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)

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 VIN 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 (VIN) is lower than a user programmed minimum setting (VAS). The fan is automatically restarted, and proportional speed control restored, when VIN exceeds VAS (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 (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.
1.0 ELECTRICAL CHARACTERISTICS

Absolute Maximum Ratings*

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
<th>Test Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply Voltage VDD</td>
<td>3.0</td>
<td>---</td>
<td>5.5</td>
<td>V</td>
<td>Pins 6, 7 Open, CF = 1 µF, VIN = VC(MAX)</td>
</tr>
<tr>
<td>Supply Current, Operating IDD</td>
<td>---</td>
<td>0.5</td>
<td>1.0</td>
<td>mA</td>
<td>Pins 6, 7 Open; Note 1 CF = 1 µF, VIN = 0.35V</td>
</tr>
<tr>
<td>Supply Current, Shutdown/ Auto-shutdown Mode IDD(SHDN)</td>
<td>---</td>
<td>25</td>
<td>---</td>
<td>µA</td>
<td></td>
</tr>
<tr>
<td>VIN, VAS Input Leakage IIN</td>
<td>-1.0</td>
<td>---</td>
<td>+1.0</td>
<td>µA</td>
<td>Note 1</td>
</tr>
<tr>
<td>VOUT Rise Time tR</td>
<td>---</td>
<td>---</td>
<td>50</td>
<td>µsec</td>
<td>IOH = 5 mA, Note 1</td>
</tr>
<tr>
<td>VOUT Fall Time tF</td>
<td>---</td>
<td>---</td>
<td>50</td>
<td>µsec</td>
<td>IOH = 1 mA, Note 1</td>
</tr>
<tr>
<td>Sink Current at VOUT Output IOL</td>
<td>1.0</td>
<td>---</td>
<td>---</td>
<td>mA</td>
<td>VOL = 10% of VDD</td>
</tr>
<tr>
<td>Source Current at VOUT Output IOH</td>
<td>5.0</td>
<td>---</td>
<td>---</td>
<td>mA</td>
<td>VOH = 80% of VDD</td>
</tr>
<tr>
<td>SENSE Input VTH(SENSE)</td>
<td>50</td>
<td>70</td>
<td>90</td>
<td>mV</td>
<td>Note 1</td>
</tr>
<tr>
<td>Output Low Voltage VOL</td>
<td>---</td>
<td>---</td>
<td>0.3</td>
<td>V</td>
<td>IOL = 2.5 mA</td>
</tr>
<tr>
<td>Voltage at VIN for 100% Duty Cycle and Overtemp. Fault V(C(MAX), V(TOT))</td>
<td>2.5</td>
<td>2.65</td>
<td>2.8</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>Voltage with Respect to GND V(C(SPAN))</td>
<td>1.3</td>
<td>1.4</td>
<td>1.5</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>Auto-shutdown Threshold VAS</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>V</td>
<td>V(C(MAX))</td>
</tr>
<tr>
<td>Voltage Applied to VIN to Ensure Reset/Shutdown VSHDN</td>
<td>---</td>
<td>---</td>
<td>VDD x 0.13</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>Voltage Applied to VIN to Release Reset Mode VREL</td>
<td>VDD x 0.19</td>
<td>---</td>
<td>---</td>
<td>V</td>
<td>VDD = 5V</td>
</tr>
<tr>
<td>Hysteresis on VSHDN, VREL VHYST</td>
<td>0.01 x VDD</td>
<td>---</td>
<td>---</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>Hysteresis on Auto-shutdown Comparator VHAS</td>
<td>70</td>
<td>---</td>
<td>---</td>
<td>mV</td>
<td></td>
</tr>
</tbody>
</table>

*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.

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

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

<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>$t_{\text{STARTUP}}$</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>
<thead>
<tr>
<th>Pin No.</th>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>VIN</td>
<td>Analog Input</td>
</tr>
<tr>
<td>2</td>
<td>CF</td>
<td>Analog Output</td>
</tr>
<tr>
<td>3</td>
<td>VAS</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>VOUT</td>
<td>Digital Output</td>
</tr>
<tr>
<td>8</td>
<td>VDD</td>
<td>Power Supply Input</td>
</tr>
</tbody>
</table>

2.1 Analog Input (VIN)
The thermistor network (or other temperature sensor) connects to the VIN 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 VOUT pin (see Section 5.0, “Typical Applications”, for more details).

2.2 Analog Output (CF)
CF is the positive terminal for the PWM ramp generator timing capacitor. The recommended CF is 1 µF for 30 Hz PWM operation.

2.3 Analog Input (VAS)
An external resistor divider connected to the VAS input sets the auto-shutdown threshold. Auto-shutdown occurs when VIN ≤ VAS. During shutdown, supply current falls to 25 µA (typical). The fan is automatically restarted when VIN ≥ (VAS + VHAS) (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 VIN > VOTF (see Section 1.0, “Electrical Characteristics”). An over-temperature indication is a non-latching condition.

2.7 Digital Output (VOUT)
VOUT 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 MOS-FET. This output has asymmetrical drive (see Section 1.0, “Electrical Characteristics”).

2.8 Power Supply Input (VDD)
VDD 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 greater 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 driving VIN to a logic low. 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.

![Typical Application Circuit Diagram](image-url)
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.

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

RT1 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 RT1 and $R_1$. For convenience, the parallel combination of RT1 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 non-linear 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 $V_{CS(SPAN)}$ 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:

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

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

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 $V_{AS}$ 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 $T_{MAX}$.

**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 $R_1$ 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 ther-
mistor resistance at $T_{MIN}$. $R_2$ is then calculated to deliver the desired speed at $T_{MIN}$. The values for $R_1$, $R_2$ and $RT_1$ are then checked at $T_{MAX}$ 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:

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

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

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

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

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

Where $RT_{MAX} =$ thermistor resistance at $T_{MAX}$.

$V_{MAX} =$ the value of $V_{IN}$ 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 $V_{MIN}$ and $V_{MAX}$ using the above equations. In this case, the circuit in Figure 5-4 can be used. Diode $D_1$ clamps $V_{IN}$ 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 $V_{AS}$ sets the temperature at which the part is automatically shut down if the sensed temperature at $V_{IN}$ drops below the set temperature at $V_{AS}$ (i.e. $V_{IN} < V_{AS}$).

As with the $V_{IN}$ 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 $T_{AS}$ is related to $T_2$ and $T_1$ by:

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

For example, if 1.25V and 2.65V at $V_{IN}$ 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 $V_{AS}$ voltage is:

\[
V_{AS} = \frac{1.4V}{(125 - 0)} \cdot \left(\frac{25 - 0}{T_{AS} - T_1} + 1.25\right)
\]

The $V_{AS}$ 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 VAS pin is no more than 1 µA. It is conservative to design for a divider current, IDIV, of 100 µA. If VDD = 5.0V then...

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

We can further specify R1 and R2 by the condition that the divider voltage is equal to our desired VAS. This yields the following:

\[ V_{AS} = \frac{VDD \cdot R_2}{R_1 + R_2} \]

Solving for the relationship between R1 and R2 results in the following equation:

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

For this example, R1 = (2.27) R2. Substituting this relationship back into the original equation yields the resistor values:

\[ R_2 = 15.3\, k\Omega, \text{ and } R_1 = 34.7\, k\Omega \]

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 Q1 in Figures 5-1, 5-6, 5-7, and 5-8. The VOUT 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 Q1 are: (1) the breakdown voltage (VBR/ICEO or VDS (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 VOUT voltage must be high enough to sufficiently drive the gate of the MOSFET to minimize the RDS(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:

\[ V_{OH} = V_{BE(SAT)} + V_{RBASE} \]
\[ V_{RBASE} = R_{BASE} \cdot I_{BASE} \]
\[ I_{BASE} = I_{FAN} / h_{FE} \]

VOH is specified as 80% of VDD in Section 1.0, “Electrical Characteristics”; VBE(SAT) is given in the chosen transistor data sheet. It is now possible to solve for RBASE.

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

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 D1 offsets the -12V power supply voltage, holding transistor Q1 off when VOUT is low. When VOUT is high, the voltage at the anode of D1 increases by VOH, causing Q1 to turn on. Operation is otherwise the same as in the case of fan operation from +12V.
FIGURE 5-6: Output Drive Transistor Circuit Topologies.

TABLE 5-1: TRANSISTORS AND MOSFETS FOR Q₁ (VDD = 5V)

<table>
<thead>
<tr>
<th>Device</th>
<th>Package</th>
<th>Max. VBE(sat)/VGS (V)</th>
<th>Min. HFE</th>
<th>VCEO/VDS (V)</th>
<th>Fan Current (mA)</th>
<th>Suggested RBASE (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>
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<td>MPS6602</td>
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<td>SI2302</td>
<td>SOT-23</td>
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<td>NA</td>
<td>20</td>
<td>500</td>
<td>Note 1</td>
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<td>MGSF1N02E</td>
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<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, VAS 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).

\[
\begin{align*}
R_1 &= 20.5 \text{kΩ} \\
R_2 &= 3.83 \text{kΩ}
\end{align*}
\]

Step 2. Set auto-shutdown level.

\[
\begin{align*}
V_{AS} &= 1.8 \text{V} \\
\text{Limit the divider current to 100 µA} \\
R_5 &= 33 \text{kΩ} \\
R_6 &= 18 \text{kΩ}
\end{align*}
\]

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 VMAX:

\[V_{MAX} = 2.64 \text{V}\]
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 000[B]. Output codes 001[B] to 111[B] 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

Legend:

- XX...X: Customer specific information*
- YY: Year code (last 2 digits of calendar year)
- WW: Week code (week of January 1 is week ‘01’)
- NNN: Alphanumeric traceability code

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.

* Standard marking consists of Microchip part number, year code, week code, traceability code (facility code, mask rev#, and assembly code). For marking beyond this, certain price adders apply. Please check with your Microchip Sales Office.
## TC648

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

![Diagram of 8-Lead Plastic Dual In-line (P)](image)

<table>
<thead>
<tr>
<th>Units</th>
<th>INCHES*</th>
<th>MILLIMETERS</th>
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<tr>
<td>Pitch</td>
<td>p</td>
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<tr>
<td>Top to Seating Plane</td>
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<td>Overall Row Spacing</td>
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<td>Mold Draft Angle Top</td>
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<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

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TC648

8-Lead Plastic Small Outline (SN) – Narrow, 150 mil (SOIC)

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* 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)

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*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.

Drawing No. C04-111
### 6.2 Taping Form

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

- **User Direction of Feed**
- **PIN 1**

<table>
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<tr>
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<th>Carrier Width (W)</th>
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<th>Reel Size</th>
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</thead>
<tbody>
<tr>
<td>8-Pin SOIC (N)</td>
<td>12 mm</td>
<td>8 mm</td>
<td>2500</td>
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</table>

#### Component Taping Orientation for 8-Pin MSOP Devices

- **User Direction of Feed**
- **PIN 1**

<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>
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</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>
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Telephone: (______) _________ - _________  FAX: (______) _________ - _________
Application (optional):
Would you like a reply?  Y  N

Device: TC648  Literature Number: DS21448C

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?
   ________________________________________________________________
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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>
</tr>
</thead>
<tbody>
<tr>
<td>Device</td>
<td>Temperature Range</td>
<td>Package</td>
</tr>
</tbody>
</table>

Device: TC648: PWM Fan Speed Controller w/Auto Shutdown and Overtemperature Alert

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) TC648EOA713: PWM Fan Speed Controller w/Auto Shutdown and Over-Temperature Alert, SOIC package, Tape and Reel.

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