PWM Fan Speed Controllers With Auto-Shutdown, Fan Restart and FanSense™ Technology for Fault Detection

Features

- Temperature-Proportional Fan Speed for Acoustic Noise Reduction and Longer Fan Life
- Efficient PWM Fan Drive
- 3.0V to 5.5V Supply Range:
  - Fan Voltage Independent of TC646B/TC648B/TC649B Supply Voltage
  - Supports any Fan Voltage
- FanSense™ Fault Detection Circuit Protects Against Fan Failure and Aids System Testing (TC646B/TC649B)
- Automatic Shutdown Mode for “Green” Systems
- Supports Low Cost NTC/PTC Thermistors
- Over-Temperature Indication (TC646B/TC648B)
- Fan Auto-Restart
- Space-Saving 8-Pin MSOP Package

Applications

- Personal Computers & Servers
- LCD Projectors
- Datacom & Telecom Equipment
- Fan Trays
- File Servers
- General-Purpose Fan Speed Control

Description

The TC646B/TC648B/TC649B devices are new versions of the existing TC646/TC648/TC649 fan speed controllers. These devices are switch-mode fan speed controllers that incorporate a new fan auto-restart function. Temperature-proportional speed control is accomplished using pulse width modulation. A thermistor (or other voltage output temperature sensor) connected to the VIN input supplies the required control voltage of 1.20V to 2.60V (typical) for 0% to 100% PWM duty cycle. The auto-shutdown threshold/temperature is set by a simple resistor divider on the VAS input. An integrated Start-Up Timer ensures reliable fan motor startup at turn-on, coming out of shutdown mode, auto-shutdown mode or following a transient fault. A logic low applied to VIN (pin 1) causes fan shutdown.

The TC646B and TC649B also feature Microchip Technology’s proprietary FanSense technology for increasing system reliability. In normal fan operation, a pulse train is present at SENSE (pin 5). A missing-pulse detector monitors this pin during fan operation. A stalled, open or unconnected fan causes the TC646B/TC649B device to turn the VOUT output on full (100% duty cycle). If the fan fault persists (a fan current pulse is not detected within a 32/f period), the FAULT output goes low. Even with the FAULT output low, the VOUT output is on full during the fan fault condition in order to attempt to restart the fan. FAULT (TC646B) or OTF (TC648B) is also asserted if the PWM reaches 100% duty cycle, indicating that maximum cooling capability has been reached and a possible overheating condition exists.

The TC646B, TC648B and TC649B devices are available in 8-pin plastic MSOP, SOIC and PDIP packages. The specified temperature range of these devices is -40 to +85ºC.
Functional Block Diagram

**TC646B/TC649B**

- **VOTF** comparator is for the TC646B device only.
- **Note:** The VOTF comparator is for the TC646B device only.

**TC648B**

- **Note:** The VOTF comparator is for the TC646B device only.

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TC646B/TC648B/TC649B

1.0 ELECTRICAL CHARACTERISTICS

Absolute Maximum Ratings†

Supply Voltage (VDD) ....................................................... 6.0V
Input Voltage, Any Pin................(GND - 0.3V) to (V DD +0.3V)
Operating Temperature Range .................... - 40°C to +125°C
Maximum Junction Temperature, Tj ........................... +150°C
ESD Protection on all pins ........................................... > 3 kV
† Notice: Stresses above those listed under “Maximum Ratings” may cause permanent damage to the device. This is a stress rating only and functional operation of the device at those or any other conditions above those indicated in the operational listings of this specification is not implied. Exposure to maximum rating conditions for extended periods may affect device reliability.

PIN FUNCTION TABLE

<table>
<thead>
<tr>
<th>Name</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>VIN</td>
<td>Analog Input</td>
</tr>
<tr>
<td>CF</td>
<td>Analog Output</td>
</tr>
<tr>
<td>VAS</td>
<td>Analog Input</td>
</tr>
<tr>
<td>GND</td>
<td>Ground</td>
</tr>
<tr>
<td>SENSE/NC</td>
<td>Analog Input. No Connect (NC) for TC648B</td>
</tr>
<tr>
<td>FAULT/OTF</td>
<td>Digital (Open-Drain) Output OTF for TC648B</td>
</tr>
<tr>
<td>VOUT</td>
<td>Digital Output</td>
</tr>
<tr>
<td>VDD</td>
<td>Power Supply Input</td>
</tr>
</tbody>
</table>

ELECTRICAL CHARACTERISTICS

Electrical Specifications: Unless otherwise specified, all limits are specified for -40°C < T A < +85°C, VDD = 3.0V to 5.5V.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Sym</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply Voltage V DD</td>
<td></td>
<td>3.0</td>
<td>—</td>
<td>5.5</td>
<td>V</td>
</tr>
<tr>
<td>Supply Current, Operating I DD</td>
<td></td>
<td>—</td>
<td>200</td>
<td>400</td>
<td>µA</td>
</tr>
<tr>
<td>Supply Current, Shutdown Mode I DD(SHDN)</td>
<td></td>
<td>—</td>
<td>30</td>
<td>—</td>
<td>µA</td>
</tr>
<tr>
<td>VOUT Output</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sink Current at VOUT Output I OL</td>
<td></td>
<td>1.0</td>
<td>—</td>
<td>—</td>
<td>mA</td>
</tr>
<tr>
<td>Source Current at VOUT Output I OH</td>
<td></td>
<td>5.0</td>
<td>—</td>
<td>—</td>
<td>mA</td>
</tr>
<tr>
<td>VIN, VAS Inputs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input Voltage at VIN for 100% PWM Duty Cycle (V_{C(MAX)})</td>
<td></td>
<td>2.45</td>
<td>2.60</td>
<td>2.75</td>
<td>V</td>
</tr>
<tr>
<td>Over-Temperature Indication Threshold (V_{OTF})</td>
<td></td>
<td></td>
<td></td>
<td>(V_{C(MAX)} + 20 mV)</td>
<td>V</td>
</tr>
<tr>
<td>Over-Temperature Indication Threshold Hysteresis (V_{OTF-HYS})</td>
<td></td>
<td></td>
<td></td>
<td>80</td>
<td>mV</td>
</tr>
<tr>
<td>(V_{C(MAX)} - V_{C(MIN)}) (V_{C(SPAN)})</td>
<td></td>
<td>1.3</td>
<td>1.4</td>
<td>1.5</td>
<td>V</td>
</tr>
<tr>
<td>Hysteresis on Auto-Shutdown Comparator (V_{HAS})</td>
<td></td>
<td></td>
<td></td>
<td>70</td>
<td>mV</td>
</tr>
<tr>
<td>Auto-Shutdown Threshold (V_{AS})</td>
<td></td>
<td></td>
<td>(V_{C(MAX)} - V_{C(SPAN)})</td>
<td>—</td>
<td>(V_{C(MAX)})</td>
</tr>
<tr>
<td>Voltage Applied to VIN to Ensure Shutdown Mode (V_{SHDN})</td>
<td></td>
<td></td>
<td>—</td>
<td>—</td>
<td>(V_{DD} \times 0.13)</td>
</tr>
<tr>
<td>Voltage Applied to VIN to Release Shutdown Mode (V_{REL})</td>
<td></td>
<td></td>
<td></td>
<td>(V_{DD} \times 0.19)</td>
<td>—</td>
</tr>
<tr>
<td>Hysteresis on (V_{SHDN} - V_{REL}) (V_{HYST})</td>
<td></td>
<td></td>
<td></td>
<td>0.03 \times V_{DD}</td>
<td>—</td>
</tr>
<tr>
<td>(VIN-VAS) Input Leakage I IN</td>
<td></td>
<td>-1.0</td>
<td>—</td>
<td>+1.0</td>
<td>µA</td>
</tr>
</tbody>
</table>

Note 1: Ensured by design, tested during characterization.
Note 2: For \(V_{DD} < 3.7V\), tSTARTUP and tMP timers are typically 13/f.
**ELECTRICAL CHARACTERISTICS (CONTINUED)**

**Electrical Specifications:** Unless otherwise specified, all limits are specified for \(-40^\circ C < T_A < +85^\circ C, V_{DD} = 3.0V\) to 5.5V.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Sym</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulse-Width Modulator</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PWM Frequency</td>
<td>f_{PWM}</td>
<td>26</td>
<td>30</td>
<td>34</td>
<td>Hz</td>
<td>(C_F = 1.0 \mu F)</td>
</tr>
</tbody>
</table>

**SENSE Input (TC646B & TC649B)**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>SENSE Input Threshold Voltage with Respect to GND</td>
<td>50</td>
<td>70</td>
<td>90</td>
<td>mV</td>
</tr>
<tr>
<td>Blanking time to ignore pulse due to (V_{OUT}) turn-on</td>
<td></td>
<td>3.0</td>
<td></td>
<td>(\mu)sec</td>
</tr>
</tbody>
</table>

**FAULT / OTF Output**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output Low Voltage</td>
<td></td>
<td></td>
<td>0.3</td>
<td>V</td>
<td>(I_{OL} = 2.5) mA</td>
</tr>
<tr>
<td>Missing Pulse Detector Timer</td>
<td></td>
<td>32/f</td>
<td></td>
<td>sec</td>
<td>TC646B and TC649B, Note 2</td>
</tr>
<tr>
<td>Start-up Timer</td>
<td></td>
<td>32/f</td>
<td></td>
<td>sec</td>
<td>Note 2</td>
</tr>
<tr>
<td>Diagnostic Timer</td>
<td></td>
<td>3/f</td>
<td></td>
<td>sec</td>
<td>TC646B and TC649B</td>
</tr>
</tbody>
</table>

**Note 1:** Ensured by design, tested during characterization.

**Note 2:** For \(V_{DD} < 3.7V\), \(t_{STARTUP}\) and \(t_{MP}\) timers are typically 13/f.

**TEMPERATURE SPECIFICATIONS**

**Electrical Characteristics:** Unless otherwise noted, all parameters apply at \(V_{DD} = 3.0V\) to 5.5V.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Sym</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature Ranges</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specified Temperature Range</td>
<td></td>
<td>-40</td>
<td></td>
<td>+85</td>
<td>°C</td>
<td></td>
</tr>
<tr>
<td>Operating Temperature Range</td>
<td></td>
<td>-40</td>
<td></td>
<td>+125</td>
<td>°C</td>
<td></td>
</tr>
<tr>
<td>Storage Temperature Range</td>
<td></td>
<td>-65</td>
<td></td>
<td>+150</td>
<td>°C</td>
<td></td>
</tr>
</tbody>
</table>

**Thermal Package Resistances**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Sym</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal Package Resistance, 8-Pin MSOP</td>
<td>(\theta_{JA})</td>
<td></td>
<td>200</td>
<td></td>
<td>°C/W</td>
<td></td>
</tr>
<tr>
<td>Thermal Package Resistance, 8-Pin SOIC</td>
<td>(\theta_{JA})</td>
<td></td>
<td>155</td>
<td></td>
<td>°C/W</td>
<td></td>
</tr>
<tr>
<td>Thermal Package Resistance, 8-Pin PDIP</td>
<td>(\theta_{JA})</td>
<td></td>
<td>125</td>
<td></td>
<td>°C/W</td>
<td></td>
</tr>
</tbody>
</table>
TIMING SPECIFICATIONS

FIGURE 1-1: TC646B/TC648B/TC649B Start-up Timing.


FIGURE 1-3: Recovery From Fan Fault (TC646B and TC649B).
FIGURE 1-4: TC646B/TC648B/TC649B Electrical Characteristics Test Circuit.

Note: C5 and C7 are adjusted to get the necessary 1 µF value.
2.0 TYPICAL PERFORMANCE CURVES

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

Note: Unless otherwise indicated, \( V_{DD} = 5\, V \), \( T_A = 25^\circ C \).

**FIGURE 2-1:** \( I_{DD} \) vs. Temperature.

**FIGURE 2-2:** PWM Sink Current \( (I_{OL}) \) vs. \( V_{OL} \).

**FIGURE 2-3:** PWM Source Current \( (I_{OH}) \) vs. \( V_{DD} - V_{OH} \).

**FIGURE 2-4:** PWM Frequency vs. Temperature.

**FIGURE 2-5:** \( I_{DD} \) vs. \( V_{DD} \).

**FIGURE 2-6:** \( I_{DD} \) Shutdown vs. Temperature.
Note: Unless otherwise indicated, V_{DD} = 5V, T_{A} = 25°C.

FIGURE 2-7: \( FAULT / OTF \ \text{V}_{OL} \) vs. Temperature.

FIGURE 2-8: \( V_{C(MAX)} \) vs. Temperature.

FIGURE 2-9: \( V_{C(MIN)} \) vs. Temperature.

FIGURE 2-10: Sense Threshold \( (V_{TH(SENSE)}) \) vs. Temperature.

FIGURE 2-11: \( FAULT / OTF \ \text{I}_{OL} \) vs. \text{V}_{OL}.

FIGURE 2-12: PWM Source Current \( (I_{OH}) \) vs. Temperature.
Note: Unless otherwise indicated, $V_{DD} = 5\text{V}$, $T_A = 25^\circ\text{C}$.

**FIGURE 2-13:** PWM Sink Current ($I_{OL}$) vs. Temperature.

**FIGURE 2-14:** $V_{SHDN}$ Threshold vs. Temperature.

**FIGURE 2-15:** $V_{REL}$ Threshold vs. Temperature.

**FIGURE 2-16:** $V_{OTF}$ Threshold vs. Temperature.

**FIGURE 2-17:** Over-Temperature Hysteresis ($V_{OTF-HYS}$) vs. Temperature.
3.0 PIN FUNCTIONS

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

TABLE 3-1: PIN FUNCTION TABLE

<table>
<thead>
<tr>
<th>Pin</th>
<th>Name</th>
<th>Function</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</td>
</tr>
<tr>
<td>5</td>
<td>SENSE/NC</td>
<td>Analog Input/No Connect. NC for TC648B.</td>
</tr>
<tr>
<td>6</td>
<td>FAULT/OTF</td>
<td>Digital (Open-Drain) Output OTF for TC648B</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>

3.1 Analog Input (V IN)

The thermistor network (or other temperature sensor) connects to V IN. A voltage range of 1.20V to 2.60V (typical) on this pin drives an active duty cycle of 0% to 100% on the V OUT pin. The TC646B, TC648B and TC649B devices enter shutdown mode when 0 \( \leq \) V IN \( \leq \) V SHDN. During shutdown, the FAULT/OTF output is inactive and supply current falls to 30 µA (typical).

3.2 Analog Output (C F)

C F is the positive terminal for the PWM ramp generator timing capacitor. The recommended value for the C F capacitor is 1.0 µF for 30 Hz PWM operation.

3.3 Analog Input (V AS)

An external resistor divider connected to V AS sets the auto-shutdown threshold. Auto-shutdown occurs when V IN < V AS. The fan is automatically restarted when V IN > (V AS + V HAS). During auto-shutdown, the FAULT/OTF output is inactive and supply current falls to 30 µA (typical).

3.4 Analog Input (SENSE)

Pulses are detected at SENSE as fan rotation chops the current through a sense resistor. The absence of pulses indicates a fan fault condition.

3.5 Digital (Open-Drain) Output (FAULT/OTF)

FAULT/OTF goes low to indicate a fault condition. When FAULT goes low due to a fan fault (TC646B and TC649B devices), the output will remain low until the fan fault condition has been removed (16 pulses have been detected at the SENSE pin in a 32/f period). For the TC646B and TC648B devices, the FAULT/OTF output will also be asserted when the V IN voltage reaches the V OTF threshold of 2.62V (typical). This gives an over-temperature/100% fan speed indication.

3.6 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. During a fan fault condition, the V OUT output is continuously on.

3.7 Power Supply Input (V DD)

The V DD pin with respect to GND provides power to the device. This bias supply voltage may be independent of the fan power supply.

3.8 Ground (GND)

Ground terminal.

3.9 No Connect (NC)

No internal connection.
4.0 DEVICE OPERATION

The TC646B/TC648B/TC649B devices are a family of temperature-proportional, PWM mode, fan speed controllers. Features of the family include minimum fan speed, fan auto-shutdown, fan auto-restart, remote shutdown, over-temperature indication and fan fault detection.

The TC64XB family is slightly different from the original TC64X family, which includes the TC642, TC646, TC647, TC648 and TC649 devices. Changes have been made to adjust the operation of the device during a fan fault condition.

The key change to the TC64XB family of devices (TC642B, TC647B, TC646B, TC648B, TC649B) is that the FAULT and VOUT outputs no longer "latch" to a state during a fan fault condition. The TC646B/TC648B/TC649B family will continue to monitor the operation of the fan so that when the fan returns to normal operation, the fan speed controller will also return to normal operation (PWM mode). The operation and features of these devices are discussed in the following sections.

4.1 Fan Speed Control Methods

The speed of a DC brushless fan is proportional to the voltage across it. This relationship will vary from fan-to-fan and should be characterized on an individual basis. The speed versus applied voltage relationship can then be used to set up the fan speed control algorithm.

There are two main methods for fan speed control. The first is pulse width modulation (PWM) and the second is linear. Using either method, the total system power requirement to run the fan is equal. The difference between the two methods is where the power is consumed.

The following example compares the two methods for a 12V, 120 mA fan running at 50% speed. With 6V applied across the fan, the fan draws an average current of 68 mA.

Using a linear control method, there is 6V across the fan and 6V across the drive element. With 6V and 68 mA, the drive element is dissipating 410 mW of power.

Using the PWM approach, the fan voltage is modulated at a 50% duty cycle, with most of the 12V being dropped across the fan. With 50% duty cycle, the fan draws a RMS current of 110 mA and an average current of 72 mA. Using a MOSFET with a 1Ω RDS(on) (a fairly typical value for this low current), the power dissipation in the drive element would be: 12 mW (Irms^2 * RDS(on)). Using a standard 2N2222A NPN transistor (assuming a Vce-sat of 0.8V), the power dissipation would be 58 mW (Iavg * Vce-sat).

The PWM approach to fan speed control results in much less power dissipation in the drive element. This allows smaller devices to be used and will not require special heatsinking to remove the power being dissipated in the package.

The other advantage of the PWM approach is that the voltage being applied to the fan is always near 12V. This eliminates any concern about not supplying a high enough voltage to run the internal fan components, which is very relevant in linear fan speed control.

4.2 PWM Fan Speed Control

The TC646B, TC648B and TC649B devices implement PWM fan speed control by varying the duty cycle of a fixed-frequency pulse train. The duty cycle of a waveform is the on time divided by the total period of the pulse. For example, if we take a 100 Hz waveform (10 ms) with an on time of 5.0 ms, the duty cycle of this waveform is 50% (5.0 ms / 10.0 ms). This example is shown in Figure 4-1.

The TC646B/TC648B/TC649B devices generate a pulse train with a typical frequency of 30 Hz (CF = 1 µF). The duty cycle can be varied from 0% to 100%. The pulse train generated by the TC646B/TC648B/TC649B device drives the gate of an external N-channel MOSFET or the base of an NPN transistor. (shown in Figure 4-2). See Section 5.5, “Output Drive Device Selection”, for more information on output drive device selection.
FIGURE 4-2: PWM Fan Drive.

By modulating the voltage applied to the gate of the MOSFET (QDRIVE), the voltage that is applied to the fan is also modulated. When the VOUT pulse is high, the voltage at the drain of QDRIVE is 0 volts. This places the full 12V across the fan for the t_on period of the pulse. When the duty cycle of the drive pulse is 100% (full on, t_on = t), the fan will run at full speed. As the duty cycle is decreased (pulse on time t_on is lowered), the fan will slow down proportionally. With the TC646B, TC648B and TC649B devices, the duty cycle is controlled by the VIN input and can also be terminated by the VAS input (auto-shutdown). This is described in more detail in Section 5.5, “Output Drive Device Selection”.

4.3 Fan Start-up

Often overlooked in fan speed control is the actual start-up control period. When starting a fan from a non-operating condition (fan speed is zero revolutions per minute (RPM)), the desired PWM duty cycle or average fan voltage cannot be applied immediately. Since the fan is at a rest position, the fan’s inertia must be overcome to get it started. The best way to accomplish this is to apply the full rated voltage to the fan for a minimum of one second. This will ensure that in all operating environments, the fan will start and operate properly. An example of the start-up timing is shown in Figure 1-1.

A key feature of the TC646B/TC648B/TC649B devices is the start-up timer. When power is first applied to the device, or when the device is brought out of the shutdown/auto-shutdown modes of operation, the VOUT output will go to a high state for 32 PWM cycles (one second for CF = 1 µF). This will drive the fan to full speed for this time frame.

During the start-up period for the TC646B and TC649B devices, the SENSE pin is being monitored for fan pulses. If pulses are detected during this period, the fan speed controller will then move to PWM operation. If pulses are not detected during the start-up period, the start-up timer is activated again. If pulses are not detected at the SENSE pin during this additional period, the FAULT output will go low to indicate that a fan fault condition has occurred. See Section 4.7, “FAULT/OTF Output”, for more details.

4.4 PWM Frequency & Duty Cycle Control (CF & VIN Pins)

The frequency of the PWM pulse train is controlled by the CF pin. By attaching a capacitor to the CF pin, the frequency of the PWM pulse train can be set to the desired value. The typical PWM frequency for a 1.0 µF capacitor is 30 Hz. The frequency can be adjusted by raising or lowering the value of the capacitor. The CF pin functions as a ramp generator. The voltage at this pin will ramp from 1.20V to 2.60V (typically) as a sawtooth waveform. An example of this is shown in Figure 4-3.

FIGURE 4-3: CF Pin Voltage.

The duty cycle of the PWM output is controlled by the voltage at the VIN input pin. The duty cycle of the PWM output is produced by comparing the voltage at the VIN pin to the voltage ramp at the CF pin. When the voltage at the VIN pin is 1.20V, the duty cycle will be 0%. When the voltage at the VIN pin is 2.60V, the PWM duty cycle will be 100% (these are both typical values). The VIN-to-PWM duty cycle relationship is shown in Figure 4-4.

The lower value of 1.20V is referred to as “VCMIN” and the 2.60V threshold is referred to as “VCMAX”. A calculation for duty cycle is shown in the equation below. The voltage range between VCMIN and VCMAX is characterized as “VCSPAN” and has a typical value of 1.4V, with minimum and maximum values of 1.3V and 1.5V, respectively.

\[
\text{Duty Cycle (\%) } = \frac{(\text{VIN} - \text{VCMIN}) \times 100}{\text{VCMAX} - \text{VCMIN}}
\]
For the TC646B, TC648B and TC649B devices, the \( V_{IN} \) pin is also used as the shutdown pin. The \( V_{SHDN} \) and \( V_{REL} \) threshold voltages are characterized in the “Electrical Characteristics Table” of Section 1.0. If the \( V_{IN} \) pin voltage is pulled below the \( V_{SHDN} \) threshold, the device will shut down (\( V_{OUT} \) output goes to a low state, the FAULT/OTF pin is inactive). If the voltage on the \( V_{IN} \) pin then rises above the release threshold (\( V_{REL} \)), the device will go through a power-up sequence (assuming that the \( V_{IN} \) voltage is also higher than the voltage at the \( V_{AS} \) pin). The power-up sequence is shown later in the “Behavioral Algorithm Flowcharts” of Section 4.9.

When the device is in shutdown/auto-shutdown mode, the \( V_{OUT} \) output is actively held low. The output can be varied from 0% (full off) to 100% duty cycle (full on). As previously discussed, the duty cycle of the \( V_{OUT} \) output is controlled via the \( V_{IN} \) input voltage and can be terminated based on the \( V_{AS} \) voltage.

A base current-limiting resistor is required when using a transistor as the external drive device in order to limit the amount of drive current that is drawn from the \( V_{OUT} \) output.

The \( V_{OUT} \) output can be directly connected to the gate of an external MOSFET. One concern when doing this, though, is that the fast turn-off time of the fan drive MOSFET can cause a problem because the fan motor looks like an inductor. When the MOSFET is turned off quickly, the current in the fan wants to continue to flow in the same direction. This causes the voltage at the drain of the MOSFET to rise. If there aren’t any clamp diodes internal to the fan, this voltage can rise above the drain-to-source voltage rating of the MOSFET. For this reason, an external clamp diode is suggested. This is shown in Figure 4-5.

### 4.5 Auto-Shutdown Mode (\( V_{AS} \))

For the TC646B, TC648B and TC649B devices, pin 3 is the \( V_{AS} \) pin and is used for setting the auto-shutdown threshold voltage.

The auto-shutdown function provides a way to set a threshold voltage (temperature) at which the fan will be shut off. This way, if the temperature in the system reaches a threshold at which the fan(s) no longer needs to operate, the fan can be shutdown automatically.

The voltage range for the \( V_{AS} \) pin is the same as the voltage range for the \( V_{IN} \) pin (1.20V to 2.60V). The voltage at the \( V_{AS} \) pin is set in this range so that when the voltage at the \( V_{IN} \) pin decreases below the voltage at the \( V_{AS} \) pin (signifying that the threshold temperature has been reached), the \( V_{OUT} \) output is shut off (goes to a low state). In auto-shutdown, the FAULT/OTF output is inactive (high-impedance). Auto-shutdown mode is exited when the \( V_{IN} \) voltage exceeds the \( V_{AS} \) voltage by the auto-shutdown hysteresis voltage (\( V_{HAS} \)). Upon exiting auto-shutdown mode, the start-up timer is triggered and the device returns to normal operation.

### 4.6 \( V_{OUT} \) Output (PWM Output)

The \( V_{OUT} \) output is a digital output designed for driving the base of a transistor or the gate of a MOSFET. The \( V_{OUT} \) output is designed to be able to quickly raise the base current or the gate voltage of the external drive device to its final value.

### 4.7 FAULT/OTF Output

The FAULT/OTF output is an open-drain, active-low output. For the TC646B and TC649B devices, pin 6 is labeled as the FAULT output and indicates when a fan fault condition has occurred. For the TC646B device, the FAULT output also indicates when an over-temperature (OTF) condition has occurred. For the TC648B device, pin 6 is the OTF output that indicates an over-temperature (OTF) condition has occurred.
For the TC646B and TC648B devices, an over-temperature condition is indicated when the \( V_{IN} \) input reaches the \( V_{OTF} \) threshold voltage (the \( V_{OTF} \) threshold voltage is typically 20 mV higher than the \( V_{CMAX} \) threshold and has 80 mV of hysteresis). This indicates that maximum cooling capacity has been reached (the fan is at full speed) and that an overheating situation can occur. When the voltage at the \( V_{IN} \) input falls below the \( V_{OTF} \) threshold voltage by the hysteresis value (\( V_{OTF-HYS} \)), the FAULT/OTF output will return to the high state (a pull-up resistor is needed on the FAULT/OTF output).

For the TC646B/TC649B devices, a fan fault condition is indicated when fan current pulses are no longer detected at the SENSE pin. Pulses at the SENSE pin indicate that the fan is spinning and conducting current. If pulses are not detected at the SENSE pin for 32 PWM cycles, the 3-cycle diagnostic timer is fired. This means that the \( V_{OUT} \) output is high for 3 PWM cycles. If pulses are detected in this 3-cycle period, normal PWM operation is resumed and no fan fault is indicated. If no pulses are detected in the 3-cycle period, the start-up timer is activated and the \( V_{OUT} \) output is driven high for 32 PWM cycles. If pulses are detected during this time-frame, normal PWM operation is resumed. If no pulses are detected during this time-period, a fan fault condition exists and the FAULT output is pulled low.

During a fan fault condition, the FAULT output will remain low until the fault condition has been removed. During this time, the \( V_{OUT} \) output is driven high continuously to attempt to restart the fan and the SENSE pin is monitored for fan pulses. If a minimum of 16 pulses are detected at the SENSE input over a 32 cycle time-period (one second for \( C_F = 1.0 \mu F \)), the fan fault condition no longer exists. Therefore, The FAULT output is released and the \( V_{OUT} \) output returns to normal PWM operation, as dictated by the \( V_{IN} \) and \( V_{AS} \) inputs.

If the \( V_{IN} \) voltage is pulled below the \( V_{SHDN} \) level during a fan fault condition, the FAULT output will be released and the \( V_{OUT} \) output will be shutdown (\( V_{OUT} = 0V \)). If the \( V_{IN} \) voltage then increases above the \( V_{REL} \) threshold and is above the \( V_{AS} \) voltage, the device will go through the normal start-up routine.

If, during a fan fault condition, the voltage at the \( V_{IN} \) pin drops below the \( V_{AS} \) voltage level, the TC646B/TC649B device will continue to hold the FAULT line low and drive the \( V_{OUT} \) output to 100% duty cycle. If the fan fault condition is then removed, the FAULT output will be released and the TC646B/TC649B device will enter auto-shutdown mode until the \( V_{IN} \) voltage is brought above the \( V_{AS} \) voltage by the auto-shutdown hysteresis value (\( V_{HAS} \)). The TC646B/TC649B device will then resume normal PWM mode operation.

The sink current capability of the FAULT output is listed in the "Electrical Characteristics Table" of Section 1.0.

### 4.8 Sensing Fan Operation (SENSE)

The SENSE input is an analog input used to monitor the fan's operation (the TC644B device does not incorporate the fan sensing feature). It does this by sensing fan current pulses that represent fan rotation. When a fan rotates, commutation of the fan current occurs as the fan poles pass the armatures of the motor. The commutation of the fan current makes the current waveform appear as pulses. There are two typical current waveforms of brushless DC fan motors, illustrated in Figures 4-6 and 4-7.
The SENSE pin senses positive voltage pulses that have an amplitude of 70 mV (typical value). Each time a pulse is detected, the missing pulse detector timer (tMP) is reset. As previously stated, if the missing pulse detector timer reaches the time for 32 cycles, the loop for diagnosing a fan fault is engaged (diagnostic timer, then the start-up timer).

Both of the fan current waveshapes shown in Figures 4-6 and 4-7 can be sensed with the sensing scheme shown in Figure 4-8.

The SENSE pin senses positive voltage pulses that have an amplitude of 70 mV (typical value). Each time a pulse is detected, the missing pulse detector timer (tMP) is reset. As previously stated, if the missing pulse detector timer reaches the time for 32 cycles, the loop for diagnosing a fan fault is engaged (diagnostic timer, then the start-up timer).

Both of the fan current waveshapes shown in Figures 4-6 and 4-7 can be sensed with the sensing scheme shown in Figure 4-8.

![FIGURE 4-8: Sensing Scheme For Fan Current.](image)

The initial pulse blanker is also implemented to stop false sensing of fan current pulses. When a fan is in a locked rotor condition, the fan current no longer commutates, it simply flows through one fan winding and is a DC current. When a fan is in a locked rotor condition and the TC646B/TC649B device is in PWM mode, it will see one current pulse each time the VOUT output is turned on. The initial pulse blanker allows the TC646B/TC649B device to ignore this pulse and recognize that the fan is in a fault condition.

4.9 Behavioral Algorithms

The behavioral algorithms for the TC646B/TC649B and TC648B devices are shown in Figure 4-9 and Figure 4-10, respectively.

The behavioral algorithms show the step-by-step decision-making process for the fan speed controller operation. The TC646B and TC649B devices are very similar with one exception: the TC649B device does not implement the over-temperature portion of the algorithm.
**FIGURE 4-9:**  TC646B/TC649B Behavioral Algorithm.
FIGURE 4-10: TC648B Behavioral Algorithm.
5.0 APPLICATIONS INFORMATION

5.1 Setting the PWM Frequency

The PWM frequency of the \( V_{OUT} \) output is set by the capacitor value attached to the \( C_F \) pin. The PWM frequency will be 30 Hz (typical) for a 1 \( \mu \)F capacitor. The relationship between frequency and capacitor value is linear, making alternate frequency selections easy.

As stated in previous sections, the PWM frequency should be kept in the range of 15 Hz to 35 Hz. This will eliminate the possibility of having audible frequencies when varying the duty cycle of the fan drive.

A very important factor to consider when selecting the PWM frequency for the TC646B/TC648B/TC649B devices is the RPM rating of the selected fan and the minimum duty cycle that you will be operating at. For fans that have a full-speed rating of 3000 RPM or less, it is desirable to use a lower PWM frequency. A lower PWM frequency allows for a longer time-period to monitor the fan current pulses. The goal is to be able to monitor at least two fan current pulses during the on-time of the \( V_{OUT} \) output.

Example: The system design requirement is to operate the fan at 50% duty cycle when ambient temperatures are below 20°C. The fan full-speed RPM rating is 3000 RPM and has four current pulses per rotation. At 50% duty cycle, the fan will be operating at approximately 1500 RPM.

\[
\text{Time for one revolution (msec.)} = \frac{60 \times 1000}{1500} = 40
\]

If one fan revolution occurs in 40 msec, each fan pulse occurs 10 msec apart. In order to detect two fan current pulses, the on-time of the \( V_{OUT} \) pulse must be at least 20 msec. With the duty cycle at 50%, the total period of one cycle must be at least 40 msec, which makes the PWM frequency 25 Hz. For this example, a PWM frequency of 20 Hz is recommended. This would define a \( C_F \) capacitor value of 1.5 \( \mu \)F.

5.2 Temperature Sensor Design

As discussed in previous sections, the \( V_{IN} \) analog input has a range of 1.20V to 2.60V (typical), which represents a duty cycle range on the \( V_{OUT} \) output of 0% to 100%, respectively. The \( V_{IN} \) voltages can be thought of as representing temperatures. The 1.20V level is the low temperature at which the system requires very little cooling. The 2.60V level is the high temperature, for which the system needs maximum cooling capability (100% fan speed).

One of the simplest ways of sensing temperature over a given range is to use a thermistor. By using a NTC thermistor, as shown in Figure 5-1, a temperature-variant voltage can be created.

\[
\frac{R_T}{R_T + R_1} \times IDIV = \frac{R_2}{R_2 + R_T}
\]

**FIGURE 5-1: Temperature Sensing Circuit.**

Figure 5-1 represents a temperature-dependent, voltage divider circuit. \( R_T \) is a conventional NTC thermistor, \( R_1 \) and \( R_2 \) are standard resistors. \( R_1 \) and \( R_T \) form a parallel resistor combination that will be referred to as \( R_{TEMP} = \frac{R_1 \times R_T}{R_1 + R_T} \). As the temperature increases, the value of \( R_T \) decreases and the value of \( R_{TEMP} \) will decrease with it. Accordingly, the voltage at \( V_{IN} \) increases as temperature increases, giving the desired relationship for the \( V_{IN} \) input. \( R_1 \) helps to linearize the response of the SENSE network and aids in obtaining the proper \( V_{IN} \) voltages over the desired temperature range. An example of this is shown in Figure 5-2.

If less current draw from \( V_{DD} \) is desired, a larger value thermistor should be chosen. The voltage at the \( V_{IN} \) pin can also be generated by a voltage output temperature sensor device. The key is to get the desired \( V_{IN} \) voltage-to-system (or component) temperature relationship.

The following equations apply to the circuit in Figure 5-1.

\[
V(T1) = \frac{V_{DD} \times R_2}{R_{TEMP(T1)} + R_2}
\]

\[
V(T2) = \frac{V_{DD} \times R_2}{R_{TEMP(T2)} + R_2}
\]

In order to solve for the values of \( R_1, R_2, V_{IN} \) and the temperatures at which they are to occur, need to be selected. The variables \( T1 \) and \( T2 \) represent the selected temperatures. The value of the thermistor at these two temperatures can be found in the thermistor.
data sheet. With the values for the thermistor and the values for \( V_{IN} \), you now have two equations from which the values for \( R_1 \) and \( R_2 \) can be found.

**Example:** The following design goals are desired:

- Duty Cycle = 50% \((V_{IN} = 1.90V)\) with Temperature \((T1) = 30°C\)
- Duty Cycle = 100% \((V_{IN} = 2.60V)\) with Temperature \((T2) = 60°C\)

Using a 100 kΩ thermistor (25°C value), we look up the thermistor values at the desired temperatures:

- \( R_T(T1) = 79428 \Omega @ 30°C \)
- \( R_T(T2) = 22593 \Omega @ 60°C \)

Substituting these numbers into the given equations produces the following numbers for \( R_1 \) and \( R_2 \):

- \( R_1 = 34.8 \, k\Omega \)
- \( R_2 = 14.7 \, k\Omega \)

**5.3 Thermistor Selection**

As with any component, there are a number of sources for thermistors. A listing of companies that manufacture thermistors can be found at www.temperatures.com/thermivendors.html. This website lists over forty suppliers of thermistor products. A brief list is shown here:

- Thermometrics®
- Ametherm®
- U.S. Sensor™
- Advanced Thermal Products™
- Quality Thermistor™
- Sensor Scientific™
- Vishay®
- muRata®

**5.4 FanSense Network**

(RSENSE and CSENSE)

The SENSE network (comprised of RSENSE and CSENSE) allows the TC646B and TC649B devices to detect commutation of the fan motor. RSENSE converts the fan current into a voltage. CSENSE AC couples this voltage signal to the SENSE pin. The goal of the SENSE network is to provide a voltage pulse to the SENSE pin that has a minimum amplitude of 90 mV. This will ensure that the current pulse caused by the fan commutation is recognized by the TC646B/TC649B device.

A 0.1 µF ceramic capacitor is recommended for CSENSE. Smaller values will require that larger sense resistors be used. Using a 0.1 µF capacitor results in reasonable values for RSENSE. Figure 5-3 illustrates a typical SENSE network.

**Figure 5-3: Typical Sense Network.**

The required value of RSENSE will change with the current rating of the fan and the fan current waveshape. A key point is that the current rating of the fan specified by the manufacturer may be a worst-case rating, with the actual current drawn by the fan being lower than this rating. For the purposes of setting the value for RSENSE, the operating fan current should be measured to get the nominal value. This can be done by using an oscilloscope current probe or using a voltage probe with a low-value resistor \((0.5 \Omega)\). Another good tool for this exercise is the TC642 Evaluation Board. This board allows the RSENSE and CSENSE values to be easily changed while allowing the voltage waveforms to be monitored to ensure the proper levels are being reached.

Table 5-1 shows values of RSENSE according to the nominal operating current of the fan. The fan currents are average values. If the fan current falls between two of the values listed, use the higher resistor value.
Another important factor to consider when selecting the \( R_{\text{SENSE}} \) value is the fan current value during a locked-rotor condition. When a fan is in a locked-rotor condition (fan blades are stopped even though power is being applied to the fan), the fan current can increase dramatically (often 2.5 to 3.0 times the normal operating fan current). This will effect the power rating of the \( R_{\text{SENSE}} \) resistor selected.

When selecting the fan for the application, the current draw of the fan during a locked-rotor condition should be considered. Especially if multiple fans are being used in the application.

There are two main types of fan designs when looking at fan current draw during a locked-rotor condition. The first is a fan that will simply draw high DC currents when put into a locked-rotor condition. Many older fans were designed this way. An example of this is a fan that draws an average current of 100 mA during normal operation. In a locked-rotor condition, this fan will draw 250 mA of average current. For this design, the \( R_{\text{SENSE}} \) power rating must be sized to handle the 250 mA condition. The fan bias supply must also take this into account.

The second style design, which represents many of the newer fan designs today, acts to limit the current in a locked-rotor condition by going into a pulse mode of operation. An example of the fan current waveshape for this style fan is shown in Figure 5-5. The fan represented in Figure 5-5 is a Panasonic®, 12V, 220 mA fan. During the on-time of the waveform, the fan current is peaking up to 550 mA. Due to the pulse mode operation, the actual RMS current of the fan is very near the 220 mA rating. Because of this, the power rating for the \( R_{\text{SENSE}} \) resistor does not have to be oversized for this application.

### Table 5-1: Fan Current vs. \( R_{\text{SENSE}} \)

<table>
<thead>
<tr>
<th>Nominal Fan Current (mA)</th>
<th>( R_{\text{SENSE}} ) (Ω)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>9.1</td>
</tr>
<tr>
<td>100</td>
<td>4.7</td>
</tr>
<tr>
<td>150</td>
<td>3.0</td>
</tr>
<tr>
<td>200</td>
<td>2.4</td>
</tr>
<tr>
<td>250</td>
<td>2.0</td>
</tr>
<tr>
<td>300</td>
<td>1.8</td>
</tr>
<tr>
<td>350</td>
<td>1.5</td>
</tr>
<tr>
<td>400</td>
<td>1.3</td>
</tr>
<tr>
<td>450</td>
<td>1.2</td>
</tr>
<tr>
<td>500</td>
<td>1.0</td>
</tr>
</tbody>
</table>

The values listed in Table 5-1 are for fans that have the fan current waveshape shown in Figure 4-7. With this waveshape, the average fan current is closer to the peak value, which requires the resistor value to be higher. When using a fan that has the fan current waveshape shown in Figure 4-6, the resistor value can often be decreased since the current peaks are higher than the average and it is the AC portion of the voltage that gets coupled to the SENSE pin.

The key point when selecting an \( R_{\text{SENSE}} \) value is to try to minimize the value in order to minimize the power dissipation in the resistor. In order to do this, it is critical to know the waveshape of the fan current and not just the average value.

Figure 5-4 shows some typical waveforms for the fan current and the voltage at the SENSE pin.
5.5 Output Drive Device Selection

The TC646B/TC648B/TC649B is designed to drive an external NPN transistor or N-channel MOSFET as the fan speed modulating element. These two arrangements are shown in Figure 5-7. For lower-current fans, NPN transistors are a very economical choice for the fan drive device. It is recommended that, for higher current fans (300 mA and above), MOSFETs be used as the fan drive device. Table 5-2 provides some possible part numbers for use as the fan drive element.

When using a NPN transistor as the fan drive element, a base current-limiting resistor must be used. This is shown in Figure 5-7.

When using MOSFETs as the fan drive element, it is very easy to turn the MOSFETs on and off at very high rates. Because the gate capacitances of these small MOSFETs are very low, the TC646B/TC648B/TC649B can charge and discharge them very quickly, leading to very fast edges. Of key concern is the turn-off edge of the MOSFET. Since the fan motor winding is essentially an inductor, once the MOSFET is turned off the current that was flowing through the motor wants to continue to flow. If the fan does not have internal clamp diodes, there is no path for this current to flow through and the voltage at the drain of the MOSFET may rise until the drain-to-source rating of the MOSFET is exceeded. This will most likely cause the MOSFET to go into avalanche mode. Since there is very little energy in this occurrence, it will probably not fail the device, but it would be a long-term reliability issue.

The following is recommended:
- Ask how the fan is designed. If the fan has clamp diodes internally, this problem will not be seen. If the fan does not have internal clamp diodes, it is a good idea to install one externally (Figure 5-6).
- Putting a resistor between VOUT and the gate of the MOSFET will also help slow down the turn-off and limit this condition.

![FIGURE 5-6: Clamp Diode For Fan Turn-Off.](image)
5.6 Bias Supply Bypassing and Noise Filtering

The bias supply (V_DD) for the TC646B/TC648B/TC649B devices should be bypassed with a 1.0 µF ceramic capacitor. This capacitor will help supply the peak currents that are required to drive the base/gate of the external fan drive devices.

As the VIN pin controls the duty cycle in a linear fashion, any noise on this pin can cause duty cycle jittering. For this reason, the VIN pin should be bypassed with a 0.01 µF capacitor.

In order to keep fan noise off of the TC646B/TC648B/TC649B device ground, individual ground returns for the TC646B/TC648B/TC649B and the low side of the fan current sense resistor should be used.

5.7 Design Example/Typical Application

The system has been designed with the following components and criteria:

System inlet air ambient temperature ranges from 0°C to 50°C. At 20°C, system cooling is no longer required, so the fan is to be turned off. Prior to turn-off, the fan should be run at 40% of its full fan speed. Full fan speed should be reached when the ambient air is 40°C.

The system has a surface mount, NTC-style thermistor in a 1206 package. The thermistor is a NTC, 100 kΩ @ 25°C, Thermometrics® part number NHQ104B425R5. The given Beta for the thermistor is 4250. The system bias voltage to run the fan controller is 5V, while the fan voltage is 12V.

---

**FIGURE 5-7:** Output Drive Device Configurations.

**TABLE 5-2:** FAN DRIVE DEVICE SELECTION TABLE (NOTE 2)

<table>
<thead>
<tr>
<th>Device</th>
<th>Package</th>
<th>Max Vbe sat / Vgs(V)</th>
<th>Min hfe</th>
<th>Vce/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>
</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.

**Note 2:** These drive devices are suggestions only. Fan currents listed are for individual fans.
The fan used in the system is a Panasonic®, Panaflo®-series fan, model number FBA06T12H.

A fault indication is desired when the fan is in a locked-rotor condition. This signal is used to indicate to the system that cooling is not available and a warning should be issued to the user. No fault indication from the fan controller is necessary for an over-temperature condition as this is being reported elsewhere.

**Step 1: Gathering Information.**

The first step in the design process is to gather the needed data on the fan and thermistor. For the fan, it is also a good idea to look at the fan current waveform, as indicated earlier in the data sheet.

**Fan Information:** Panasonic number: FBA06T12H
- Voltage = 12V
- Current = 145 mA (data sheet number)

**FIGURE 5-8:** FBA06T12H Fan Current Waveform.

From the waveform in Figure 5-8, the fan current has an average value of 120 mA, with peaks up to 150 mA. This information will help in the selection of the RSENSE and CSENSE values later on. Also of interest for the RSENSE selection value is what the fan current does in a locked-rotor condition.

**FIGURE 5-9:** FBA06T12H Locked-Rotor Fan Current.

From Figure 5-9, it is seen that in a locked-rotor fault condition, the fan goes into a pulsed current mode of operation. During this mode, when the fan is conducting current, the peak current value is 360 mA for periods of 200 msec. This is significantly higher than the average full fan speed current shown in Figure 5-8. However, because of the pulse mode, the average fan current in a locked-rotor condition is lower and was measured at 68 mA. The RMS current during this mode, which is necessary for current sense resistor (RSENSE) value selection, was measured at 154 mA. This is slightly higher than the RMS value during full fan speed operation.

**Thermistor Information:** Thermometrics part number: NHQ104B425R5
- Resistance Value: 100 kΩ @ 25ºC
- Beta Value (β): 4250

From this information, the thermistor values at 20ºC and 40ºC must be found. This information is needed in order to select the proper resistor values for R1 and R2 (see Figure 5-13), which sets the VIN voltage.

The equation for determining the thermistor values is shown below:

\[
R_T = R_{T0} \exp \left[ \frac{\beta (T_0 - T)}{T \cdot T_0} \right]
\]

R\(_{T0}\) is the thermistor value at 25ºC, T\(_0\) is 298.15 and T is the temperature of interest. All temperatures are in degrees kelvin.

Using this equation, the values for the thermistor are found to be:
- R\(_T\) (20ºC) = 127,462Ω
- R\(_T\) (40ºC) = 50,520Ω
Step 2: Selecting the Fan Controller.
The requirements for the fan controller are that it have auto-shutdown capability at 20ºC and also indicate a fan fault condition. No over-temperature indication is necessary. From these specifications, the proper selection is the TC649B device.

Step 3: Setting the PWM Frequency.
The fan is rated at 4200 RPM with a 12V input. The goal is to run to a 40% duty cycle (roughly 40% fan speed), which equates to approximately 1700 RPM. At 1700 RPM, one full fan revolution occurs every 35 msec. The fan being used is a four-pole fan that gives four current pulses per revolution. With this information, and viewing test results at 40% duty cycle, two fan current pulses were always seen during the PWM on time with a PWM frequency of 30 Hz. For this reason, the $C_F$ value is selected to be 1.0 µF.

Step 4: Setting the $V_{IN}$ Voltage.
From the design criteria, the desired duty cycle at 20ºC is 40% and full fan speed should be reached at 40ºC. Based on a $V_{IN}$ voltage range of 1.20V to 2.60V, which represents 0% to 100% duty cycle, the 40% duty cycle voltage can be found using the following equation:

\[
V_{IN} = (DC * 1.4V) + 1.20V
\]

\[DC = Desired Duty Cycle\]

Using the above equation, the $V_{IN}$ values are calculated to be:
- $V_{IN}$ (40%) = 1.76V
- $V_{IN}$ (100%) = 2.60V

Using these values along with the thermistor resistance values calculated earlier, the $R_1$ and $R_2$ resistor values can now be calculated using the following equation:

\[
EQUATION
\]

Using standard 1% resistor values, the selected $R_1$ and $R_2$ values are:
- $R_1 = 237 \, k\Omega$
- $R_2 = 45.3 \, k\Omega$

A graph of the $V_{IN}$ voltage, thermistor resistance and $R_{TEMP}$ resistance versus temperature for this configuration is shown in Figure 5-10.

Step 5: Setting the Auto-Shutdown Voltage ($V_{AS}$).
Setting the voltage for the auto-shutdown is done using a simple resistor voltage divider. The criteria for the voltage divider in this design is that it draw no more than 100 µA of current. The required auto-shutdown voltage was determined earlier in the selection of the $V_{IN}$ voltage at 40% duty cycle, since this was also set at the temperature that auto-shutdown is to occur (20ºC).

- $V_{AS} = 1.76V$

Given this desired setpoint and knowing the desired divider current, the following equations can be used to solve for the resistor values for $R_3$ and $R_4$:

\[
EQUATION
\]

Using the equations above, the resistor values for $R_3$ and $R_4$ are found to be:
- $R_3 = 32.4 \, k\Omega$
- $R_4 = 17.6 \, k\Omega$

Using standard 1% resistor values yields the following values:
- $R_3 = 32.4 \, k\Omega$
- $R_4 = 17.8 \, k\Omega$
Step 6: Selecting the Fan Drive Device ($Q_1$).

Since the fan operating current is below 200 mA, a transistor or MOSFET can be used as the fan drive device. In order to reduce component count and current draw, the drive device for this design is chosen to be a N-channel MOSFET. Selecting from Table 5-2, there are two MOSFETs that are good choices, the MGSF1N02E and the SI2302. These devices have the same pinout and are interchangeable for this design.

Step 7: Selecting the $R_{SENSE}$ and $C_{SENSE}$ Values.

The goal again for selecting these values is to ensure that the signal at the SENSE pin is 90 mV in amplitude under all operating conditions. This will ensure that the pulses are detected by the TC649B device and that the fan operation is detected.

The fan current waveform is shown in Figure 5-8, and as discussed previously, with a waveform of this shape, the current sense resistor values shown in Table 5-1 are good reference values. Given the average fan operating current was measured to be 120 mA, this falls between two of the values listed in the table. For reference purposes, both values have been tested and these results are shown in Figures 5-11 (4.7Ω) and 5-12 (3.0Ω). The selected $C_{SENSE}$ value is 0.1 µF, as this provides the appropriate coupling of the voltage to the SENSE pin.

FIGURE 5-11: SENSE pin voltage with 4.7Ω sense resistor.

FIGURE 5-12: SENSE pin voltage with 3.0Ω sense resistor.

Since the 3.0Ω value of sense resistor provides the proper voltage to the SENSE pin, it is the correct choice for this solution as it will also provide the lowest power dissipation and the maximum amount of voltage to the fan. Using the RMS fan current which was measured previously, the power dissipation in the resistor during a fan fault condition is 71 mW ($I_{rms}^2 \times R_{SENSE}$). This number will set the wattage rating of the resistor that is selected. The selected value will vary depending upon the derating guidelines that are used.

Now that all the values have been selected, the schematic representation of this design can be seen in Figure 5-13.
Bypass capacitor $C_{VDD}$ is added to the design to decouple the bias voltage. This is good to have, especially when using a MOSFET as the drive device. This helps to give a localized low-impedance source for the current required to charge the gate capacitance of $Q_1$. Two other bypass capacitors (labeled as $C_B$) were also added to decouple the $V_{IN}$ and $V_{AS}$ nodes. These were added simply to remove any noise present that might cause false triggerings or PWM jitter. $R_5$ is the pull-up resistor for the FAULT output. The value for this resistor is system-dependent.
6.0 PACKAGING INFORMATION

6.1 Package Marking Information

8-Lead PDIP (300 mil)

Example:

TC646BCPA
025
0215

Legend:

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

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 device marking consists of Microchip part number, year code, week code, and traceability code.
8-Lead Plastic Dual In-line (PA) – 300 mil (PDIP)

<table>
<thead>
<tr>
<th>Units</th>
<th>INCHES*</th>
<th>MILLIMETERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimension Limits</td>
<td>MIN</td>
<td>NOM</td>
</tr>
<tr>
<td>Number of Pins n</td>
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<td>8</td>
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<tr>
<td>Pitch p</td>
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<tr>
<td>Lead Thickness c</td>
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<td>Upper Lead Width B1</td>
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<td>Lower Lead Width B</td>
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<td>0.018</td>
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<td>10</td>
</tr>
<tr>
<td>Mold Draft Angle Bottom β</td>
<td>5</td>
<td>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 .010” (0.254mm) per side.
JEDEC Equivalent: MS-001
Drawing No. C04-018

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TC646B/TC648B/TC649B

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

<table>
<thead>
<tr>
<th>Units</th>
<th>INCHES*</th>
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<tr>
<td>Dimension Limits</td>
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<td>Number of Pins</td>
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<td>Pitch</td>
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<td>Overall Height</td>
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<td>.228</td>
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<tr>
<td>Foot Angle</td>
<td>f</td>
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<tr>
<td>Lead Thickness</td>
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<tr>
<td>Lead Width</td>
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<td>.013</td>
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<tr>
<td>Mold Draft Angle Top</td>
<td>α</td>
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</tr>
<tr>
<td>Mold Draft Angle Bottom</td>
<td>β</td>
<td>0</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.
JEDEC Equivalent: MS-012
Drawing No. C04-057
## TC646B/TC648B/TC649B

8-Lead Plastic Micro Small Outline Package (UA) (MSOP)

**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: MO-187**

**Drawing No. CO4-111**

---

### Table: Dimensions and Configuration

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<tr>
<td>Dimension Limits</td>
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<td>NOM</td>
</tr>
<tr>
<td>Number of Pins</td>
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<td>Pitch</td>
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<tr>
<td>Overall Height</td>
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<td>Molded Package Thickness</td>
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<td>.037 REF</td>
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<tr>
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<tr>
<td>Lead Thickness</td>
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<td>.003</td>
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<tr>
<td>Lead Width</td>
<td>B</td>
<td>.009</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

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

Component Taping Orientation for 8-Pin MSOP Devices

User Direction of Feed

PIN 1

Standard Reel Component Orientation for 713 or TR Suffix Device

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

<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>

Component Taping Orientation for 8-Pin SOIC Devices

User Direction of Feed

PIN 1

Standard Reel Component Orientation for 713 or TR Suffix Device

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

<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 SOIC</td>
<td>12 mm</td>
<td>8 mm</td>
<td>2500</td>
<td>13 in.</td>
</tr>
</tbody>
</table>
TC646B/TC648B/TC649B

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>Temperature Range</th>
<th>/XX</th>
<th>Package</th>
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<td>Device:</td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>TC648B: PWM Fan Speed Controller with Auto-Shutdown and Over-Temp Detection</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>TC649B: PWM Fan Speed Controller with Fan Restart, Auto-Shutdown and Fan Fault Detection</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>-40°C to +85°C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Package:</td>
<td>OA = Plastic SOIC, (150 mil Body), 8-lead</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>PA = Plastic DIP (300 mil Body), 8-lead</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>UA = Plastic Micro Small Outline (MSOP), 8-lead</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>713 = Tape and Reel (SOIC and MSOP) (TC646B and TC648B only)</td>
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<td></td>
<td>TR = Tape and Reel (SOIC and MSOP) (TC649B only)</td>
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</tr>
</tbody>
</table>

Examples:

- a) TC646BEOA: SOIC package.
- b) TC646BEOA713: Tape and Reel, SOIC package.
- c) TC646BEPA: PDIP package.
- d) TC646BEUA: MSOP package.
- a) TC648BEOA: SOIC package.
- b) TC648BEPA: PDIP package.
- c) TC648BEUA: MSOP package.
- d) TC648BEUA713: Tape and Reel, MSOP package.
- a) TC649BEOA: SOIC package.
- b) TC649BEPA: PDIP package.
- c) TC649BEUA: MSOP package.
- d) TC649BEUA: MSOP package.

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2. The Microchip Corporate Literature Center U.S. FAX: (480) 792-7277
3. The Microchip Worldwide Site (www.microchip.com)

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

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