PWM Fan Speed Controller with Auto-Shutdown and FanSense™ Technology

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 TC649 Supply Voltage
  - Supports any Fan Voltage
- FanSense™ Fault Detection Circuits Protect Against Fan Failure and Aid System Testing
- Automatic Shutdown Mode for “Green” Systems
- Supports Low Cost NTC/PTC Thermistors
- Space Saving 8-Pin MSOP Package

Applications

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

Available Tools

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

Package Types

<table>
<thead>
<tr>
<th>SOIC/PDIP/MSOP</th>
</tr>
</thead>
<tbody>
<tr>
<td>V IN</td>
</tr>
<tr>
<td>C F</td>
</tr>
<tr>
<td>V AS</td>
</tr>
<tr>
<td>GND</td>
</tr>
<tr>
<td>8</td>
</tr>
<tr>
<td>7</td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>5</td>
</tr>
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General Description

The TC649 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 TC649 automatically suspends fan operation when measured temperature (V IN) is below a user programmed minimum setting (V AS). An integrated Start-up Timer ensures reliable motor start-up at turn-on, coming out of shutdown mode, auto-shutdown mode or following a transient fault.

In normal fan operation, a pulse train is present at SENSE (Pin 5). The TC649 features Microchip Technology’s proprietary FanSense™ technology for increasing system reliability. A missing pulse detector monitors this pin during fan operation. A stalled, open or unconnected fan causes the TC649 to trigger its Start-up Timer once. If the fault persists, the FAULT output goes low, and the device is latched in its shutdown mode. See Section 5.0, “Typical Applications”, for more information and system design guidelines.

The TC649 is available in the 8-pin PDIP, SOIC and MSOP packages and is available in the industrial and extended commercial temperature ranges.
1.0 ELECTRICAL CHARACTERISTICS

Absolute Maximum Ratings*

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

Package Thermal Resistance:
   PDIP (RθJA) ............................................125°C/W
   SOIC (RθJA) ............................................155°C/W
   MSOP (RθJA) ..........................................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

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
<th>Test Conditions</th>
</tr>
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<tbody>
<tr>
<td>VDD</td>
<td>Supply Voltage</td>
<td>3.0</td>
<td>—</td>
<td>5.5</td>
<td>V</td>
<td>Pins 6, 7 Open,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>C_F = 1 µF, V_IN = V_C(MAX).</td>
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<tr>
<td>IDD</td>
<td>Supply Current, Operating</td>
<td>—</td>
<td>0.5</td>
<td>1.0</td>
<td>mA</td>
<td>Pins 6, 7 Open;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Note 1 C_F = 1 µF, V_IN = 0.3V</td>
</tr>
<tr>
<td>IDD(SHDN)</td>
<td>Supply Current, Shutdown/</td>
<td>—</td>
<td>25</td>
<td>—</td>
<td>µA</td>
<td>Pins 6, 7 Open;</td>
</tr>
<tr>
<td></td>
<td>Auto-shutdown Mode</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Note 1</td>
</tr>
<tr>
<td>I_IN</td>
<td>V_IN, V_AS Input Leakage</td>
<td>-1.0</td>
<td>—</td>
<td>+1.0</td>
<td>µA</td>
<td></td>
</tr>
<tr>
<td>VOUT Output</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I_R</td>
<td>V_OUT Rise Time</td>
<td>—</td>
<td>—</td>
<td>50</td>
<td>µsec</td>
<td>I_OH = 5 mA, Note 1</td>
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<tr>
<td>I_F</td>
<td>V_OUT Fall Time</td>
<td>—</td>
<td>—</td>
<td>50</td>
<td>µsec</td>
<td>I_OH = 1 mA, Note 1</td>
</tr>
<tr>
<td>I_SHDN</td>
<td>Pulse Width (On V_IN) to Clear Fault Mode</td>
<td>30</td>
<td>—</td>
<td>—</td>
<td>µsec</td>
<td>V_SHDN, V_HYST Specifications, Note 1</td>
</tr>
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<td>I_OH</td>
<td>Sink Current at V_OUT Output</td>
<td>1.0</td>
<td>—</td>
<td>—</td>
<td>mA</td>
<td>V_OH = 10% of V_DD</td>
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<tr>
<td>I_OH</td>
<td>Source Current at V_OUT Output</td>
<td>5.0</td>
<td>—</td>
<td>—</td>
<td>mA</td>
<td>V_OH = 80% of V_DD</td>
</tr>
</tbody>
</table>

SENSE Input

| V_TH(SENSE) | SENSE Input threshold Voltage with Respect to GND | 50  | 70  | 90  | mV  | Note 1 |

FAULT Output

| V_OH  | Output Low Voltage | —   | —   | 0.3 | V   | I_OH = 2.5 mA |
| I_MPP | Missing Pulse Detector Timer | —   | 32/F | —  | Sec | C_F = 1.0 µF |
| I_START | Start-up Timer | —   | 32/F | —  | Sec | C_F = 1.0 µF |
| I_DIAG | Diagnostic Timer | —   | 3/F  | —  | Sec | C_F = 1.0 µF |

V_IN, V_AS Inputs

| V_C(MAX) | Voltage at V_IN for 100% Duty Cycle | 2.5  | 2.65 | 2.8 | V   |
| V_C(SPAN) | V_C(MAX) - V_C(MIN) | 1.3  | 1.4  | 1.5 | V   |
| V_AS | Auto-shutdown Threshold | V_C(MAX) - V_C(SPAN) | —   | V_C(MAX) | V |
| V_SHDN | Voltage applied to V_IN to Release Reset/Shutdown | —   | —   | V_DD x 0.13 | V |
| V_REL | Voltage applied to V_IN to Release Reset Mode | V_DD x 0.19 | —   | —   | V   | V_DD = 5V, See Figure 5-11 |
| V_HYST | Hysteresis on V_SHDN, V_REL | —   | 0.01 x V_DD | —   | V   |
| V_HAS | Hysteresis on Auto-shutdown Comparator | —   | 70   | —   | mV  |

Pulse Width Modulator

| FOSC | PWM Frequency | 26  | 30  | 34  | Hz  | C_F = 1.0 µF |

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

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

TABLE 2-1: PIN FUNCTION TABLE

<table>
<thead>
<tr>
<th>Pin No.</th>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>V_IN</td>
<td>Analog Input</td>
</tr>
<tr>
<td>2</td>
<td>C_F</td>
<td>Analog Output</td>
</tr>
<tr>
<td>3</td>
<td>V_AS</td>
<td>Analog Input</td>
</tr>
<tr>
<td>4</td>
<td>GND</td>
<td>Ground Terminal</td>
</tr>
<tr>
<td>5</td>
<td>SENSE</td>
<td>Analog Input</td>
</tr>
<tr>
<td>6</td>
<td>FAULT</td>
<td>Digital (Open Collector) Output</td>
</tr>
<tr>
<td>7</td>
<td>V_OUT</td>
<td>Digital Output</td>
</tr>
<tr>
<td>8</td>
<td>V_DD</td>
<td>Power Supply Input</td>
</tr>
</tbody>
</table>

2.1 Analog Input (V_IN)

The thermistor network (or other temperature sensor) connects to the V_IN input. A voltage range of 1.25V to 2.65V (typical) on this pin drives an active duty cycle of 0% to 100% on the V_OUT pin. The TC649 enters shutdown mode when V_IN ≤ V_SHDN. During shutdown, the FAULT output is inactive, and supply current falls to 25 µA (typical). The TC649 exits shutdown mode when V_IN ≥ V_REL. See Section 5.0, "Typical Applications", for more details.

2.2 Analog Output (C_F)

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

2.3 Analog Input (V_AS)

An external resistor divider connected to the V_AS input sets the auto-shutdown threshold. Auto-shutdown occurs when V_IN ≤ V_AS. The fan is automatically restarted when V_IN ≥ (V_AS + V_HAS). See Section 5.0, "Typical Applications", for more details.

2.4 Ground (GND)

GND denotes the ground terminal.

2.5 Analog Input (SENSE)

Pulses are detected at the SENSE pin as fan rotation chops the current through a sense resistor (R_SENSE). The absence of pulses indicates a fault. See Section 5.0, "Typical Applications", for more details.

2.6 Digital Output (FAULT)

The FAULT line goes low to indicate a fault condition. When FAULT goes low due to a fan fault condition, the device is latched in shutdown mode until deliberately cleared or until power is cycled.

2.7 Digital Output (V_OUT)

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

2.8 Power Supply Input (V_DD)

V_DD may be independent of the fan's power supply (see Section 1.0, "Electrical Characteristics").
3.0 DETAILED DESCRIPTION

3.1 PWM

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

3.2 VOUT Output

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

3.3 Start-Up Timer

To ensure reliable fan start-up, the Start-up Timer turns the VOUT output on for 32 cycles of the PWM whenever the fan is started from the off state. This occurs at power-up and when coming out of shutdown or auto-shutdown mode. If the PWM frequency is 30 Hz (CF = 1 µF) the resulting start-up time will be approximately one second. If a fan fault is detected (see Section 3.5, FAULT Output), the Diagnostic Timer is triggered once, followed by the Start-up Timer. If the fault persists, the device is shut down (see Section 3.5, FAULT Output).

3.4 SENSE Input

(FanSense™ Technology)

The SENSE input (Pin 5) is connected to a low value current sensing resistor in the ground return leg of the fan circuit. During normal fan operation, commutation occurs as each pole of the fan is energized. This causes brief interruptions in the fan current, seen as pulses across the sense resistor. If the device is not in shutdown or auto-shutdown mode, and pulses are not appearing at the SENSE input, a fault exists.

The short, rapid change in fan current (high dl/dt) causes a corresponding dV/dt across the sense resistor, RSENSE. The waveform on RSENSE is differentiated and converted to a logic-level pulse-train by CSENSE and the internal signal processing circuitry. The presence and frequency of this pulse-train is a direct indication of fan operation. See Section 5.0, “Typical Applications”, for more details.

3.5 FAULT Output

Pulses appearing at SENSE due to the PWM turning on are blanked, and the remaining pulses are filtered by a missing pulse detector. If consecutive pulses are not detected for thirty-two PWM cycles (∼1 Sec if CF = 1 µF), the Diagnostic Timer is activated, and VOUT is driven high continuously for three PWM cycles (∼100 msec if CF = 1 µF). If a pulse is not detected within this window, the Start-up Timer is triggered (see Section 3.3, “Start-up Timer”). This should clear a transient fault condition. If the missing pulse detector times out again, the PWM is stopped and FAULT goes low. When FAULT is activated due to this condition, the device is latched in shutdown mode and will remain off indefinitely. The TC649 is thus prevented from attempting to drive a fan under catastrophic fault conditions.

One of two things will restore operation: Cycling power off and then on again; or pulling VIN below VSHDN and releasing it to a level above VREL. When one of these two conditions is satisfied, the normal start-up cycle is triggered and operation will resume, provided the fault has been cleared.

3.6 Auto-Shutdown Mode

If the voltage on VIN becomes less than the voltage on VAS, the fan is automatically shut off (auto-shutdown mode). The TC649 exits auto-shutdown mode when the voltage on VIN becomes higher than the voltage on VAS by VHAS (the auto-shutdown hysteresis voltage, see Figure 3-1). The Start-up Timer is triggered and normal operation is resumed upon exiting auto-shutdown mode. The FAULT output is unconditionally inactive in auto-shutdown mode.
3.7 Shutdown Mode (RESET)

If an unconditional shutdown and/or device reset is desired, the TC649 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 FAULT output is unconditionally inactive. The TC649 should not be shut down unless all heat producing activity in the system is at a negligible level. The TC649 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 TC649 into its power-up state. The Start-up and Fault Timers and any current faults are cleared. FAULT 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 no fault conditions exist and \( V_{IN} > (V_{AS} + V_{HAS}) \).

**Note:** If \( V_{IN} < V_{AS} \) when the device exits shutdown mode, the fan will not restart, but will be in auto-shutdown mode. If a fan fault has occurred and the device has latched itself into shutdown mode, performing a reset will not clear the fault unless \( V_{IN} > (V_{AS} + V_{HAS}) \). If \( V_{IN} \) is not greater than \( V_{AS} + V_{HAS} \) upon exiting shutdown mode, the fan will not be restarted, and there will be no way to establish that the fan fault has been cleared. 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 TC649 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 \( V_{DD} \) (50mV 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:** The fan will remain off as long as the \( V_{IN} \) pin is being held low or \( V_{IN} < V_{AS} + V_{HAS} \).
4.0 SYSTEM BEHAVIOR

The flowcharts describing the TC649’s behavioral algorithm are shown in Figure 4-1. They can be summarized as follows:

4.1 Power-Up

(1) Assuming the device is not being held in shutdown or auto-shutdown mode ($V_{IN} > V_{AS}$)... 

(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) During this Start-up Timer, if a fan pulse is detected, branch to Normal Operation; if none are received...

(4) Activate the 32-cycle Start-up Timer one more time and look for fan pulse; if a fan pulse is detected, proceed to Normal Operation; if none are received...

(5) Proceed to Fan Fault. 

(6) End.

4.2 Normal Operation

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

(1) Reset the missing pulse detector. 

(2) Is TC649 in shutdown or auto-shutdown mode? If so...
   a. $V_{OUT}$ duty cycle goes to zero. 
   b. FAULT is disabled. 
   c. Exit the loop and wait for $V_{IN} > (V_{AS} + V_{HAS})$ to resume operation. 

(3) Drive $V_{OUT}$ to a duty cycle proportional to $V_{IN}$ on a cycle by cycle basis. 

(4) If a fan pulse is detected, branch back to the start of the loop (1). 

(5) If the missing pulse detector times out …

(6) Activate the 3-cycle Diagnostic Timer and look for pulses; if a fan pulse is detected, branch back to the start of the loop (1); if none are received...

(7) Activate the 32-cycle Start-up Timer and look for pulses; if a fan pulse is detected, branch back to the start of the loop (1); if none are received...

(8) Quit Normal Operation and go to Fan Fault. 

(9) End.

4.3 Fan Fault

Fan Fault is an infinite loop wherein the TC649 is latched in shutdown mode. This mode can only be released by a reset (i.e., $V_{IN}$ being brought below $V_{SHDN}$, then above $(V_{AS} + V_{HAS})$ or by power-cycling).

(1) While in this state, FAULT is latched on (low) and the $V_{OUT}$ output is disabled. 

(2) A reset sequence applied to the $V_{IN}$ pin will exit the loop to Power-up. 

(3) End.
FIGURE 4-1: TC649 Behavioral Algorithm Flowchart.
5.0 TYPICAL APPLICATIONS

Designing with the TC649 involves the following:

1. The temperature sensor network must be configured to deliver 1.25V to 2.65V on V\text{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\text{AS}.

3. The output drive transistor and associated circuitry must be selected.

4. The SENSE network, R\text{SENSE} and C\text{SENSE}, must be designed for maximum efficiency while delivering adequate signal amplitude.

5. If 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 TC649 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 TC649 should consult the documentation for both TC642EV (DS21403) and TC642DEMO (DS21401). Figure 5-1 shows the base schematic for the TC642DEMO.

![Typical Application Circuit](image_url)

**Notes:**
- *See cautions regarding Latch-up Considerations in Section 5.0, "Typical Applications".
- **Optional. See Section 5.0, "Typical Applications" for details.**
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.

![Temperature Sensing Circuit](image)

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

Figure 5-2 shows a simple temperature dependent voltage divider circuit. \( RT_1 \) is a conventional NTC thermistor, while \( R_1 \) 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 TC649. A 100 kΩ NTC thermistor is selected for this application in order to keep \( I_{DIV} \) at a minimum.

For the voltage range at \( V_{IN} \) to be equal to 1.25V to 2.65V, the temperature range of this configuration is 0°C to 50°C. If a different temperature range is required from this circuit, \( R_1 \) should be chosen to equal the resistance value of the thermistor at the center of this new temperature range. It is suggested that a maximum temperature range of 50°C be used with this circuit due to thermistor linearity limitations. With this change, \( R_2 \) is adjusted according to the following equations:

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

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

Where \( T_1 \) and \( T_2 \) define the temperature range of the circuit. \( R_{TEMP} \) is the parallel equivalent of the thermistor and \( R_1 \) at those temperatures.


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

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

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

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

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

The \( V_{AS} \) voltage may be set using a simple resistor divider, as is shown in Figure 5-3.
Per Section 1.0, “Electrical Characteristics”, the leakage current at the VAS pin is no more than 1 µA. It is conservative to design for a divider current, I_{DIV}, of 100 µA. If V_{DD} = 5.0V then:

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

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:

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

Solving for the relationship between R_1 and R_2 results in:

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

In the case of this example, R_1 = (2.27) R_2. Substituting this relationship back into the V_{AS} equation above yields the resistor values:

- R_2 = 15.3 k\Omega
- 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.

### 5.3 Operations at Low Duty Cycle

One boundary condition which may impact the selection of the minimum fan speed is the irregular activation of the Diagnostic Timer due to the TC649 “missing” fan commutation pulses at low speeds. This is a natural consequence of low PWM duty cycles (typically 25% or less). Recall that the SENSE function detects commutation of the fan as disturbances in the current through R_{SENSE}. These can only occur when the fan is energized (i.e., V_{OUT} is “on”). At very low duty cycles, the V_{OUT} output is “off” most of the time. The fan may be rotating normally, but the commutation events are occurring during the PWM’s off-time.

The phase relationship between the fan’s commutation and the PWM edges tends to “walk around” as the system operates. At certain points, the TC649 may fail to capture a pulse within the 32-cycle missing pulse detector window. If this happens, the 3-cycle Diagnostic Timer will be activated, the V_{OUT} output will be active continuously for three cycles and, if the fan is operating normally, a pulse will be detected. If all is well, the system will return to normal operation. There is no harm in this behavior, but it may be audible to the user as the fan accelerates briefly when the Diagnostic Timer fires. For this reason, it is recommended that V_{AS} be set no lower than 1.8V.

### 5.4 FanSense™ Network (R_{SENSE} and C_{SENSE})

The FanSense network, comprised of R_{SENSE} and C_{SENSE}, allows the TC649 to detect commutation of the fan motor (FanSense™ technology). This network can be thought of as a differentiator and threshold detector. The function of R_{SENSE} is to convert the fan current into a voltage. C_{SENSE} serves to AC-couple this voltage signal and provide a ground-referenced input to the SENSE pin. Designing a proper SENSE network is simply a matter of scaling R_{SENSE} to provide the necessary amount of gain (i.e., the current-to-voltage conversion ratio). A 0.1 µF ceramic capacitor is recommended for C_{SENSE}. Smaller values require larger sense resistors, and higher value capacitors are bulkier and more expensive. Using a 0.1 µF capacitor results in reasonable values for R_{SENSE}. Figure 5-4 illustrates a typical SENSE network. Figure 5-5 shows the waveforms observed using a typical SENSE network.
Table 5-1 lists the recommended values of $R_{\text{SENSE}}$ based on the nominal operating current of the fan. Note that the current draw specified by the fan manufacturer may be a worst-case rating for near-stall conditions and may not be the fan’s nominal operating current. The values in Table 5-1 refer to actual average operating current. If the fan current falls between two of the values listed, use the higher resistor value. The end result of employing Table 5-1 is that the signal developed across the sense resistor is approximately 450 mV in amplitude.

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

<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>

### 5.5 Output Drive Transistor Selection

The TC649 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, 5-4, 5-6, 5-7, 5-8 and 5-9. The $V_{\text{OUT}}$ 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 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 TC649’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 fan sensing function to work correctly, it is imperative that the pass transistor be fully saturated when “on”.

![DIAGRAM](image-url)
Table 5-2 gives examples of some commonly available transistors and MOSFETs. This table should be used as a guide only since there are many transistors and MOSFETs which will work just as well as those listed. The critical issues when choosing a device to use as Q1 are: (1) the breakdown voltage (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.

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

**TABLE 5-2:** TRANSISTORS AND MOSFETS FOR Q1 (V_{DD} = 5V)

<table>
<thead>
<tr>
<th>Device</th>
<th>Package</th>
<th>Max. $V_{BE(sat)}/V_{GS}$ (V)</th>
<th>Min. $H_F$</th>
<th>$V_{CEO}/V_{DS}$ (V)</th>
<th>Fan Current (mA)</th>
<th>Suggested $R_{BASE}$ (Ω)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MMBT2222A</td>
<td>SOT-23</td>
<td>1.2</td>
<td>50</td>
<td>40</td>
<td>150</td>
<td>800</td>
</tr>
<tr>
<td>MPS2222A</td>
<td>TO-92</td>
<td>1.2</td>
<td>50</td>
<td>40</td>
<td>150</td>
<td>800</td>
</tr>
<tr>
<td>MPS6602</td>
<td>TO-92</td>
<td>1.2</td>
<td>50</td>
<td>40</td>
<td>500</td>
<td>301</td>
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<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.
A base-current limiting resistor is required with bipolar transistors (Figure 5-7). The correct value for this resistor can be determined as follows:

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

\[
V_{RSENSE} = I_{FAN} \times R_{SENSE}
\]

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

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

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

**EQUATION**

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

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 as shown in Figure 5-8, with zener diode \(D_1\) offsetting 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 \(V_{OUT}\), causing \(Q_1\) to turn on. Operation is otherwise the same as in the case of fan operation from +12V.

**FIGURE 5-7:** Circuit For Determining \(R_{BASE}\).

**FIGURE 5-8:** Powering the Fan from a -12V Supply.

Note: * Value depends on the specific application and is shown for example only. See Section 5.0, “Typical Applications”, for more details.
5.6 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_\text{AS} divider or shutdown circuit) are powered by a supply different from that of the TC649. Care should be taken to ensure that the TC649’s V_{\text{DD}} supply powers up first. If possible, the networks attached to V_{\text{IN}} and V_{\text{AS}} should connect to the V_{\text{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.

5.7 Power Supply Routing and Bypassing

Noise present on the V_{\text{IN}} and V_{\text{AS}} inputs may cause erroneous operation of the FAULT output. As a result, these inputs should be bypassed with a 0.01 µF capacitor mounted as close to the package as possible. This is especially true of V_{\text{IN}}, which is usually drive from a high impedance source (such as a thermistor). Additionally, the V_{\text{DD}} input should be bypassed with a 1 µF capacitor with grounds being kept as short as possible. To keep fan noise off the TC649 ground pin, individual ground returns for the TC649 and the low side of the fan current sense resistor should be used.

**Design Example**

Step 1. Calculate R_1 and R_2 based on using an NTC having a resistance of 10 kΩ at T_{\text{MIN}} (25°C) and 4.65 kΩ at T_{\text{MAX}} (45°C) (see Figure 5-9).

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

Step 2. Set auto-shutdown Level.

\[
V_{\text{AS}} = 1.8\, \text{V}.
\]

Limit the divider current to 100 µA

\[
\begin{align*}
R_5 &= 33 \, \text{k}\Omega \\
R_6 &= 18 \, \text{k}\Omega
\end{align*}
\]

Step 3. Design the output circuit.

Maximum fan motor current = 250 mA.

Q_1 beta is chosen at 50 from which

\[
R_7 = 800 \, \Omega
\]

![FIGURE 5-9: Design Example.](image-url)
5.8 TC649 as a Microcontroller Peripheral

In a system containing a microcontroller or other host intelligence, the TC649 can be effectively managed as a CPU peripheral. Routine fan control functions can be performed by the TC649 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 R1 through R6 (5% tolerance) form a crude 3-bit DAC that translates this 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 5-10.

With VA set at 1.8V, the TC649 enters auto-shutdown when the processor’s output code is 000[2]. Output codes 001[2] to 111[2] 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 TC649 following detection of a fault condition. The FAULT output can be connected to the processor’s interrupt input or to another I/O pin for polled operation.

FIGURE 5-10: TC649 as a Microcontroller Peripheral.

FIGURE 5-11: VRELEASE vs. Temperature.
6.0 PACKAGING INFORMATION

6.1 Package Marking Information

Legend:

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

Note: In the event the full Microchip part number cannot be marked on one line, it will be carried over to the next line thus limiting the number of available characters for customer specific information.

* Standard marking consists of Microchip part number, year code, week code, traceability code (facility code, mask rev#, and assembly code). For marking beyond this, certain price adders apply. Please check with your Microchip Sales Office.
## TC649

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

### Dimensions

<table>
<thead>
<tr>
<th>Units</th>
<th>INCHES*</th>
<th>MILLIMETERS</th>
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</thead>
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<td>Mold Draft Angle Bottom</td>
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* Controlling Parameter
§ Significant Characteristic

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

### Dimensions

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*Controlling Parameter
§ Significant Characteristic

**Notes:**
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JEDEC Equivalent: MS-012
Drawing No. C04-057

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

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<tr>
<td>Mold Draft Angle Bottom</td>
<td>β</td>
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</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.

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

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

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

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

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

<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>
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Device: TC649 Literature Number: DS21449C

Questions:

1. What are the best features of this document?

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

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

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

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

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

7. How would you improve this document?
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To order or obtain information, e.g., on pricing or delivery, refer to the factory or the listed sales office.

<table>
<thead>
<tr>
<th>PART NO.</th>
<th>X</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Device</td>
<td>Temperature Range</td>
<td>Package</td>
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<td></td>
<td>-40°C to +85°C</td>
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<td>TC649E:</td>
<td>E = -40°C to +85°C</td>
<td>OA = Plastic SOIC, (150 mil Body), 8-lead</td>
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</tbody>
</table>

**Examples:**
- a) TC649VOA: PWM Fan Speed Controller w/ Auto-Shutdown and Fault Detection, SOIC package.
- b) TC649VOA: PWM Fan Speed Controller w/ Auto-Shutdown and Fault Detection, MSOP package.
- c) TC649VOA: PWM Fan Speed Controller w/ Auto-Shutdown and Fault Detection, PDIP package.
- d) TC649EOATR: PWM Fan Speed Controller w/ Auto-Shutdown and Fault Detection, SOIC package, Tape and Reel.

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AMERICAS
Corporate Office
2335 West Chandler Blvd.
Chandler, AZ 85224-6199
Tel: 480-792-7200 Fax: 480-792-7277
Technical Support: 480-792-7627
Web Address: http://www.microchip.com

Rocky Mountain
2335 West Chandler Blvd.
Chandler, AZ 85224-6199
Tel: 480-792-7966 Fax: 480-792-4338

Atlanta
500 Sugar Mill Road, Suite 200B
Atlanta, GA 30350
Tel: 770-640-0034 Fax: 770-640-0307

Boston
2 Lan Drive, Suite 120
Westford, MA 01886
Tel: 978-692-3848 Fax: 978-692-3821

Chicago
333 Pierce Road, Suite 180
Itasca, IL 60143
Tel: 630-285-0071 Fax: 630-285-0075

Dallas
4570 Westgrove Drive, Suite 160
Addison, TX 75001
Tel: 972-818-7423 Fax: 972-818-2924

Detroit
Tri-Atia Office Building
22005 Northwestern Highway, Suite 190
Farmington Hills, MI 48334
Tel: 248-538-2250 Fax: 248-538-2260

Kokomo
2767 S. Albright Road
Kokomo, Indiana 46902
Tel: 765-864-8360 Fax: 765-864-8387

Los Angeles
18201 Von Karman, Suite 1050
Irvine, CA 92612
Tel: 949-263-1888 Fax: 949-263-1338

New York
150 Motor Parkway, Suite 202
Hauppauge, NY 11788
Tel: 631-273-5305 Fax: 631-273-5335

San Jose
Microchip Technology Inc.
2107 North First Street, Suite 590
San Jose, CA 95131
Tel: 408-436-7955 Fax: 408-436-7965

Toronto
6285 Northam Drive, Suite 108
Mississauga, Ontario L4V 1X5, Canada
Tel: 905-673-0699 Fax: 905-673-6509

ASIA/PACIFIC
Australia
Microchip Technology Australia Pty Ltd
Suite 22, 41 Rawson Street
Epping 2121, NSW
Australia
Tel: 61-2-9868-6733 Fax: 61-2-9868-6755

China - Beijing
Microchip Technology Consulting (Shanghai) Co., Ltd., Beijing Liaison Office
Unit 915
Bei Hai Wang Tai Bldg., No. 6 Chaoyangmen Beidajie
Beijing, 100027, No. China
Tel: 86-10-85282100 Fax: 86-10-85282104

China - Chengdu
Microchip Technology Consulting (Shanghai) Co., Ltd., Chengdu Liaison Office
Rm. 2401, 24th Floor,
Ming Xing Financial Tower
No. 88 TIDU Street
Chengdu 610016, China
Tel: 86-28-86766200 Fax: 86-28-86766599

China - Fuzhou
Microchip Technology Consulting (Shanghai) Co., Ltd., Fuzhou Liaison Office
No. 71 Wusi Road
Fuzhou 350001, China
Tel: 86-591-7503506 Fax: 86-591-7503521

China - Hong Kong SAR
Microchip Technology Hong Kong Ltd.
Unit 901-6, Tower 2, Metroplaza
223 Hing Fong Road
Kwai Fong, N.T., Hong Kong
Tel: 852-2401-1200 Fax: 852-2401-3431

India
Microchip Technology Inc.
India Liaison Office
Divyasree Chambers
1 Floor, Wing A (A3/A4)
No. 11, O’Shaugnessy Road
Bangalore, 560 025, India
Tel: 91-80-2290061 Fax: 91-80-2290062

Japan
Microchip Technology Japan K.K.
Benex S-1 6F
3-18-20, Shinjyokohama
Kohoku-Ku, Yokohama-shi
Kanagawa, 222-0033, Japan
Tel: 81-45-471-6166 Fax: 81-45-471-6122

Korea
Microchip Technology Korea
168-1, Youngbo Bldg. 3 Floor
Samsung-Dong, Kangnam-Ku
Seoul, Korea 135-882
Tel: 82-2-554-7200 Fax: 82-2-558-5934

Singapore
Microchip Technology Singapore Pte Ltd.
200 Middle Road
#07-02 Prime Centre
Singapore, 188980
Tel: 65-6334-8870 Fax: 65-6334-8850

Taiwan
Microchip Technology (Barbados) Inc.,
Taiwan Branch
11F-3, No. 207
Tung Hua North Road
Taipei, 106, Taiwan
Tel: 886-2-2717-7175 Fax: 886-2-2545-0139

EUROPE
Austria
Microchip Technology Austria GmbH
Durlisstrasse 2
A-4600 Wels
Austria
Tel: 43-7242-2244-399 Fax: 43-7242-2244-393

Denmark
Microchip Technology Nordic ApS
Regus Business Centre
Laurup høj 1-3
Ballerpur DK-2750 Denmark
Tel: 45 4420 9895 Fax: 45 4420 9910

France
Microchip Technology SARL
Parc d’Activite du Moulin de Massy
43 Rue du Saule Trapu
Batiment A - 1er Etage
91300 Massy, France
Tel: 33-1-69-53-63-20 Fax: 33-1-69-30-90-79

Germany
Microchip Technology GmbH
Steinheilstrasse 10
D-85737 Ismaning, Germany
Tel: 49-89-6579-1-1 Fax: 49-89-6579-44

Italy
Microchip Technology SRL
Centro Direzionale Colleoni
Palazzo Taurus 1 V. Le Colleoni 1
91300 Massy, France
Tel: 33-1-69-53-63-20 Fax: 33-1-69-30-90-79

United Kingdom
Microchip Ltd.
505 Eskdale Road
Winnersh Triangle
Wokingham
Berkshire, England RG41 5TU
Tel: 44 118 921 5869 Fax: 44-118 921-5820

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