. It is conservative to design for a divider current, I_{DIV}, of 100 µA. If V_{DD} = 5.0V then...

**EQUATION**

\[
I_{DIV} = 1e^{-4}A = \frac{5.0V}{R_1 + R_2}, \text{ therefore}
\]

\[
R_1 + R_2 = \frac{5.0V}{1e^{-4}A} = 50,000\Omega = 50 \text{ k}\Omega
\]

We can further specify R_1 and R_2 by the condition that the divider voltage is equal to our desired V_{AS}. This yields the following:

**EQUATION**

\[
V_{AS} = \frac{V_{DD} \times R_2}{R_1 + R_2}
\]

Solving for the relationship between R_1 and R_2 results in the following equation:

**EQUATION**

\[
R_1 = R_2 \times \frac{V_{DD} - V_{AS}}{V_{AS}} = R_2 \times (5 - 1.53) = 1.53
\]

For this example, R_1 = (2.27) R_2. Substituting this relationship back into the original equation yields the resistor values:

R_2 = 15.3 kΩ, and R_1 = 34.7 kΩ

In this case, the standard values of 34.8 kΩ and 15.4 kΩ are very close to the calculated values and would be more than adequate.

### 5.4 Output Drive Transistor Selection

The TC648 is designed to drive an external transistor or MOSFET for modulating power to the fan. This is shown as Q_1 in Figures 5-1, 5-6, 5-7, and 5-8. The V_{OUT} pin has a minimum source current of 5 mA and a minimum sink current of 1 mA. Bipolar transistors or MOSFETs may be used as the power switching element, as is shown in Figure 5-6. When high current gain is needed to drive larger fans, two transistors may be used in a Darlington configuration. These circuit topologies are shown in Figure 5-6: (a) shows a single NPN transistor used as the switching element; (b) illustrates the Darlington pair; and (c) shows an N-channel MOSFET.

One major advantage of the TC648's PWM control scheme versus linear speed control is that the power dissipation in the pass element is kept very low. Generally, low cost devices in very small packages, such as TO-92 or SOT, can be used effectively. For fans with nominal operating currents of no more than 200 mA, a single transistor usually suffices. Above 200 mA, the Darlington or MOSFET solution is recommended. For the power dissipation to be kept low, it is imperative that the pass transistor be fully saturated when "on".

Table 5-1 gives examples of some commonly available transistors and MOSFETs. This table should be used as a guide only since there are many transistors and MOSFETs which will work just as well as those listed. The critical issues when choosing a device to use as Q_1 are: (1) the breakdown voltage (V_{BR(CEO)} or V_{DS} (MOSFET)) must be large enough to withstand the highest voltage applied to the fan (Note: This will occur when the fan is off); (2) 5 mA of base drive current must be enough to saturate the transistor when conducting the full fan current (transistor must have sufficient gain); (3) the V_{OUT} voltage must be high enough to sufficiently drive the gate of the MOSFET to minimize the R_{DS(on)} of the device; (4) rated fan current draw must be within the transistor's/MOSFET's current handling capability; and (5) power dissipation must be kept within the limits of the chosen device.

A base-current limiting resistor is required with bipolar transistors. The correct value for this resistor can be determined as follows:

\[
V_{OH} = V_{BE(SAT)} + V_{RBASE}
\]

\[
V_{RBASE} = R_{BASE} \times I_{BASE}
\]

\[
I_{BASE} = \frac{I_{FAN}}{h_{FE}}
\]

V_{OH} is specified as 80% of V_{DD} in Section 1.0, “Electrical Characteristics”; V_{BE(SAT)} is given in the chosen transistor data sheet. It is now possible to solve for R_{BASE}.

**EQUATION**

\[
R_{BASE} = \frac{V_{OH} - V_{BE(SAT)}}{I_{BASE}}
\]

Some applications benefit from the fan being powered from a negative supply to keep motor noise out of the positive supply rails. This can be accomplished by the method shown in Figure 5-7. Zener diode D_1 offsets the -12V power supply voltage, holding transistor Q_1 off when V_{OUT} is low. When V_{OUT} is high, the voltage at the anode of D_1 increases by V_{OH}, causing Q_1 to turn on. Operation is otherwise the same as in the case of fan operation from +12V.
TABLE 5-1:  TRANSISTORS AND MOSFETS FOR Q₁ (V_DD = 5V)

<table>
<thead>
<tr>
<th>Device</th>
<th>Package</th>
<th>Max. V_{BE(sat)}/V_{GS} (V)</th>
<th>Min. H_FE</th>
<th>V_{CEO}/V_{DS} (V)</th>
<th>Fan Current (mA)</th>
<th>Suggested R_BASE (Ω)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MMBT2222A</td>
<td>SOT-23</td>
<td>1.2</td>
<td>50</td>
<td>40</td>
<td>150</td>
<td>800</td>
</tr>
<tr>
<td>MPS2222A</td>
<td>TO-92</td>
<td>1.2</td>
<td>50</td>
<td>40</td>
<td>150</td>
<td>800</td>
</tr>
<tr>
<td>MPS6602</td>
<td>TO-92</td>
<td>1.2</td>
<td>50</td>
<td>40</td>
<td>500</td>
<td>301</td>
</tr>
<tr>
<td>SI2302</td>
<td>SOT-23</td>
<td>2.5</td>
<td>NA</td>
<td>20</td>
<td>500</td>
<td>Note 1</td>
</tr>
<tr>
<td>MGSF1N02E</td>
<td>SOT-23</td>
<td>2.5</td>
<td>NA</td>
<td>20</td>
<td>500</td>
<td>Note 1</td>
</tr>
<tr>
<td>SI4410</td>
<td>SO-8</td>
<td>4.5</td>
<td>NA</td>
<td>30</td>
<td>1000</td>
<td>Note 1</td>
</tr>
<tr>
<td>SI2308</td>
<td>SOT-23</td>
<td>4.5</td>
<td>NA</td>
<td>60</td>
<td>500</td>
<td>Note 1</td>
</tr>
</tbody>
</table>

Note 1: A series gate resistor may be used in order to control the MOSFET turn-on and turn-off times.
5.5 Latch-up Considerations

As with any CMOS IC, the potential exists for latch-up if signals are applied to the device which are outside the power supply range. This is of particular concern during power-up if the external circuitry (such as the sensor network, V_AS divider or shutdown circuit) are powered by a supply different from that of the TC648. Care should be taken to ensure that the TC648’s VDD supply powers up first. If possible, the networks attached to VIN and VAS should connect to the VDD supply at the same physical location as the IC itself. Even if the IC and any external networks are powered by the same supply, physical separation of the connecting points can result in enough parasitic capacitance and/or inductance in the power supply connections to delay one power supply “routing” versus another.

5.6 Power Supply Routing and Bypassing

Noise present on the VIN and VAS inputs may cause erroneous operation of the OTF output. As a result, these inputs should be bypassed with a 0.01 µF capacitor mounted as close to the package as possible. This is especially true of VIN, which is usually driven from a high impedance source (such as a thermistor). Additionally, the VDD input should be bypassed with a 1 µF capacitor and grounds should be kept as short as possible. To keep fan noise off the TC648 ground pin, individual ground returns for the TC648 and the low side of the fan drive device should be used.

Auto-Shutdown Mode Design Example

Step 1. Calculate R1 and R2 based on using an NTC having a resistance of 10 kΩ at T_MIN (25°C) and 4.65 kΩ at T_MAX (45°C) (see Figure 5-8).

\[
R_1 = 20.5 \text{ kΩ} \\
R_2 = 3.83 \text{ kΩ}
\]

Step 2. Set auto-shutdown level.

\[
V_{AS} = 1.8V \\
R_5 = 33 \text{ kΩ} \\
R_6 = 18 \text{ kΩ}
\]

Step 3. Design the output circuit

Maximum fan motor current = 250 mA.

Q1 beta is chosen at 50 from which

\[
R_7 = 800 \text{ Ω}
\]

5.7 Minimum Speed Mode Design Example

Given:

Minimum speed = 40%(1.8V) \\
T_MIN = 30°C, T_MAX = 95°C \\
Thermistor = 100 kΩ at 25°C \\
RT_MIN = 79.4 kΩ, RT_MAX = 6.5 kΩ

Step 1: Calculate R1:

\[
R_1 = 7.9 \text{ kΩ (Use closest standard value: 7.87 kΩ)}
\]

Calculate R2:

\[
R_2 = 4.05 \text{ kΩ (Use closest standard value: 4.02 kΩ)}
\]

Step 2: Verify V_MAX:

\[
V_{MAX} = 2.64V
\]
FIGURE 5-8:  Design Example.

5.8 TC648 as a Microcontroller Peripheral

In a system containing a microcontroller or other host intelligence, the TC648 can be effectively managed as a CPU peripheral. Routine fan control functions can be performed by the TC648 without processor intervention. The microcontroller receives temperature data from one or more points throughout the system. It calculates a fan operating speed based on an algorithm specifically designed for the application at hand. The processor controls fan speed using complementary port bits I/O1 through I/O3.

Resistors $R_1$ through $R_6$ (5% tolerance) form a crude 3-bit DAC that translates the 3-bit code from the processor’s outputs into a 1.6V DC control signal. A monolithic DAC or digital pot may be used instead of the circuit shown in Figure 5-9.

With $V_{AS}$ set at 1.8V, the TC648 enters auto-shutdown when the processor’s output code is 000B. Output codes 001B to 111B operate the fan from roughly 40% to 100% of full speed. An open-drain output from the processor (I/O0) can be used to reset the TC648 following detection of a fault condition. The OTF output can be connected to the processor's interrupt input, or to another I/O pin, for polled operation.
FIGURE 5-9: TC648 as a Microcontroller Peripheral.
6.0 PACKAGING INFORMATION

6.1 Package Marking Information

8-Lead PDIP (300 mil)

Example:

\[
\begin{array}{c}
\text{XXXXXXXX} \\
\text{NNN} \\
\text{YYWW}
\end{array}
\]

8-Lead SOIC (150 mil)

Example:

\[
\begin{array}{c}
\text{XXXXXXXX} \\
\text{YYWW} \\
\text{NNN}
\end{array}
\]

8-Lead MSOP

Example:

\[
\begin{array}{c}
\text{XXXXXXXX} \\
\text{YWWNNN}
\end{array}
\]

Legend:  
XX...X Customer-specific information  
Y Year code (last digit of calendar year)  
YY Year code (last 2 digits of calendar year)  
WWW Week code (week of January 1 is week ‘01’)  
NNN Alphanumeric traceability code  
\(\varepsilon_3\) Pb-free JEDEC designator for Matte Tin (Sn)  
* This package is Pb-free. The Pb-free JEDEC designator (\(\varepsilon_3\)) can be found on the outer packaging for this package.

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.
8-Lead Plastic Dual In-line (P) – 300 mil (PDIP)

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

<table>
<thead>
<tr>
<th>Units</th>
<th>INCHES*</th>
<th>MILLIMETERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimension</td>
<td>MIN</td>
<td>NOM</td>
</tr>
<tr>
<td>Number of Pins</td>
<td>n</td>
<td>8</td>
</tr>
<tr>
<td>Pitch</td>
<td>p</td>
<td>.100</td>
</tr>
<tr>
<td>Top to Seating Plane</td>
<td>A</td>
<td>.140</td>
</tr>
<tr>
<td>Molded Package Thickness</td>
<td>A2</td>
<td>.115</td>
</tr>
<tr>
<td>Base to Seating Plane</td>
<td>A1</td>
<td>.015</td>
</tr>
<tr>
<td>Shoulder to Shoulder Width</td>
<td>E</td>
<td>.300</td>
</tr>
<tr>
<td>Molded Package Width</td>
<td>E1</td>
<td>.240</td>
</tr>
<tr>
<td>Overall Length</td>
<td>D</td>
<td>1.200</td>
</tr>
<tr>
<td>Tip to Seating Plane</td>
<td>L</td>
<td>.125</td>
</tr>
<tr>
<td>Lead Thickness</td>
<td>c</td>
<td>.006</td>
</tr>
<tr>
<td>Upper Lead Width</td>
<td>B1</td>
<td>.045</td>
</tr>
<tr>
<td>Lower Lead Width</td>
<td>B</td>
<td>.014</td>
</tr>
<tr>
<td>Overall Row Spacing</td>
<td>eB</td>
<td>.310</td>
</tr>
<tr>
<td>Mold Draft Angle Top</td>
<td>α</td>
<td>5</td>
</tr>
<tr>
<td>Mold Draft Angle Bottom</td>
<td>β</td>
<td>5</td>
</tr>
</tbody>
</table>

* Controlling Parameter
§ Significant Characteristic

Notes:
Dimensions D and E1 do not include mold flash or protrusions. Mold flash or protrusions shall not exceed .010” (0.254mm) per side.
JEDEC Equivalent: MS-001
Drawing No. C04-018
### 8-Lead Plastic Small Outline (SN) – Narrow, 150 mil (SOIC)

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

<table>
<thead>
<tr>
<th>Units</th>
<th>INCHES*</th>
<th>MILLIMETERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Pins</td>
<td>n</td>
<td>8</td>
</tr>
<tr>
<td>Pitch</td>
<td>p</td>
<td>.050</td>
</tr>
<tr>
<td>Overall Height</td>
<td>A</td>
<td>.053/.061/.069</td>
</tr>
<tr>
<td>Molded Package Thickness</td>
<td>A2</td>
<td>.052/.056/.061</td>
</tr>
<tr>
<td>Standoff §</td>
<td>A1</td>
<td>.004/.007/.010</td>
</tr>
<tr>
<td>Overall Width</td>
<td>E</td>
<td>.228/.237/.244</td>
</tr>
<tr>
<td>Overall Length</td>
<td>D</td>
<td>.189/.193/.197</td>
</tr>
<tr>
<td>Chamfer Distance</td>
<td>h</td>
<td>.010/.015/.020</td>
</tr>
<tr>
<td>Foot Length</td>
<td>L</td>
<td>.019/.025/.030</td>
</tr>
<tr>
<td>Foot Angle</td>
<td>f</td>
<td>0/4/8</td>
</tr>
<tr>
<td>Lead Thickness</td>
<td>c</td>
<td>.006/.009/.010</td>
</tr>
<tr>
<td>Lead Width</td>
<td>B</td>
<td>.013/.017/.020</td>
</tr>
<tr>
<td>Mold Draft Angle Top</td>
<td>α</td>
<td>0/12/15</td>
</tr>
<tr>
<td>Mold Draft Angle Bottom</td>
<td>β</td>
<td>0/12/15</td>
</tr>
</tbody>
</table>

* Controlling Parameter
§ Significant Characteristic

**Notes:**
Dimensions D and E1 do not include mold flash or protrusions. Mold flash or protrusions shall not exceed .010” (0.254mm) per side.
JEDEC Equivalent: MS-012
Drawing No. C04-057
8-Lead Plastic Micro Small Outline Package (MS) (MSOP)

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

<table>
<thead>
<tr>
<th>Units</th>
<th>INCHES</th>
<th>MILLIMETERS*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Pins</td>
<td>MIN: 8</td>
<td>NOM: 8</td>
</tr>
<tr>
<td>Pitch</td>
<td>MIN: 0.026</td>
<td>NOM: 0.05</td>
</tr>
<tr>
<td>Overall Height</td>
<td>MIN: 1.044</td>
<td>NOM: 1.18</td>
</tr>
<tr>
<td>Molded Package Thickness</td>
<td>MIN: 0.038</td>
<td>NOM: 0.076</td>
</tr>
<tr>
<td>Standoff</td>
<td>MIN: 0.006</td>
<td>NOM: 0.03</td>
</tr>
<tr>
<td>Overall Width</td>
<td>MIN: 1.200</td>
<td>NOM: 1.47</td>
</tr>
<tr>
<td>Molded Package Width</td>
<td>MIN: 1.122</td>
<td>NOM: 1.49</td>
</tr>
<tr>
<td>Overall Length</td>
<td>MIN: 1.220</td>
<td>NOM: 1.72</td>
</tr>
<tr>
<td>Foot Length</td>
<td>MIN: 0.028</td>
<td>NOM: 0.06</td>
</tr>
<tr>
<td>Footprint (Reference)</td>
<td>MIN: 0.039</td>
<td>NOM: 0.09</td>
</tr>
<tr>
<td>Foot Angle</td>
<td>MIN: 0.006</td>
<td>NOM: 0.015</td>
</tr>
<tr>
<td>Lead Thickness</td>
<td>MIN: 0.008</td>
<td>NOM: 0.010</td>
</tr>
<tr>
<td>Lead Width</td>
<td>MIN: 0.016</td>
<td>NOM: 0.025</td>
</tr>
<tr>
<td>Mold Draft Angle Top</td>
<td>MIN: 0.07</td>
<td>NOM: 0.10</td>
</tr>
<tr>
<td>Mold Draft Angle Bottom</td>
<td>MIN: 0.07</td>
<td>NOM: 0.10</td>
</tr>
</tbody>
</table>

*Controlling Parameter
§ Significant Characteristic

Notes:
Dimensions D and E1 do not include mold flash or protrusions. Mold flash or protrusions shall not exceed 0.010” (0.254mm) per side.

Drawing No. C04-111
6.2 Taping Form

Component Taping Orientation for 8-Pin SOIC (Narrow) Devices

User Direction of Feed

PIN 1

W

P

Standard Reel Component Orientation for 713 Suffix Device

<table>
<thead>
<tr>
<th>Package</th>
<th>Carrier Width (W)</th>
<th>Pitch (P)</th>
<th>Part Per Full Reel</th>
<th>Reel Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>8-Pin SOIC (N)</td>
<td>12 mm</td>
<td>8 mm</td>
<td>2500</td>
<td>13 in</td>
</tr>
</tbody>
</table>

Component Taping Orientation for 8-Pin MSOP Devices

User Direction of Feed

PIN 1

W

P

Standard Reel Component Orientation for 713 Suffix Device

<table>
<thead>
<tr>
<th>Package</th>
<th>Carrier Width (W)</th>
<th>Pitch (P)</th>
<th>Part Per Full Reel</th>
<th>Reel Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>8-Pin MSOP</td>
<td>12 mm</td>
<td>8 mm</td>
<td>2500</td>
<td>13 in</td>
</tr>
</tbody>
</table>
7.0 REVISION HISTORY

Revision D (December 2012)

Added a note to each package outline drawing.
THE MICROCHIP WEB SITE

Microchip provides online support via our WWW site at www.microchip.com. This web site is used as a means to make files and information easily available to customers. Accessible by using your favorite Internet browser, the web site contains the following information:

- **Product Support** – Data sheets and errata, application notes and sample programs, design resources, user’s guides and hardware support documents, latest software releases and archived software
- **General Technical Support** – Frequently Asked Questions (FAQ), technical support requests, online discussion groups, Microchip consultant program member listing
- **Business of Microchip** – Product selector and ordering guides, latest Microchip press releases, listing of seminars and events, listings of Microchip sales offices, distributors and factory representatives

CUSTOMER CHANGE NOTIFICATION SERVICE

Microchip’s customer notification service helps keep customers current on Microchip products. Subscribers will receive e-mail notification whenever there are changes, updates, revisions or errata related to a specified product family or development tool of interest.

To register, access the Microchip web site at www.microchip.com. Under “Support”, click on “Customer Change Notification” and follow the registration instructions.

CUSTOMER SUPPORT

Users of Microchip products can receive assistance through several channels:

- Distributor or Representative
- Local Sales Office
- Field Application Engineer (FAE)
- Technical Support

Customers should contact their distributor, representative or field application engineer (FAE) for support. Local sales offices are also available to help customers. A listing of sales offices and locations is included in the back of this document.

Technical support is available through the web site at: http://microchip.com/support
READER RESPONSE

It is our intention to provide you with the best documentation possible to ensure successful use of your Microchip product. If you wish to provide your comments on organization, clarity, subject matter, and ways in which our documentation can better serve you, please FAX your comments to the Technical Publications Manager at (480) 792-4150.

Please list the following information, and use this outline to provide us with your comments about this document.

TO: Technical Publications Manager
RE: Reader Response

From: Name
Company ________________________________
Address ___________________________________
City / State / ZIP / Country ________________________________
Telephone: (______) _________ - _________ FAX: (_____) _________ - _________

Application (optional):

Would you like a reply?       Y       N

Device: Literature Number: DS21448D

Questions:

1. What are the best features of this document?

2. How does this document meet your hardware and software development needs?

3. Do you find the organization of this document easy to follow? If not, why?

4. What additions to the document do you think would enhance the structure and subject?

5. What deletions from the document could be made without affecting the overall usefulness?

6. Is there any incorrect or misleading information (what and where)?

7. How would you improve this document?
PRODUCT IDENTIFICATION SYSTEM

To order or obtain information, e.g., on pricing or delivery, refer to the factory or the listed sales office.

<table>
<thead>
<tr>
<th>PART NO.</th>
<th>X</th>
<th>/XX</th>
<th>Device</th>
<th>Temperature Range</th>
<th>Package</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>TC648: PWM Fan Speed Controller w/Auto Shutdown and Overtemperature Alert</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Temperature Range:**
- V = 0°C to +85°C
- E = -40°C to +85°C

**Package:**
- PA = Plastic DIP (300 mil Body), 8-lead
- OA = Plastic SOIC, (150 mil Body), 8-lead
- UA = Plastic Micro Small Outline (MSOP), 8-lead

* PDIP package is only offered in the V temp range

**Examples:**

- a) TC648VOA: PWM Fan Speed Controller w/Auto Shutdown and Over-Temperature Alert, SOIC package.
- b) TC648VUA: PWM Fan Speed Controller w/Auto Shutdown and Over-Temperature Alert, MSOP package.
- c) TC648VPA: PWM Fan Speed Controller w/Auto Shutdown and Over-Temperature Alert, PDIP package.
- d) TC648E0A713: PWM Fan Speed Controller w/Auto Shutdown and Over-Temperature Alert, SOIC package, Tape and Reel.

**Sales and Support**

**Data Sheets**
Products supported by a preliminary Data Sheet may have an errata sheet describing minor operational differences and recommended workarounds. To determine if an errata sheet exists for a particular device, please contact one of the following:

1. Your local Microchip sales office
2. The Microchip Worldwide Site (www.microchip.com)

Please specify which device, revision of silicon and Data Sheet (include Literature #) you are using.

**New Customer Notification System**
Register on our web site (www.microchip.com/cn) to receive the most current information on our products.
Note the following details of the code protection feature on Microchip devices:

- Microchip products meet the specification contained in their particular Microchip Data Sheet.
- Microchip believes that its family of products is one of the most secure families of its kind on the market today, when used in the intended manner and under normal conditions.
- There are dishonest and possibly illegal methods used to breach the code protection feature. All of these methods, to our knowledge, require using the Microchip products in a manner outside the operating specifications contained in Microchip’s Data Sheets. Most likely, the person doing so is engaged in theft of intellectual property.
- Microchip is willing to work with the customer who is concerned about the integrity of their code.
- Neither Microchip nor any other semiconductor manufacturer can guarantee the security of their code. Code protection does not mean that we are guaranteeing the product as “unbreakable.”

Code protection is constantly evolving. We at Microchip are committed to continuously improving the code protection features of our products. Attempts to break Microchip’s code protection feature may be a violation of the Digital Millennium Copyright Act. If such acts allow unauthorized access to your software or other copyrighted work, you may have a right to sue for relief under that Act.

Information contained in this publication regarding device applications and the like is provided only for your convenience and may be superseded by updates. It is your responsibility to ensure that your application meets with your specifications. MICROCHIP MAKES NO REPRESENTATIONS OR WARRANTIES OF ANY KIND WHETHER EXPRESS OR IMPLIED, WRITTEN OR ORAL, STATUTORY OR OTHERWISE, RELATED TO THE INFORMATION, INCLUDING BUT NOT LIMITED TO ITS CONDITION, QUALITY, PERFORMANCE, MERCHANTABILITY OR FITNESS FOR PURPOSE. Microchip disclaims all liability arising from this information and its use. Use of Microchip devices in life support and/or safety applications is entirely at the buyer’s risk, and the buyer agrees to defend, indemnify and hold harmless Microchip from any and all damages, claims, suits, or expenses resulting from such use. No licenses are conveyed, implicitly or otherwise, under any Microchip intellectual property rights.

Trademarks
The Microchip name and logo, the Microchip logo, dsPIC, FlashFlex, Keeloq, Keeloq logo, MPLAB, PIC, Picmicro, PICSTART, PIC32 logo, rPIC, SST, SST Logo, SuperFlash and Uni/O are registered trademarks of Microchip Technology Incorporated in the U.S.A. and other countries.
FilterLab, Hampshire, Hi-TECH C, Linear Active Thermistor, MTP, SEEVAL and The Embedded Control Solutions Company are registered trademarks of Microchip Technology Incorporated in the U.S.A.
Silicon Storage Technology is a registered trademark of Microchip Technology Inc. in other countries.
Analog-for-the-Digital Age, Application Maestro, BodyCom, chipKIT, chipKIT logo, CodeGuard, dsPICDEM, dsPICDEM.net, dsPICworks, dsSPEAK, ECAN, ECONOMONITOR, FanSense, HI-TIDE, In-Circuit Serial Programming, ICSP, Mindi, MiWi, MPASM, MPF, MPLAB Certified logo, MPLIB, MPLINK, mTouch, Omniscient Code Generation, PICC, PICC-18, PICDEM, PICDEM.net, PICKit, PICtail, REAL ICE, rFLAB, Select Mode, SQI, Serial Quad I/O, Total Endurance, TSHARC, UniWinDriver, WiperLock, ZENA and Z-Scale are trademarks of Microchip Technology Incorporated in the U.S.A. and other countries.
SQTP is a service mark of Microchip Technology Incorporated in the U.S.A.
GestIC and ULPP are registered trademarks of Microchip Technology Germany II GmbH & Co. & KG, a subsidiary of Microchip Technology Inc., in other countries.

All other trademarks mentioned herein are property of their respective companies.
© 2001-2012, Microchip Technology Incorporated, Printed in the U.S.A., All Rights Reserved.
Printed on recycled paper.
ISBN: 9781620768297

Microchip received ISO/TS-16949:2009 certification for its worldwide headquarters, design and wafer fabrication facilities in Chandler and Tempe, Arizona; Gresham, Oregon and design centers in California and India. The Company’s quality system processes and procedures are for its PIC® MCUs and dsPIC® DSCs, Keeloq® code hopping devices, Serial EEPROMs, microperipherals, nonvolatile memory and analog products. In addition, Microchip’s quality system for the design and manufacture of development systems is ISO 9001:2000 certified.
### Worldwide Sales and Service

#### AMERICAS

**Corporate Office**
2355 West Chandler Blvd.
Chandler, AZ 85224-6199
Tel: 480-792-7200
Fax: 480-792-7277

Technical Support:
[www.microchip.com/support](http://www.microchip.com/support)

**Atlanta**
Duluth, GA
Tel: 678-957-9614
Fax: 678-957-1455

**Boston**
Westborough, MA
Tel: 774-760-0087
Fax: 774-760-0088

**Chicago**
Itasca, IL
Tel: 630-285-0071
Fax: 630-285-0075

**Cleveland**
Independence, OH
Tel: 216-447-0464
Fax: 216-447-0643

**Dallas**
Addison, TX
Tel: 972-818-7423
Fax: 972-818-2924

**Detroit**
Farmington Hills, MI
Tel: 248-538-2250
Fax: 248-538-2260

**Indianapolis**
Noblesville, IN
Tel: 317-773-8323
Fax: 317-773-5453

**Los Angeles**
Mission Viejo, CA
Tel: 949-462-9523
Fax: 949-462-9608

**Santa Clara**
Santa Clara, CA
Tel: 408-961-6444
Fax: 408-961-6445

**Toronto**
Mississauga, Ontario, Canada
Tel: 905-673-0699
Fax: 905-673-6509

#### ASIA/PACIFIC

**Asia Pacific Office**
Suites 3707-14, 37th Floor
Tower 6, The Gateway
Harbour City, Kowloon
Hong Kong
Tel: 852-2401-1200
Fax: 852-2401-3431

**Australia - Sydney**
Tel: 61-2-8868-6733
Fax: 61-2-8868-6755

**China - Beijing**
Tel: 86-10-8569-7000
Fax: 86-10-8528-2104

**China - Chengdu**
Tel: 86-28-8665-5511
Fax: 86-28-8665-7889

**China - Chongqing**
Tel: 86-23-8980-9588
Fax: 86-23-8980-9500

**China - Hangzhou**
Tel: 86-571-2819-3187
Fax: 86-571-2819-3189

**China - Hong Kong SAR**
Tel: 852-2943-5100
Fax: 852-2401-3431

**China - Nanjing**
Tel: 86-25-8473-2460
Fax: 86-25-8473-2470

**China - Qingdao**
Tel: 86-532-8502-7355
Fax: 86-532-8502-7205

**China - Shanghai**
Tel: 86-21-5407-5066
Fax: 86-21-5407-5000

**China - Shenyang**
Tel: 86-24-2334-2393
Fax: 86-24-2334-2829

**China - Shenzhen**
Tel: 86-755-8864-2200
Fax: 86-755-8203-1760

**China - Wuhan**
Tel: 86-27-5980-5300
Fax: 86-27-5980-5118

**China - Xian**
Tel: 86-29-8833-7252
Fax: 86-29-8833-7256

**China - Xiamen**
Tel: 86-592-2388138
Fax: 86-592-2388130

**China - Zhuhai**
Tel: 86-756-3210040
Fax: 86-756-3210049

**India - Bangalore**
Tel: 91-80-3090-4444
Fax: 91-80-3090-4123

**India - New Delhi**
Tel: 91-11-4160-8631
Fax: 91-11-4160-8632

**India - Pune**
Tel: 91-20-2566-1512
Fax: 91-20-2566-1513

**Japan - Osaka**
Tel: 81-6-6152-7160
Fax: 81-6-6152-9310

**Japan - Tokyo**
Tel: 81-3-6880-3770
Fax: 81-3-6880-3771

**Korea - Daegu**
Tel: 82-53-744-4301
Fax: 82-53-744-4302

**Korea - Seoul**
Tel: 82-2-554-7200
Fax: 82-2-558-5932 or 82-2-558-5934

**Malaysia - Kuala Lumpur**
Tel: 60-3-6201-9857
Fax: 60-3-6201-9859

**Malaysia - Penang**
Tel: 60-4-227-8870
Fax: 60-4-227-4068

**Philippines - Manila**
Tel: 63-2-634-9065
Fax: 63-2-634-9069

**Singapore**
Tel: 65-6334-8870
Fax: 65-6334-8850

**Taiwan - Hsin Chu**
Tel: 886-3-5778-366
Fax: 886-3-5770-955

**Taiwan - Kaohsiung**
Tel: 886-7-213-7828
Fax: 886-7-330-9305

**Taiwan - Taipei**
Tel: 886-2-2508-8600
Fax: 886-2-2508-0102

**Thailand - Bangkok**
Tel: 66-2-694-1351
Fax: 66-2-694-1350

#### EUROPE

**Austria - Wels**
Tel: 43-7242-2244-39
Fax: 43-7242-2244-393

**Denmark - Copenhagen**
Tel: 45-4450-2828
Fax: 45-4485-2829

**France - Paris**
Tel: 33-1-69-53-63-20
Fax: 33-1-69-30-90-79

**Germany - Munich**
Tel: 49-89-627-144-0
Fax: 49-89-627-144-44

**Italy - Milan**
Tel: 39-0331-742611
Fax: 39-0331-466781

**Netherlands - Drunen**
Tel: 31-416-690399
Fax: 31-416-690340

**Spain - Madrid**
Tel: 34-91-708-08-90
Fax: 34-91-708-08-91

**UK - Wokingham**
Tel: 44-118-921-5869
Fax: 44-118-921-5820

11/29/12