

## Fan Speed Controller with Auto-Shutdown and Over-Temperature Alert

### 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

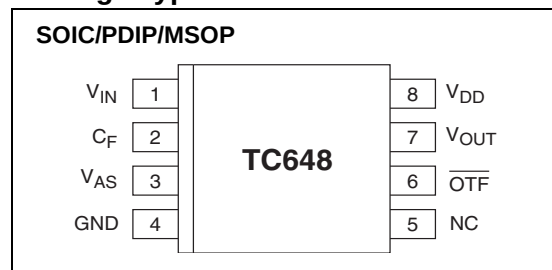
### Applications

- 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



### General Description

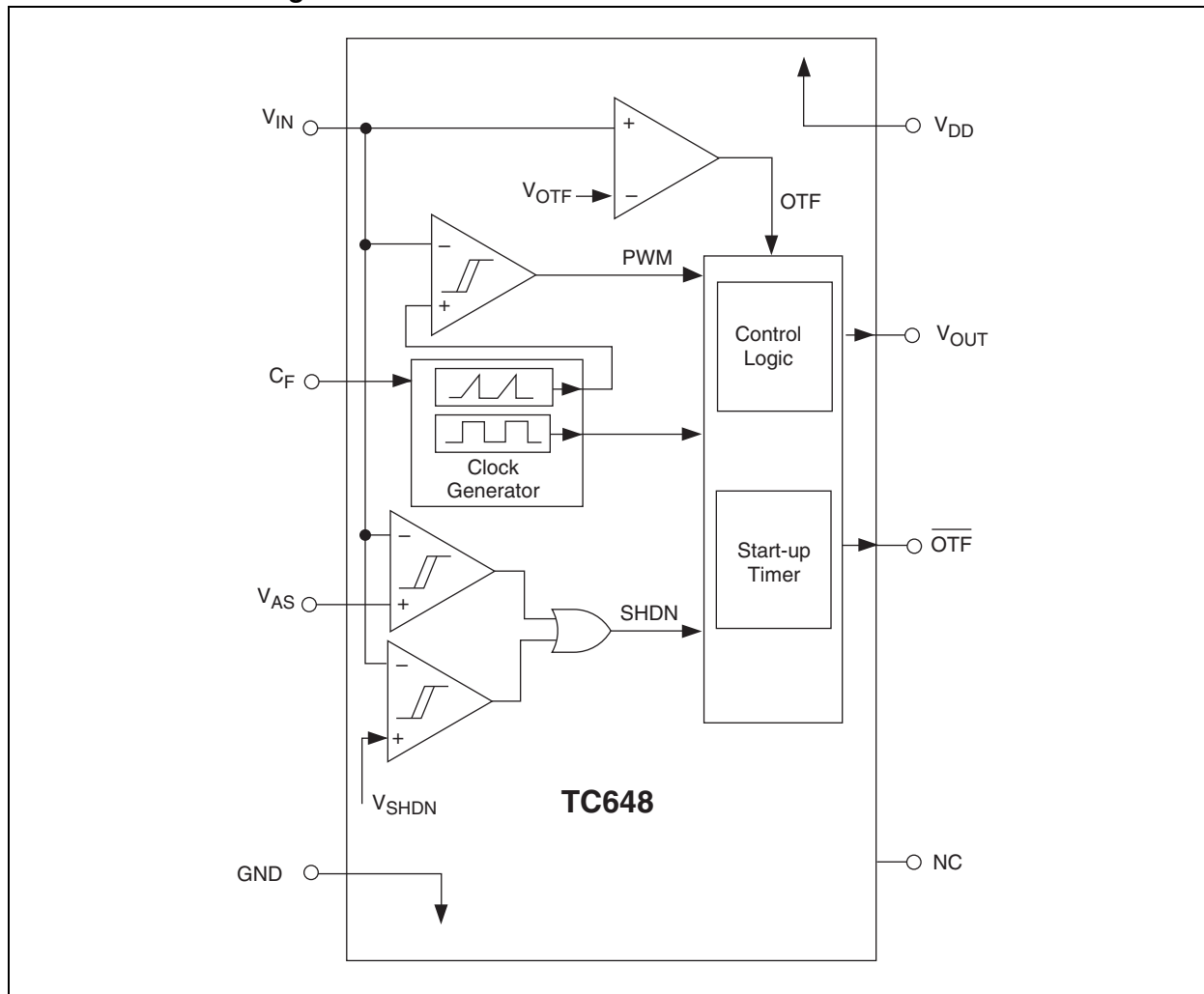
The TC648 is a switch mode, fan speed controller for use with brushless DC fans. Temperature proportional speed control is accomplished using pulse width modulation (PWM). A thermistor (or other voltage output temperature sensor) connected to the  $V_{IN}$  input furnishes the required control voltage 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 ( $V_{IN}$ ) is lower than a user programmed minimum setting ( $V_{AS}$ ). The fan is automatically restarted, and proportional speed control restored, when  $V_{IN}$  exceeds  $V_{AS}$  (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 ( $\overline{OTF}$ ) 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.

# TC648

## Functional Block Diagram



## 1.0 ELECTRICAL CHARACTERISTICS

### Absolute Maximum Ratings\*

Supply Voltage ..... 6V  
 Input Voltage, Any Pin... (GND – 0.3V) to (V<sub>DD</sub> + 0.3V)  
 Package Thermal Resistance:  
     PDIP (R<sub>θJA</sub>)..... 125°C/W  
     SOIC (R<sub>θJA</sub>) ..... 155°C/W  
     MSOP (R<sub>θJA</sub>) ..... 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: Unless otherwise specified, T <sub>MIN</sub> ≤ T <sub>A</sub> ≤ T <sub>MAX</sub> , V <sub>DD</sub> = 3.0V to 5.5V |                                                                    |                                            |                        |                        |       |                                                                                 |
|-----------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------|--------------------------------------------|------------------------|------------------------|-------|---------------------------------------------------------------------------------|
| Symbol                                                                                                                                        | Parameter                                                          | Min                                        | Typ                    | Max                    | Units | Test Conditions                                                                 |
| V <sub>DD</sub>                                                                                                                               | Supply Voltage                                                     | 3.0                                        | —                      | 5.5                    | V     |                                                                                 |
| I <sub>DD</sub>                                                                                                                               | Supply Current, Operating                                          | —                                          | 0.5                    | 1.0                    | mA    | Pins 6, 7 Open, C <sub>F</sub> = 1 μF, V <sub>IN</sub> = V <sub>C(MAX)</sub>    |
| I <sub>DD(SHDN)</sub>                                                                                                                         | Supply Current, Shutdown/ Auto-shutdown Mode                       | —                                          | 25                     | —                      | μA    | Pins 6, 7 Open; <b>Note 1</b><br>C <sub>F</sub> = 1 μF, V <sub>IN</sub> = 0.35V |
| I <sub>IN</sub>                                                                                                                               | V <sub>IN</sub> , V <sub>AS</sub> Input Leakage                    | -1.0                                       | —                      | +1.0                   | μA    | <b>Note 1</b>                                                                   |
| <b>V<sub>OUT</sub> Output</b>                                                                                                                 |                                                                    |                                            |                        |                        |       |                                                                                 |
| t <sub>R</sub>                                                                                                                                | V <sub>OUT</sub> Rise Time                                         | —                                          | —                      | 50                     | μsec  | I <sub>OH</sub> = 5 mA, <b>Note 1</b>                                           |
| t <sub>F</sub>                                                                                                                                | V <sub>OUT</sub> Fall Time                                         | —                                          | —                      | 50                     | μsec  | I <sub>OL</sub> = 1 mA, <b>Note 1</b>                                           |
| I <sub>OL</sub>                                                                                                                               | Sink Current at V <sub>OUT</sub> Output                            | 1.0                                        | —                      | —                      | mA    | V <sub>OL</sub> = 10% of V <sub>DD</sub>                                        |
| I <sub>OH</sub>                                                                                                                               | Source Current at V <sub>OUT</sub> Output                          | 5.0                                        | —                      | —                      | mA    | V <sub>OH</sub> = 80% of V <sub>DD</sub>                                        |
| <b>SENSE Input</b>                                                                                                                            |                                                                    |                                            |                        |                        |       |                                                                                 |
| V <sub>TH(SENSE)</sub>                                                                                                                        | SENSE Input Threshold Voltage with Respect to GND                  | 50                                         | 70                     | 90                     | mV    | <b>Note 1</b>                                                                   |
| <b>OTF Output</b>                                                                                                                             |                                                                    |                                            |                        |                        |       |                                                                                 |
| V <sub>OL</sub>                                                                                                                               | Output Low Voltage                                                 | —                                          | —                      | 0.3                    | V     | I <sub>OL</sub> = 2.5 mA                                                        |
| <b>V<sub>IN</sub>, V<sub>AS</sub> Inputs</b>                                                                                                  |                                                                    |                                            |                        |                        |       |                                                                                 |
| V <sub>C(MAX)</sub> , V <sub>OTF</sub>                                                                                                        | Voltage at V <sub>IN</sub> for 100% Duty Cycle and Overtemp. Fault | 2.5                                        | 2.65                   | 2.8                    | V     |                                                                                 |
| V <sub>C(SPAN)</sub>                                                                                                                          | V <sub>C(MAX)</sub> - V <sub>C(MIN)</sub>                          | 1.3                                        | 1.4                    | 1.5                    | V     |                                                                                 |
| V <sub>AS</sub>                                                                                                                               | Auto-shutdown Threshold                                            | V <sub>C(MAX)</sub> - V <sub>C(SPAN)</sub> | —                      | V <sub>C(MAX)</sub>    | V     |                                                                                 |
| V <sub>SHDN</sub>                                                                                                                             | Voltage Applied to V <sub>IN</sub> to Ensure Reset/Shutdown        | —                                          | —                      | V <sub>DD</sub> × 0.13 | V     |                                                                                 |
| V <sub>REL</sub>                                                                                                                              | Voltage Applied to V <sub>IN</sub> to Release Reset Mode           | V <sub>DD</sub> × 0.19                     | —                      | —                      | V     | V <sub>DD</sub> = 5V                                                            |
| V <sub>HYST</sub>                                                                                                                             | Hysteresis on V <sub>SHDN</sub> , V <sub>REL</sub>                 | —                                          | 0.01 × V <sub>DD</sub> | —                      | V     |                                                                                 |
| V <sub>HAS</sub>                                                                                                                              | Hysteresis on Auto-shutdown Comparator                             | —                                          | 70                     | —                      | mV    |                                                                                 |

**Note 1:** Ensured by design, not tested.

# TC648

## DC ELECTRICAL SPECIFICATIONS (CONTINUED)

| Electrical Characteristics: Unless otherwise specified, $T_{MIN} \leq T_A \leq T_{MAX}$ , $V_{DD} = 3.0V$ to $5.5V$ |                |     |      |     |       |                   |
|---------------------------------------------------------------------------------------------------------------------|----------------|-----|------|-----|-------|-------------------|
| Symbol                                                                                                              | Parameter      | Min | Typ  | Max | Units | Test Conditions   |
| Pulse Width Modulator                                                                                               |                |     |      |     |       |                   |
| $F_{OSC}$                                                                                                           | PWM Frequency  | 26  | 30   | 34  | Hz    | $C_F = 1.0 \mu F$ |
| $t_{STARTUP}$                                                                                                       | Start-up Timer | —   | 32/F | —   | Sec   | $C_F = 1.0 \mu F$ |

**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**

| Pin No. | Symbol           | Description                     |
|---------|------------------|---------------------------------|
| 1       | $V_{IN}$         | Analog Input                    |
| 2       | $C_F$            | Analog Output                   |
| 3       | $V_{AS}$         | Analog Input                    |
| 4       | GND              | Ground Terminal                 |
| 5       | NC               | No Internal Connection          |
| 6       | $\overline{OTF}$ | Digital (Open Collector) Output |
| 7       | $V_{OUT}$        | Digital Output                  |
| 8       | $V_{DD}$         | Power Supply Input              |

### 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  $\mu$ F 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  $\mu$ A (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 ( $\overline{OTF}$ )

$\overline{OTF}$  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  $C_F$  pin. A frequency of 30 Hz is recommended for most applications ( $C_F = 1 \mu F$ ). 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 $V_{OUT}$ Output

The  $V_{OUT}$  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  $V_{OUT}$  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 ( $C_F = 1 \mu F$ ), the resulting start-up time will be approximately one second.

### 3.4 Over-Temperature Fault ( $\overline{OTF}$ ) Output

$\overline{OTF}$  is asserted when the PWM control voltage applied to  $V_{IN}$  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.  $\overline{OTF}$  will become inactive when  $V_{IN} < V_{OTF}$ .

### 3.5 Auto-Shutdown Mode

If the voltage on  $V_{IN}$  becomes less than the voltage on  $V_{AS}$ , the fan is automatically shut off (auto-shutdown mode). The TC648 exits auto-shutdown mode when the voltage on  $V_{IN}$  becomes higher than the voltage on  $V_{AS}$  by  $V_{HAS}$  (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  $V_{AS}$  input should be grounded if auto-shutdown mode is not used.

### 3.6 Shutdown Mode (Reset)

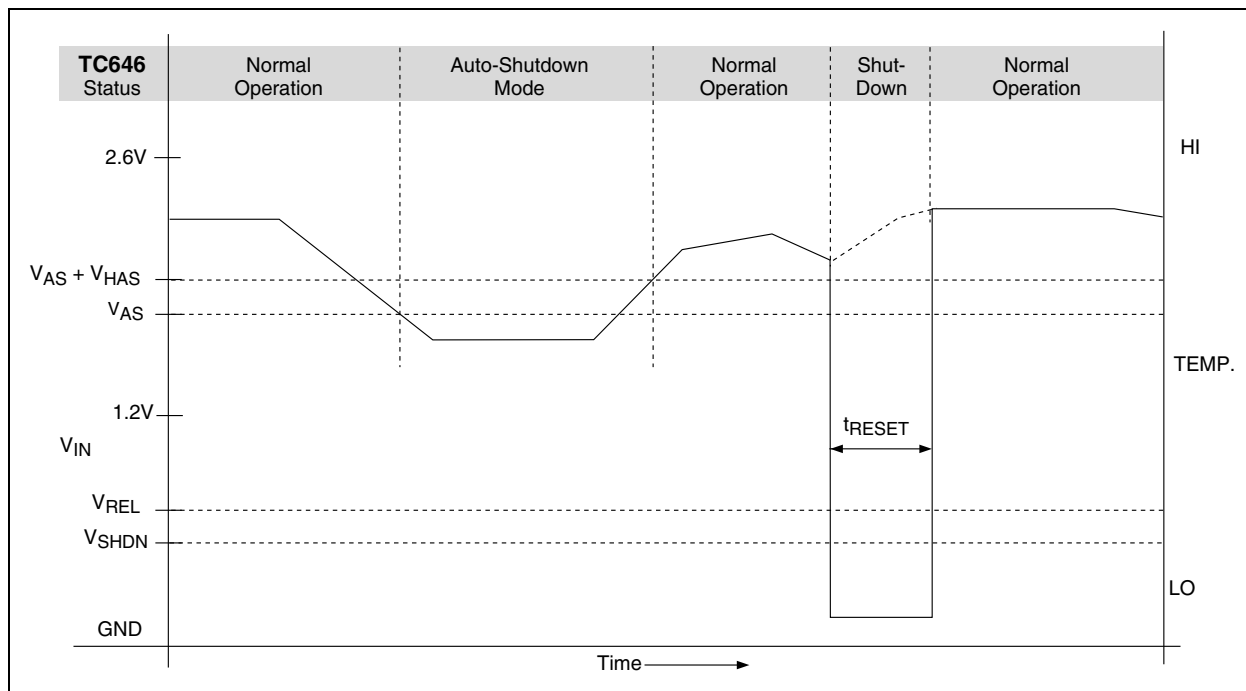
If an unconditional shutdown and/or device reset is desired, the TC648 may be placed in shutdown mode by forcing  $V_{IN}$  to a logic low (i.e.,  $V_{IN} < V_{SHDN}$ ) (see Figure 3-1). In this mode, all functions cease and the  $\overline{OTF}$  output is unconditionally inactive. The TC648 should not be shut down unless all heat producing activity in the system is at a negligible level. The TC648 exits shutdown mode when  $V_{IN}$  becomes greater than  $V_{REL}$ , the release voltage.

Entering shutdown mode also performs a complete device reset. Shutdown mode resets the TC648 into its power-up state.  $\overline{OTF}$  is unconditionally inactive in shutdown mode. Upon exiting shutdown mode ( $V_{IN} > V_{REL}$ ), the Start-up Timer will be triggered and normal operation will resume, assuming  $V_{IN} > V_{AS} + V_{HAS}$ .

**Note:** If  $V_{IN} < V_{AS}$  when the device exits shutdown mode, the fan will not restart as it will be in auto-shutdown mode.

If  $V_{IN}$  is not greater than  $(V_{AS} + V_{HAS})$  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  $V_{IN} > (V_{AS} + V_{HAS})$  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  $V_{DD}$  (50 mV at  $V_{DD} = 5.0V$ ), is designed into the  $V_{SHDN}/V_{REL}$  threshold. The levels specified for  $V_{SHDN}$  and  $V_{REL}$  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  $V_{IN}$  pin is being held low or  $V_{IN} < V_{AS} + V_{HAS}$ .



**FIGURE 3-1:** TC648 Nominal Operation.

## 4.0 SYSTEM BEHAVIOR

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

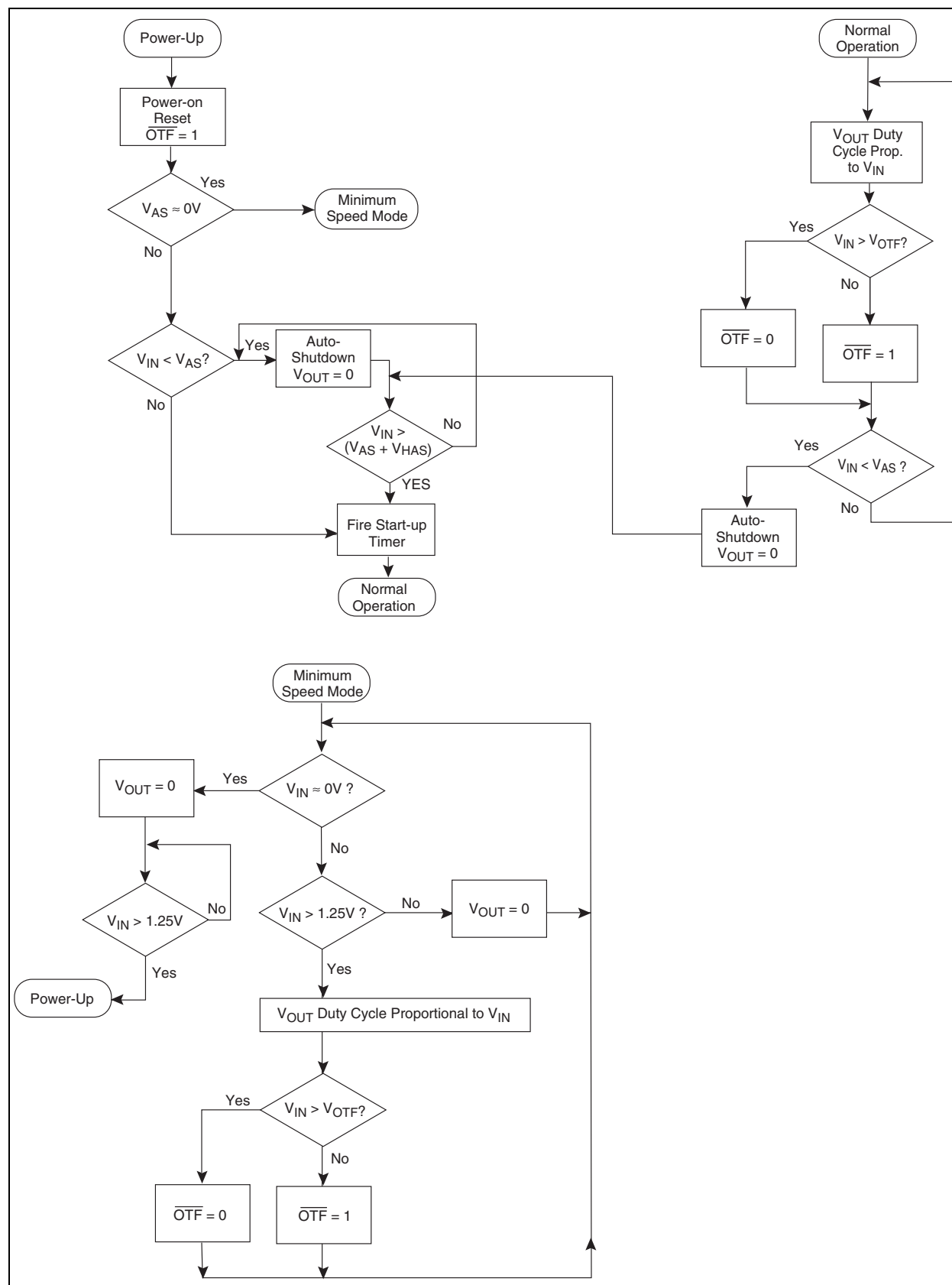
### 4.1 Power-Up

- (1) Assuming the device is not being held in shut-down or auto-shutdown mode ( $V_{IN} > V_{AS}$ ).....
- (2) Turn  $V_{OUT}$  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  $V_{OUT}$  to a duty cycle proportional to  $V_{IN}$  on a cycle by cycle basis.
- (2) If an over-temperature fault occurs, ( $V_{IN} > V_{OTF}$ ), activate  $\overline{OTF}$ ; release  $\overline{OTF}$  when  $V_{IN} < V_{OTF}$ .
- (3) Is the TC648 in shutdown or auto-shutdown mode?  
If so.....
  - a.  $V_{OUT}$  duty cycle goes to zero.
  - b.  $\overline{OTF}$  is disabled.
  - c. Exit the loop and wait for  $V_{IN} > (V_{AS} + V_{HAS})$ , then execute Power-up sequence.
- (4) End.



**FIGURE 4-1:** TC648 Behavioral Algorithm Flowcharts.

## 5.0 TYPICAL APPLICATIONS

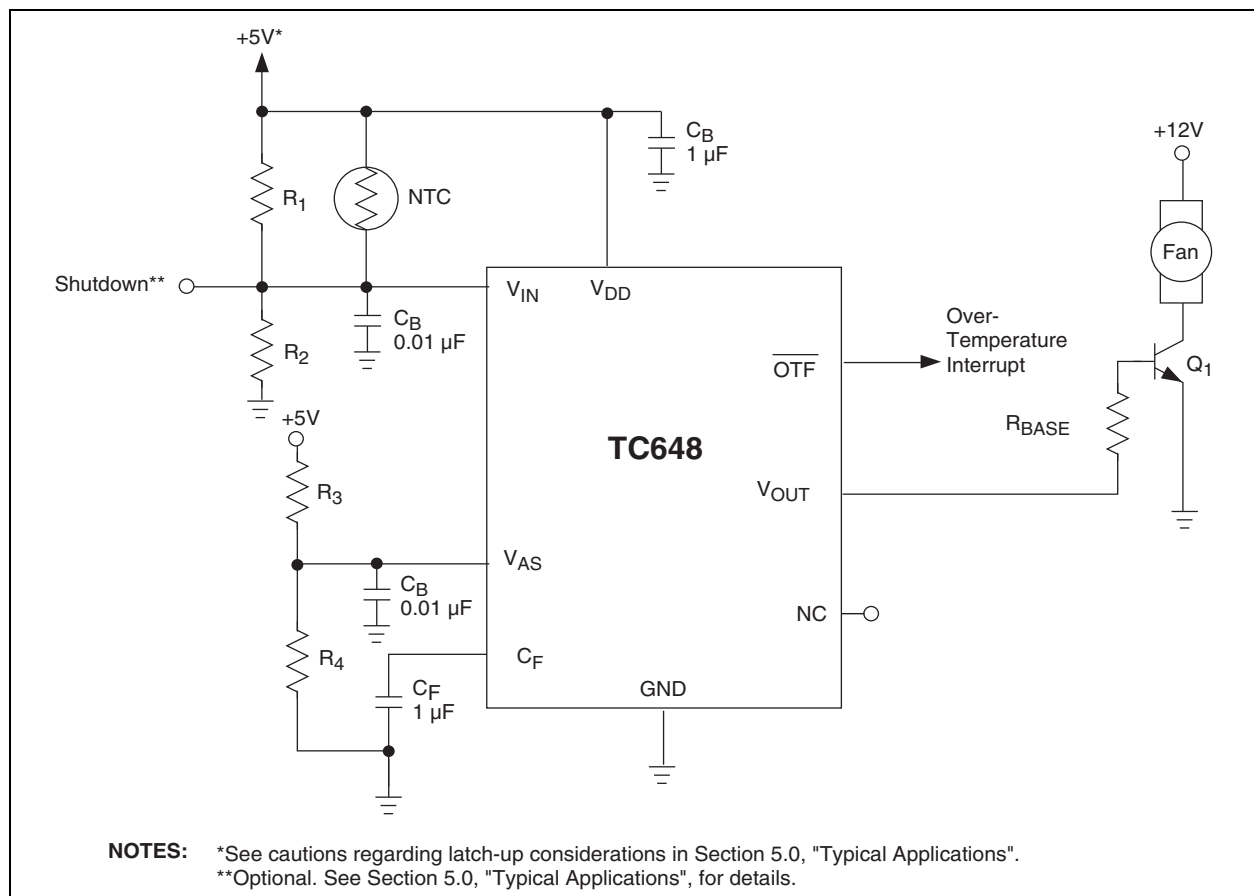
Designing with the TC648 involves the following:

- (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.

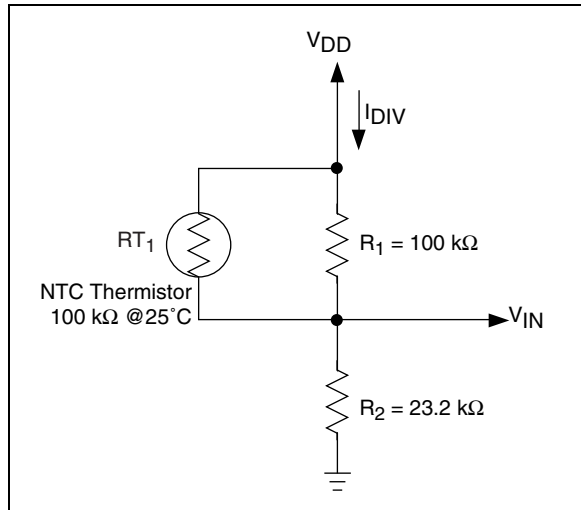
An Excel-based spreadsheet is also available for designing the thermistor network for the TC64X fan controllers. This file (TC64X Therm) is available for downloading from the Microchip website at [www.microchip.com](http://www.microchip.com).



**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.



**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 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  $V_{C(SPAN)}$  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:

## EQUATION

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

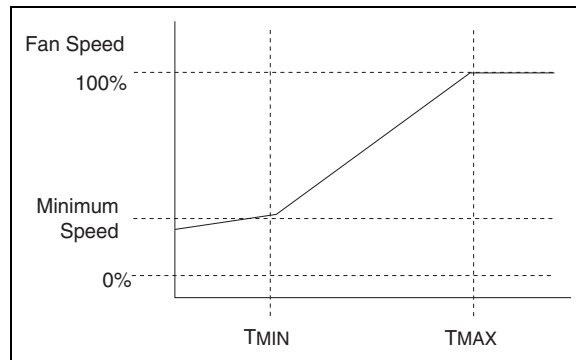
$$\frac{V_{DD} \times R_2}{R_{TEMP}(T_2) + R_2} = V(T_2)$$

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](http://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

thermistor 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:

## EQUATION

$$R_1 = (0.1)(RT_{1MIN})$$

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

## EQUATION

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

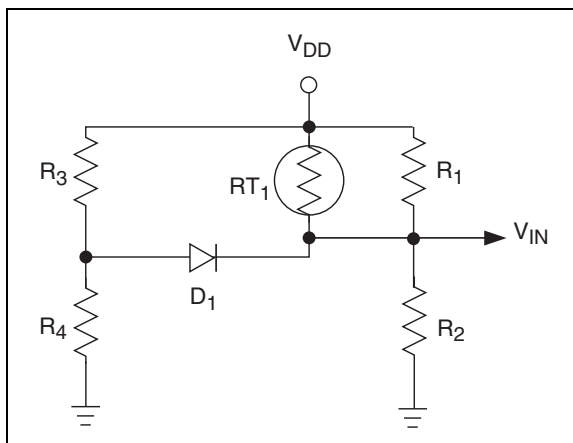
Where  $V_{MIN}$  = the value of  $V_{IN}$  required for minimum fan speed.  $V_{DD}$  = Power Supply Voltage

## EQUATION

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

Where  $RT_{1MAX}$  = 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.



**FIGURE 5-4:** Minimum Fan Speed Circuit.

## 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:

## EQUATION

$$\frac{2.65 - 1.25V}{T_2 - T_1} = \frac{V_{AS} - 1.25}{T_{AS} - T_1}$$

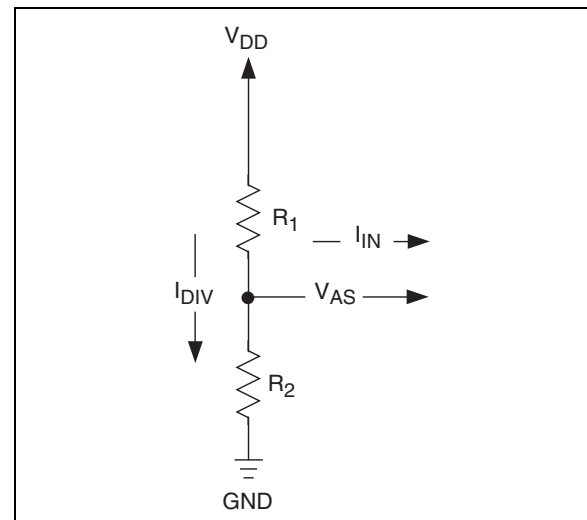
$$V_{AS} = \left( \frac{1.4V}{T_2 - T_1} \right) (T_{AS} - T_1) + 1.25$$

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

## EQUATION

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

The  $V_{AS}$  voltage may be set using a simple resistor divider, as shown in Figure 5-5.



**FIGURE 5-5:**  $V_{AS}$  Circuit.

Per Section 1.0, "Electrical Characteristics", the leakage current at the  $V_{AS}$  pin is no more than  $1\ \mu A$ . It is conservative to design for a divider current,  $I_{DIV}$ , of  $100\ \mu A$ . If  $V_{DD} = 5.0V$  then...

## EQUATION

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

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

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

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

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

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

In this case, the standard values of  $34.8\ k\Omega$  and  $15.4\ k\Omega$  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:

$$V_{OH} = V_{BE(SAT)} + V_{R_{BASE}}$$

$$V_{R_{BASE}} = R_{BASE} \times I_{BASE}$$

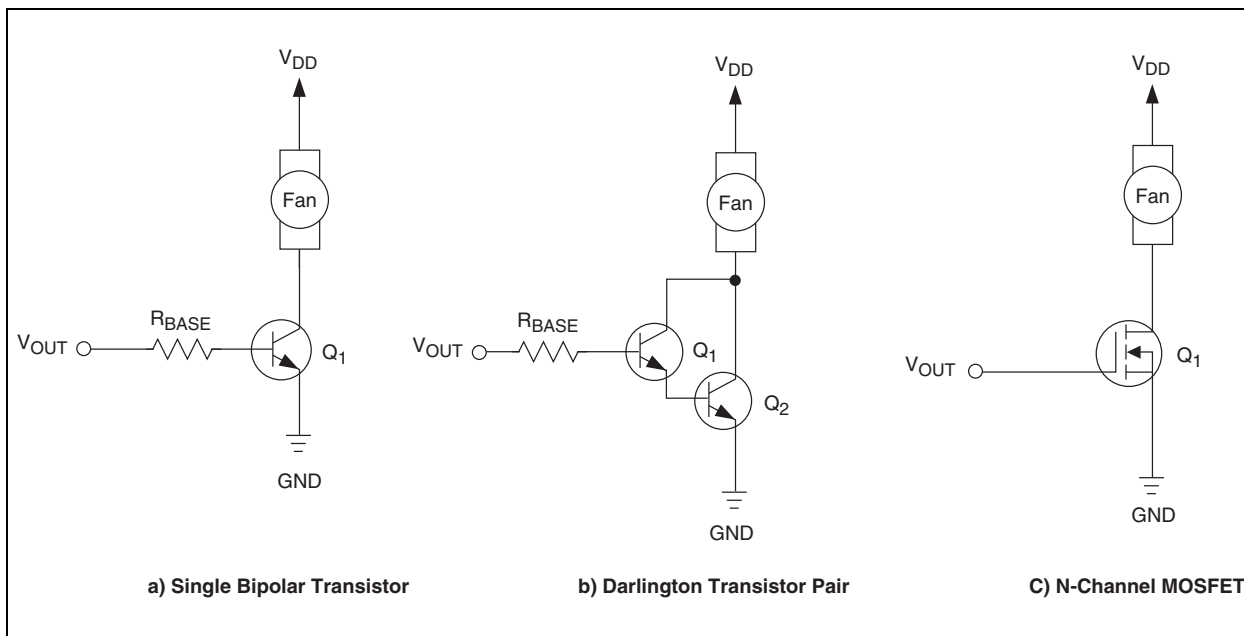
$$I_{BASE} = I_{FAN} / h_{FE}$$

$V_{OH}$  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  $+12V$ .

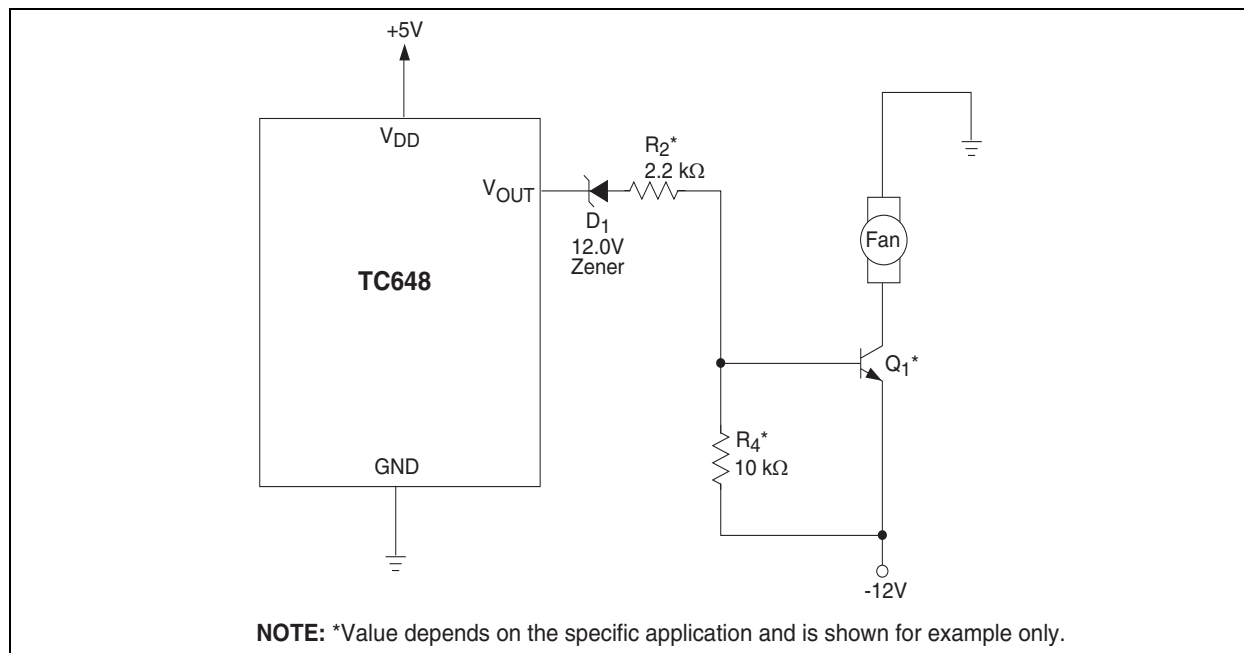


**FIGURE 5-6:** Output Drive Transistor Circuit Topologies.

**TABLE 5-1:** TRANSISTORS AND MOSFETS FOR  $Q_1$  ( $V_{DD} = 5V$ )

| Device    | Package | Max. $V_{BE(sat)}/V_{GS}$<br>(V) | Min. $H_{FE}$ | $V_{CE0}/V_{DS}$<br>(V) | Fan Current<br>(mA) | Suggested<br>$R_{BASE}$ ( $\Omega$ ) |
|-----------|---------|----------------------------------|---------------|-------------------------|---------------------|--------------------------------------|
| MMBT2222A | SOT-23  | 1.2                              | 50            | 40                      | 150                 | 800                                  |
| MPS2222A  | TO-92   | 1.2                              | 50            | 40                      | 150                 | 800                                  |
| MPS6602   | TO-92   | 1.2                              | 50            | 40                      | 500                 | 301                                  |
| SI2302    | SOT-23  | 2.5                              | NA            | 20                      | 500                 | <b>Note 1</b>                        |
| MGSF1N02E | SOT-23  | 2.5                              | NA            | 20                      | 500                 | <b>Note 1</b>                        |
| SI4410    | SO-8    | 4.5                              | NA            | 30                      | 1000                | <b>Note 1</b>                        |
| SI2308    | SOT-23  | 4.5                              | NA            | 60                      | 500                 | <b>Note 1</b>                        |

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



**FIGURE 5-7:** Powering the Fan from a -12V Supply.

## 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  $V_{DD}$  supply powers up first. If possible, the networks attached to  $V_{IN}$  and  $V_{AS}$  should connect to the  $V_{DD}$  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  $V_{IN}$  and  $V_{AS}$  inputs may cause erroneous operation of the  $\overline{OTF}$  output. As a result, these inputs should be bypassed with a 0.01  $\mu F$  capacitor mounted as close to the package as possible. This is especially true of  $V_{IN}$ , which is usually driven from a high impedance source (such as a thermistor). Additionally, the  $V_{DD}$  input should be bypassed with a 1  $\mu F$  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  $R_1$  and  $R_2$  based on using an NTC having a resistance of 10 k $\Omega$  at  $T_{MIN}$  (25°C) and 4.65 k $\Omega$  at  $T_{MAX}$  (45°C) (see Figure 5-8).

$$R_1 = 20.5 \text{ k}\Omega$$

$$R_2 = 3.83 \text{ k}\Omega$$

**Step 2.** Set auto-shutdown level.

$$V_{AS} = 1.8V$$

$$\text{Limit the divider current to } 100 \mu A$$

$$R_5 = 33 \text{ k}\Omega$$

$$R_6 = 18 \text{ k}\Omega$$

**Step 3.** Design the output circuit

$$\text{Maximum fan motor current} = 250 \text{ mA.}$$

$$Q_1 \text{ beta is chosen at } 50 \text{ from which}$$

$$R_7 = 800 \Omega.$$

## 5.7 Minimum Speed Mode Design Example

Given:

$$\text{Minimum speed} = 40\%(1.8V)$$

$$T_{MIN} = 30^\circ C, T_{MAX} = 95^\circ C$$

$$\text{Thermistor} = 100 \text{ k}\Omega \text{ at } 25^\circ C$$

$$RT_{MIN} = 79.4 \text{ k}\Omega, RT_{MAX} = 6.5 \text{ k}\Omega$$

**Step 1:** Calculate  $R_1$ :

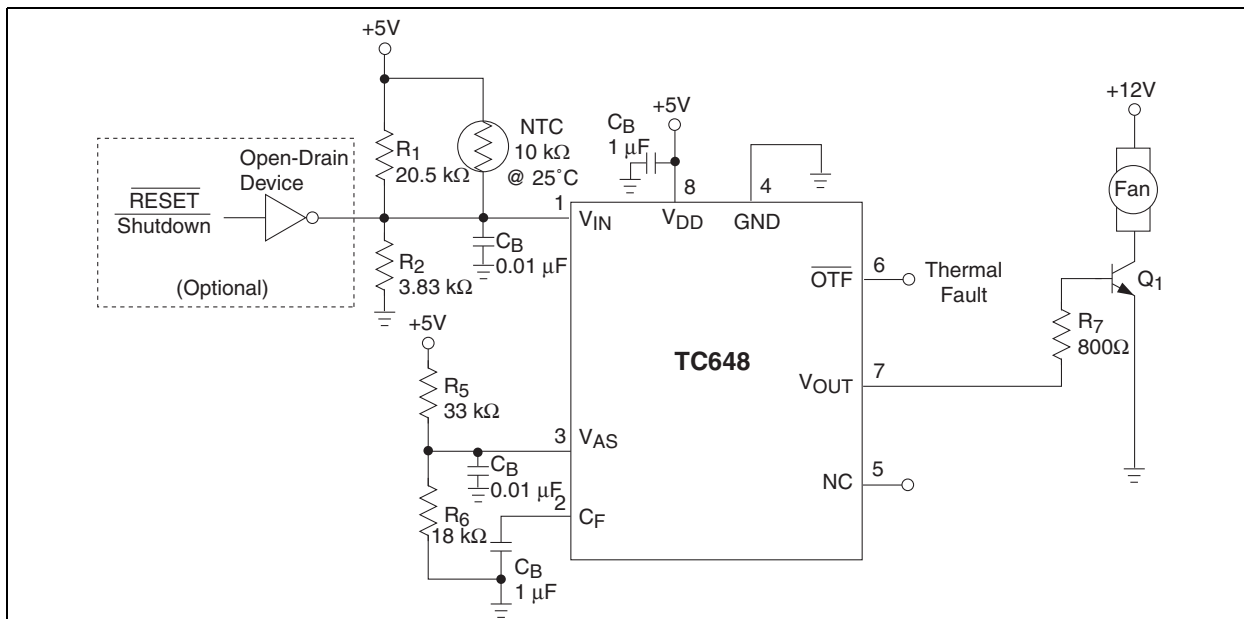
$$R_1 = 7.9 \text{ k}\Omega \text{ (Use closest standard value: } 7.87 \text{ k}\Omega)$$

Calculate  $R_2$ :

$$R_2 = 4.05 \text{ k}\Omega \text{ (Use closest standard value: } 4.02 \text{ k}\Omega)$$

**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 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  $\overline{OTF}$  output can be connected to the processor's interrupt input, or to another I/O pin, for polled operation.

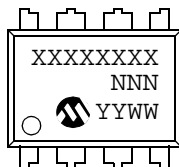
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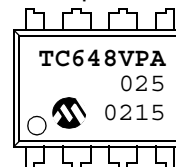
## 6.0 PACKAGING INFORMATION

### 6.1 Package Marking Information

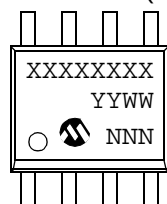
8-Lead PDIP (300 mil)



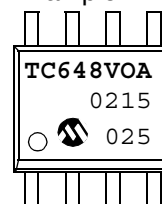
Example:



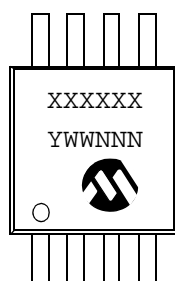
8-Lead SOIC (150 mil)



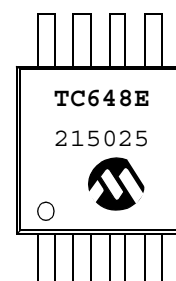
Example:



8-Lead MSOP



Example:



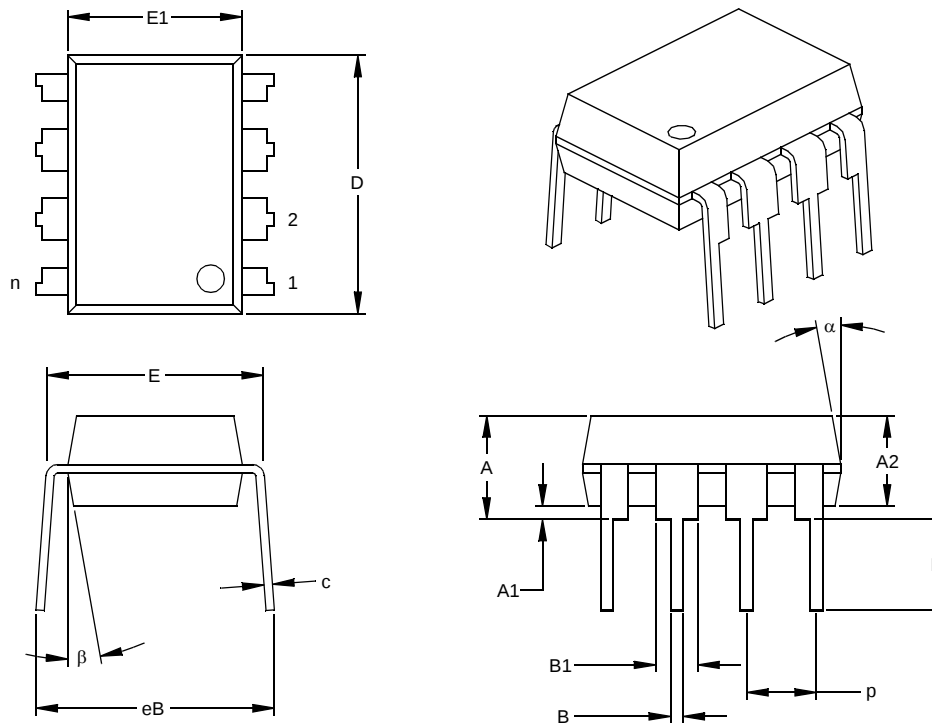
|                |        |                                                                                                                  |
|----------------|--------|------------------------------------------------------------------------------------------------------------------|
| <b>Legend:</b> | XX...X | Customer-specific information                                                                                    |
|                | Y      | Year code (last digit of calendar year)                                                                          |
|                | YY     | Year code (last 2 digits of calendar year)                                                                       |
|                | WW     | Week code (week of January 1 is week '01')                                                                       |
|                | NNN    | Alphanumeric traceability code                                                                                   |
|                | (e3)   | Pb-free JEDEC designator for Matte Tin (Sn)                                                                      |
|                | *      | This package is Pb-free. The Pb-free JEDEC designator (e3) can be found on the outer packaging for this package. |

**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.

# TC648

## 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/packageing>



| Units                      |      | INCHES* |      |      | MILLIMETERS |      |       |
|----------------------------|------|---------|------|------|-------------|------|-------|
| Dimension Limits           |      | MIN     | NOM  | MAX  | MIN         | NOM  | MAX   |
| Number of Pins             | n    |         | 8    |      |             | 8    |       |
| Pitch                      | p    |         | .100 |      |             | 2.54 |       |
| Top to Seating Plane       | A    | .140    | .155 | .170 | 3.56        | 3.94 | 4.32  |
| Molded Package Thickness   | A2   | .115    | .130 | .145 | 2.92        | 3.30 | 3.68  |
| Base to Seating Plane      | A1   | .015    |      |      | 0.38        |      |       |
| Shoulder to Shoulder Width | E    | .300    | .313 | .325 | 7.62        | 7.94 | 8.26  |
| Molded Package Width       | E1   | .240    | .250 | .260 | 6.10        | 6.35 | 6.60  |
| Overall Length             | D    | .360    | .373 | .385 | 9.14        | 9.46 | 9.78  |
| Tip to Seating Plane       | L    | .125    | .130 | .135 | 3.18        | 3.30 | 3.43  |
| Lead Thickness             | c    | .008    | .012 | .015 | 0.20        | 0.29 | 0.38  |
| Upper Lead Width           | B1   | .045    | .058 | .070 | 1.14        | 1.46 | 1.78  |
| Lower Lead Width           | B    | .014    | .018 | .022 | 0.36        | 0.46 | 0.56  |
| Overall Row Spacing        | § eB | .310    | .370 | .430 | 7.87        | 9.40 | 10.92 |
| Mold Draft Angle Top       | α    | 5       | 10   | 15   | 5           | 10   | 15    |
| Mold Draft Angle Bottom    | β    | 5       | 10   | 15   | 5           | 10   | 15    |

\* Controlling Parameter

§ Significant Characteristic

### Notes:

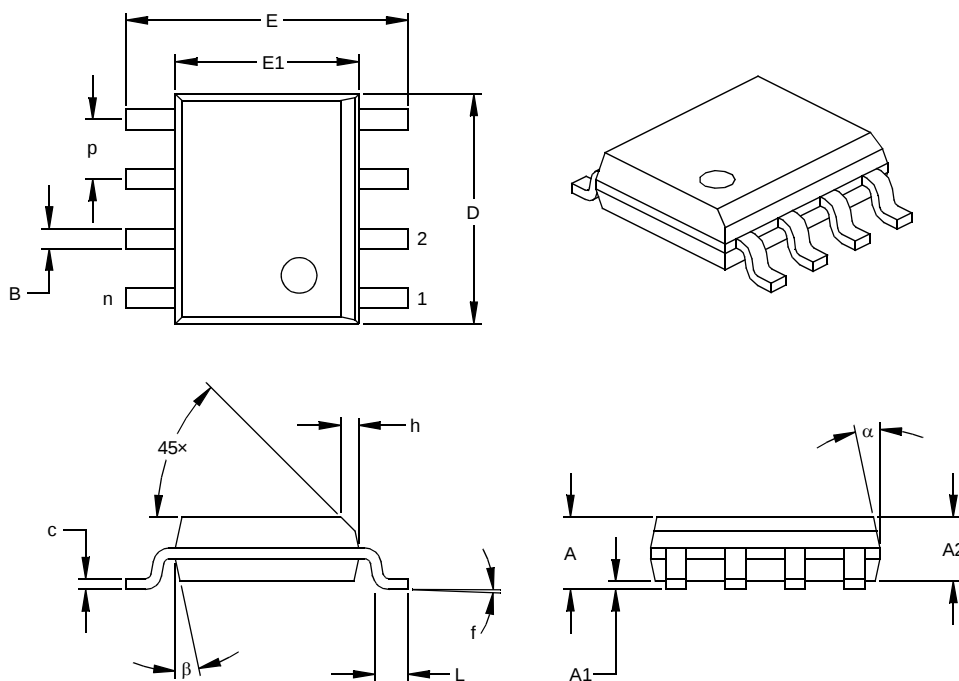
Dimensions D and E1 do not include mold flash or protrusions. Mold flash or protrusions shall not exceed .010" (0.254mm) per side.

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>



| Units                    |    | INCHES* |      |      | MILLIMETERS |      |      |
|--------------------------|----|---------|------|------|-------------|------|------|
| Dimension Limits         |    | MIN     | NOM  | MAX  | MIN         | NOM  | MAX  |
| Number of Pins           | n  |         | 8    |      |             | 8    |      |
| Pitch                    | p  |         | .050 |      |             | 1.27 |      |
| Overall Height           | A  | .053    | .061 | .069 | 1.35        | 1.55 | 1.75 |
| Molded Package Thickness | A2 | .052    | .056 | .061 | 1.32        | 1.42 | 1.55 |
| Standoff §               | A1 | .004    | .007 | .010 | 0.10        | 0.18 | 0.25 |
| Overall Width            | E  | .228    | .237 | .244 | 5.79        | 6.02 | 6.20 |
| Molded Package Width     | E1 | .146    | .154 | .157 | 3.71        | 3.91 | 3.99 |
| Overall Length           | D  | .189    | .193 | .197 | 4.80        | 4.90 | 5.00 |
| Chamfer Distance         | h  | .010    | .015 | .020 | 0.25        | 0.38 | 0.51 |
| Foot Length              | L  | .019    | .025 | .030 | 0.48        | 0.62 | 0.76 |
| Foot Angle               | f  | 0       | 4    | 8    | 0           | 4    | 8    |
| Lead Thickness           | c  | .008    | .009 | .010 | 0.20        | 0.23 | 0.25 |
| Lead Width               | B  | .013    | .017 | .020 | 0.33        | 0.42 | 0.51 |
| Mold Draft Angle Top     | α  | 0       | 12   | 15   | 0           | 12   | 15   |
| Mold Draft Angle Bottom  | β  | 0       | 12   | 15   | 0           | 12   | 15   |

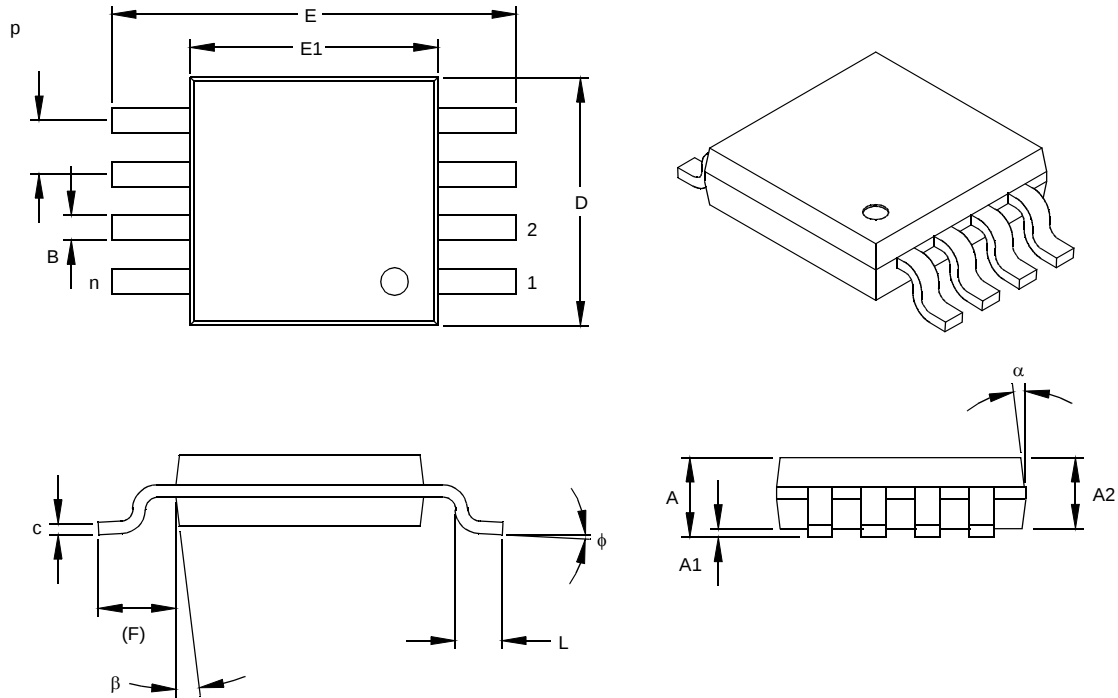
\* Controlling Parameter  
§ Significant Characteristic

**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>



| Units                    |    | INCHES |      |      | MILLIMETERS* |      |      |
|--------------------------|----|--------|------|------|--------------|------|------|
| Dimension Limits         |    | MIN    | NOM  | MAX  | MIN          | NOM  | MAX  |
| Number of Pins           | n  |        | 8    |      |              |      | 8    |
| Pitch                    | p  | .026   |      |      | 0.65         |      |      |
| Overall Height           | A  |        |      | .044 |              |      | 1.18 |
| Molded Package Thickness | A2 | .030   | .034 | .038 | 0.76         | 0.86 | 0.97 |
| Standoff §               | A1 | .002   |      | .006 | 0.05         |      | 0.15 |
| Overall Width            | E  | .184   | .193 | .200 | 4.67         | 4.90 | 5.08 |
| Molded Package Width     | E1 | .114   | .118 | .122 | 2.90         | 3.00 | 3.10 |
| Overall Length           | D  | .114   | .118 | .122 | 2.90         | 3.00 | 3.10 |
| Foot Length              | L  | .016   | .022 | .028 | 0.40         | 0.55 | 0.70 |
| Footprint (Reference)    | F  | .035   | .037 | .039 | 0.90         | 0.95 | 1.00 |
| Foot Angle               | φ  | 0      |      | 6    | 0            |      | 6    |
| Lead Thickness           | c  | .004   | .006 | .008 | 0.10         | 0.15 | 0.20 |
| Lead Width               | B  | .010   | .012 | .016 | 0.25         | 0.30 | 0.40 |
| Mold Draft Angle Top     | α  |        | 7    |      |              | 7    |      |
| Mold Draft Angle Bottom  | β  |        | 7    |      |              | 7    |      |

\*Controlling Parameter

§ Significant Characteristic

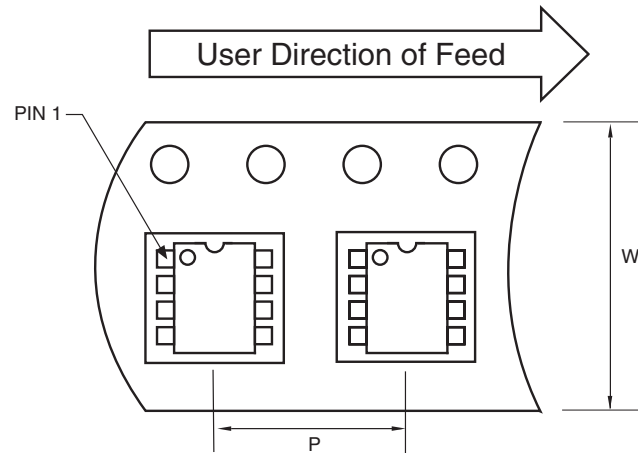
**Notes:**

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

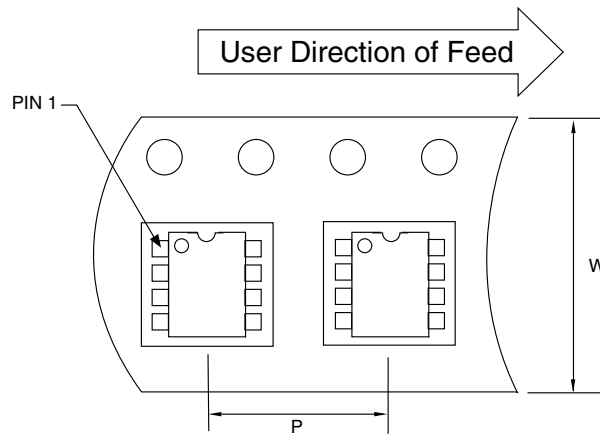


Standard Reel Component Orientation  
for 713 Suffix Device

#### Carrier Tape, Number of Components Per Reel and Reel Size

| Package        | Carrier Width (W) | Pitch (P) | Part Per Full Reel | Reel Size |
|----------------|-------------------|-----------|--------------------|-----------|
| 8-Pin SOIC (N) | 12 mm             | 8 mm      | 2500               | 13 in     |

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



Standard Reel Component Orientation  
for 713 Suffix Device

#### Carrier Tape, Number of Components Per Reel and Reel Size

| Package    | Carrier Width (W) | Pitch (P) | Part Per Full Reel | Reel Size |
|------------|-------------------|-----------|--------------------|-----------|
| 8-Pin MSOP | 12 mm             | 8 mm      | 2500               | 13 in     |

## 7.0 REVISION HISTORY

### Revision D (December 2012)

Added a note to each package outline drawing.

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

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

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7. How would you improve this document?

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## PRODUCT IDENTIFICATION SYSTEM

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

| <u>PART NO.</u>    |                                                                           | <u>X</u>                                     | <u>/XX</u> |
|--------------------|---------------------------------------------------------------------------|----------------------------------------------|------------|
| Device             |                                                                           | Temperature Range                            | Package    |
| 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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# TC648

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NOTES:

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