# TC642

## PWM Fan Speed Controller with 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 TC642 Supply Voltage
  - Supports any Fan Voltage
- FanSense™ Fault Detection Circuits Protect Against Fan Failure and Aid System Testing
- Shutdown Mode for "Green" Systems
- Supports Low Cost NTC/PTC Thermistors
- Space Saving 8-Pin MSOP Package
- Over-temperature Indication

### Applications

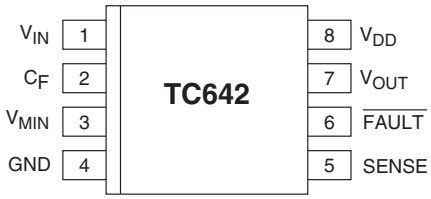
- Power Supplies
- Personal Computers
- File Servers
- Telecom Equipment
- UPSs, Power Amps, etc.
- General Purpose Fan Speed Control

### Available Tools

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

### Package Types

**SOIC/PDIP/MSOP**




### General Description

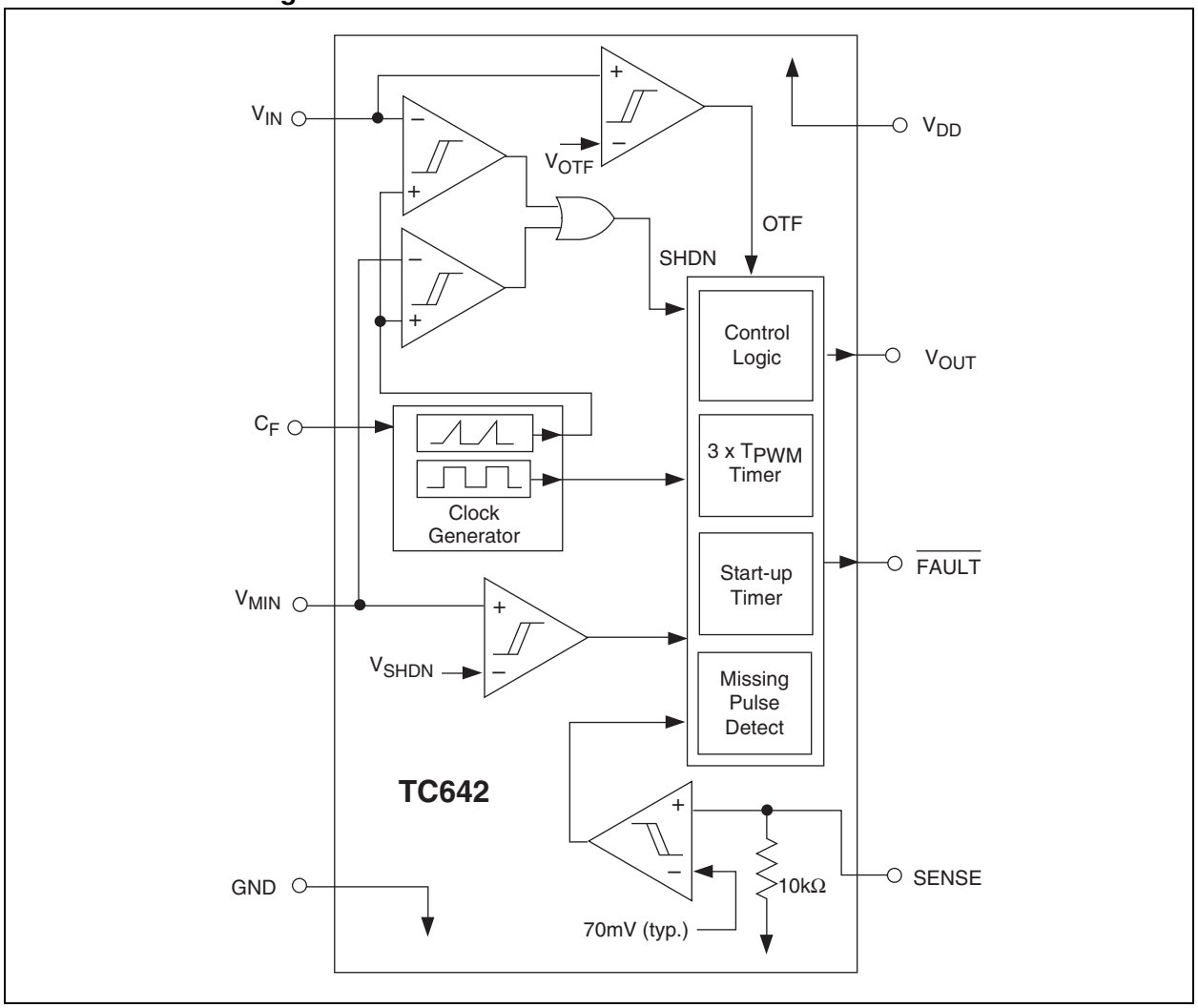
The TC642 is a switch mode fan speed controller for use with brushless DC fans. Temperature proportional speed control is accomplished using pulse width modulation (PWM). A thermistor (or other voltage output temperature sensor) connected to the $V_{IN}$ input furnishes the required control voltage of 1.25V to 2.65V (typical) for 0% to 100% PWM duty cycle. Minimum fan speed is set by a simple resistor divider on the $V_{MIN}$ input. An integrated Start-up Timer ensures reliable motor start-up at turn-on, coming out of shutdown mode or following a transient fault. A logic low applied to $V_{MIN}$ (Pin 3) causes fan shutdown.

The TC642 also features 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 TC642 to trigger its Start-up Timer once. If the fault persists, the $\overline{FAULT}$ output goes low and the device is latched in its shutdown mode. $\overline{FAULT}$ is also asserted if the PWM reaches 100% duty cycle, indicating a possible thermal runaway situation, although the fan continues to run. See Section 5.0, “Typical Applications”, for more information and system design guidelines.

The TC642 is available in the standard 8-pin plastic DIP, SOIC and MSOP packages and is available in the commercial, extended commercial and industrial temperature ranges.

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## Functional Block Diagram





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## 1.0 ELECTRICAL CHARACTERISTICS

**Absolute Maximum Ratings***

Supply Voltage ..... 6V

Input Voltage, Any Pin .... (GND – 0.3V) to ($V_{DD}$ +0.3V)

Package Thermal Resistance:

PDIP ($R_{\theta JA}$) ..... 125°C/W
SOIC ($R_{\theta JA}$) ..... 155°C/W
MSOP ($R_{\theta JA}$) ..... 200°C/W

Specified Temperature Range ..... -40°C to +125°C

Storage Temperature Range ..... -65°C to +150°C

*Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only and functional operation of the device at these or any other conditions above those indicated in the operation sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

### ELECTRICAL SPECIFICATIONS

**Electrical Characteristics:** $T_{MIN} < T_A < T_{MAX}$, $V_{DD}$ = 3.0V to 5.5V, unless otherwise specified.

| Symbol | Parameter | Min | Typ | Max | Units | Test Conditions |
|---|---|---|---|---|---|---|
| $V_{DD}$ | Supply Voltage | 3.0 | — | 5.5 | V | |
| $I_{DD}$ | Supply Current, Operating | — | 0.5 | 1.0 | mA | Pins 6, 7 Open, $C_F$ = 1 µF, $V_{IN} = V_{C(MAX)}$ |
| $I_{DD(SHDN)}$ | Supply Current, Shutdown Mode | — | 25 | — | µA | Pins 6, 7 Open, $C_F$ = 1 µF, $V_{MIN}$ = 0.35V, **Note 1** |
| $I_{IN}$ | $V_{IN}$, $V_{MIN}$ Input Leakage | - 1.0 | — | +1.0 | µA | **Note 1** |
| **$V_{OUT}$ Output** | | | | | | |
| $t_R$ | $V_{OUT}$ Rise Time | — | — | 50 | µsec | $I_{OH}$ = 5 mA, **Note 1** |
| $t_F$ | $V_{OUT}$ Fall Time | — | — | 50 | µsec | $I_{OL}$ = 1 mA, **Note 1** |
| $t_{SHDN}$ | Pulse Width (On $V_{MIN}$) to Clear Fault Mode | 30 | — | — | µsec | $V_{SHDN}$, $V_{HYST}$ Specifications, **Note 1** |
| $I_{OL}$ | Sink Current at $V_{OUT}$ Output | 1.0 | — | — | mA | $V_{OL}$ = 10% of $V_{DD}$ |
| $I_{OH}$ | Source Current at $V_{OUT}$ Output | 5.0 | — | — | mA | $V_{OH}$ = 80% of $V_{DD}$ |
| **$V_{IN}$, $V_{MIN}$ Inputs** | | | | | | |
| $V_{C(MAX)}$, $V_{OTF}$ | Input Voltage at $V_{IN}$ or $V_{MIN}$ for 100% PWM 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 | |
| $V_{SHDN}$ | Voltage Applied to $V_{MIN}$ to ensure Shutdown Mode | — | — | $V_{DD}$ x 0.13 | V | |
| $V_{REL}$ | Voltage Applied to $V_{MIN}$ to Release Shutdown Mode | $V_{DD}$ x 0.19 | — | — | V | $V_{DD}$ = 5V |
| **Pulse Width Modulator** | | | | | | |
| $F_{PWM}$ | PWM Frequency | 26 | 30 | 34 | Hz | $C_F$ = 1.0 µF |
| **SENSE Input** | | | | | | |
| $V_{TH(SENSE)}$ | SENSE Input Threshold Voltage with Respect to GND | 50 | 70 | 90 | mV | **Note 1** |
| **$\overline{FAULT}$ Output** | | | | | | |
| $V_{OL}$ | Output Low Voltage | — | — | 0.3 | V | $I_{OL}$ = 2.5 mA |
| $t_{MP}$ | Missing Pulse Detector Timer | — | 32/F | — | Sec | |
| $t_{STARTUP}$ | Start-up Timer | — | 32/F | — | Sec | |
| $t_{DIAG}$ | Diagnostic Timer | — | 3/F | — | Sec | |

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

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## 2.0 PIN DESCRIPTIONS

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

**TABLE 2-1: PIN FUNCTION TABLE**

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

### 2.1 Analog Input ($V_{IN}$)

The thermistor network (or other temperature sensor) connects to the $V_{IN}$ input. A voltage range of 1.25V to 2.65V (typical) on this pin drives an active duty cycle of 0% to 100% on the $V_{OUT}$ pin.

### 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 ($V_{MIN}$)

An external resistor divider connected to the $V_{MIN}$ input sets the minimum fan speed by fixing the minimum PWM duty cycle (1.25V to 2.65V = 0% to 100%, typical). The TC642 enters shutdown mode when $V_{MIN} \leq V_{SHDN}$. During shutdown, the $\overline{FAULT}$ output is inactive and supply current falls to 25 µA (typical). The TC642 exits shutdown mode when $V_{MIN} \geq V_{REL}$ (see Section 5.0, “Typical Applications”).

### 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. The absence of pulses indicates a fault.

### 2.6 Digital Output ($\overline{FAULT}$)

The $\overline{FAULT}$ line goes low to indicate a fault condition. When $\overline{FAULT}$ goes low due to a fan fault condition, the device is latched in shutdown mode until deliberately cleared or until power is cycled. $\overline{FAULT}$ may be connected to $V_{MIN}$ if a hard shutdown is desired. $\overline{FAULT}$ will also be asserted when the PWM reaches 100% duty cycle, indicating that maximum cooling capability has been reached and a possible over-temperature condition may occur. This is a non-latching state and the $\overline{FAULT}$ output will go high when the PWM duty cycle goes below 100%.

### 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”).


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## 3.0 DETAILED DESCRIPTION

### 3.1 PWM

The PWM circuit consists of a ramp generator and threshold detector. The frequency of the PWM is determined by the value of the capacitor connected to the $C_F$ input. A frequency of 30 Hz is recommended ($C_F$ = 1 µF). The PWM is also the time base for the Start-up Timer (see Section 3.4, “Start-Up Timer”). The PWM voltage control range is 1.25V to 2.65V (typical) for 0% to 100% output duty cycle.

### 3.2 $\overline{\text{FAULT}}$ Output

The TC642 detects faults in two ways.

First, pulses appearing at SENSE due to the PWM turning on are blanked, with the remaining pulses filtered by a missing pulse detector. If consecutive pulses are not detected for 32 PWM cycles (≅1 Sec if $C_F$ = 1 µF), the Diagnostic Timer is activated, and $V_{OUT}$ is driven high continuously for three PWM cycles (≅100 msec if $C_F$ = 1 µF). If a pulse is not detected within this window, the Start-up Timer is triggered (see Section 3.4). This should clear a transient fault condition. If the missing pulse detector times out again, the PWM is stopped and $\overline{\text{FAULT}}$ goes low. When $\overline{\text{FAULT}}$ is activated due to this condition, the device is latched in shutdown mode and will remain off indefinitely.

| **Note:** | At this point, action *must* be taken to restart the fan by momentarily pulling $V_{MIN}$ below $V_{SHDN}$, or cycling system power. In either case, the fan *cannot* remain disabled due to a fault condition, as severe system damage could result. If the fan cannot be restarted, the system should be shut down. |
|---|---|

The TC642 may be configured to continuously attempt fan restarts, if so desired.

Continuous restart mode is enabled by connecting the $\overline{\text{FAULT}}$ output to $V_{MIN}$ through a 0.01 µF capacitor, as shown in Figure 3-1. When connected in this manner, the TC642 automatically attempts to restart the fan every time a fault condition occurs. When the $\overline{\text{FAULT}}$ output is driven low, the $V_{MIN}$ input is momentarily pulled below $V_{SHDN}$, initiating a reset and clearing the fault condition. Normal fan start-up is then attempted as previously described. The $\overline{\text{FAULT}}$ output may be connected to external logic (or the interrupt input of a microcontroller) to shut the TC642 down if multiple fault pulses are detected at approximately one second intervals. Diode $D_1$, capacitor $C_1$ and resistors $R_5$ and $R_6$ are provided to ensure fan restarts are the result of a fan fault and not an over-temperature fault. A CMOS logic OR gate may be substituted for these components, if available.

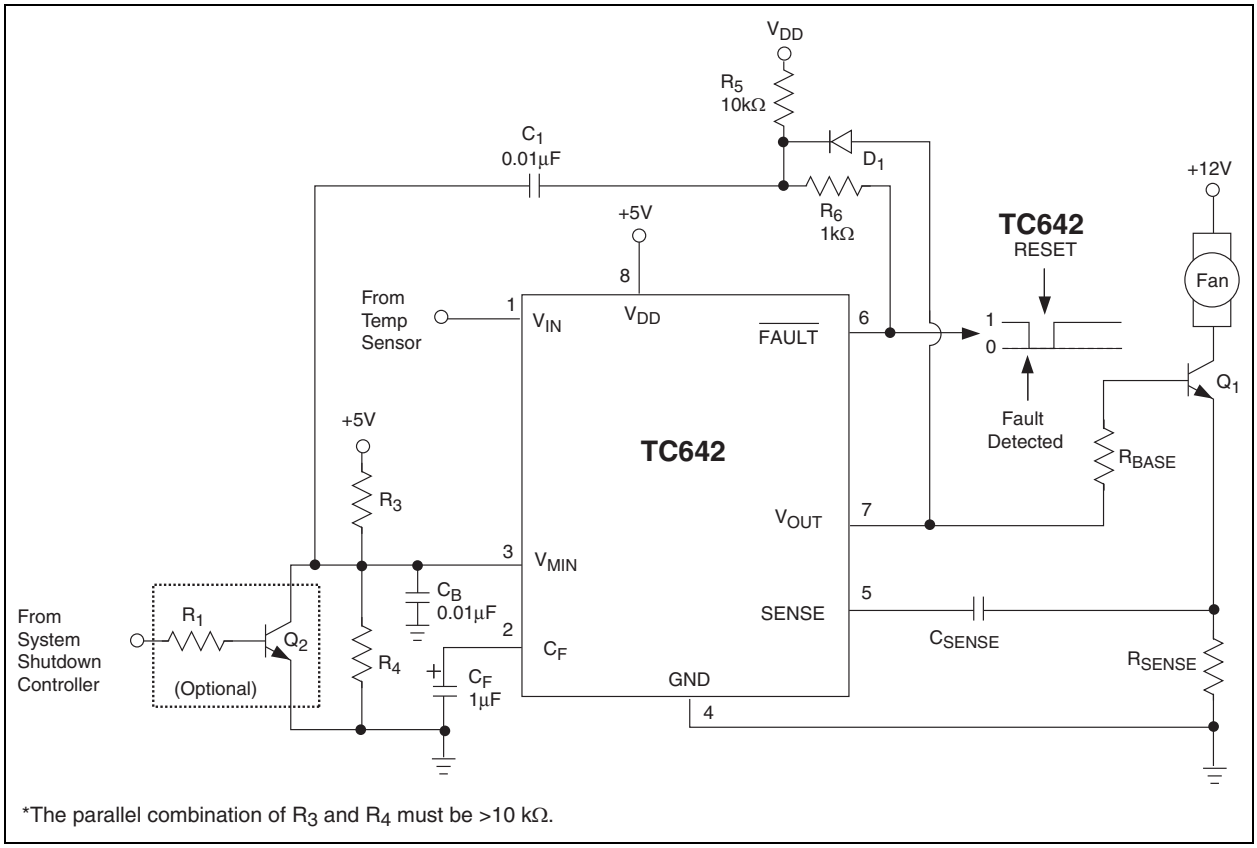



***FIGURE 3-1:*** *Fan Fault Output Circuit.*

The second condition by which the TC642 detects a fault is when the PWM control voltage applied to $V_{IN}$ becomes greater than that needed to drive 100% duty cycle (see Section 1.0, "Electrical Characteristics"). This indicates that the fan is at maximum drive and the potential exists for system overheating. Either heat dissipation in the system has gone beyond the cooling system's design limits or some subtle fault exists (such as fan bearing failure or an airflow obstruction). This output may be treated as a system overheat warning and be used to trigger system shutdown. However, in this case, the fan will continue to run even when $\overline{FAULT}$ is asserted. If a shutdown is desired, $\overline{FAULT}$ may be connected to $V_{MIN}$ outside the device. This will latch the TC642 in shutdown mode when any fault occurs.

## 3.3 $V_{OUT}$ Output

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

## 3.4 Start-Up Timer

To ensure reliable fan start-up, the Start-up Timer turns the $V_{OUT}$ output on for 32 cycles of the PWM whenever the fan is started from the off state. This occurs at power-up and when coming out of shutdown mode. If the PWM frequency is 30 Hz ($C_F$ = 1 µF), the resulting start-up time will be approximately one second. If a fault is detected, the Diagnostic Timer is triggered once, followed by the Start-up Timer. If the fault persists, the device is shut down (see Section 3.2, "$\overline{FAULT}$ Output").

## 3.5 Shutdown Control (Optional)

If $V_{MIN}$ (Pin 3) is pulled below $V_{SHDN}$, the TC642 will go into shutdown mode. This can be accomplished by driving $V_{MIN}$ with an open-drain logic signal or by using an external transistor, as shown in Figure 3-1. All functions are suspended until the voltage on $V_{MIN}$ becomes higher than $V_{REL}$ (0.85V @ $V_{DD}$ = 5.0V). Pulling $V_{MIN}$ below $V_{SHDN}$ will always result in complete device shutdown and reset. The $\overline{FAULT}$ output is unconditionally inactive in shutdown mode.

A small amount of hysteresis, typically one percent of $V_{DD}$ (50 mV at $V_{DD}$ = 5.0V), is designed into the $V_{SHDN}$ and $V_{REL}$ thresholds. The levels specified for $V_{SHDN}$ and $V_{REL}$ in Section 1.0, "Electrical Characteristics", include this hysteresis, plus adequate margin to account for normal variations in the absolute value of the threshold and hysteresis.

**CAUTION:** Shutdown mode is unconditional. That is, the fan will not be activated regardless of the voltage at $V_{IN}$. The fan should not be shut down until all heat producing activity in the system is at a negligible level.

## 3.6 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 mode, and pulses are not appearing at the SENSE input, a fault exists.

The short, rapid change in fan current (high dI/dt) causes a corresponding dV/dt across the sense resistor, $R_{SENSE}$. The waveform on $R_{SENSE}$ is differentiated and converted to a logic-level pulse-train by $C_{SENSE}$ 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).


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## 4.0 SYSTEM BEHAVIOR

The flowcharts describing the TC642'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 mode ($V_{MIN} > V_{REL}$)…

(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 a 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 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 TC642 in shutdown? If so…

a. $V_{OUT}$ duty cycle goes to zero.
b. $\overline{FAULT}$ is disabled.
c. Exit the loop and wait for $V_{MIN} > V_{REL}$ to resume operation (indistinguishable from power-up).

(3) If an over-temperature fault occurs ($V_{IN} > V_{OTF}$), activate $\overline{FAULT}$; release $\overline{FAULT}$ when $V_{IN} < V_{OTF}$.

(4) Drive $V_{OUT}$ to a duty cycle proportional to the greater of $V_{IN}$ and $V_{MIN}$ on a cycle by cycle basis.

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

(6) If the missing pulse detector times out …

(7) 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…

(8) 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…

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

(10) End.

### 4.3 Fan Fault

Fan fault is an infinite loop wherein the TC642 is latched in shutdown mode. This mode can only be released by a reset (i.e., $V_{MIN}$ being brought below $V_{SHDN}$, then above $V_{REL}$, or by power-cycling).

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

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

(3) End.

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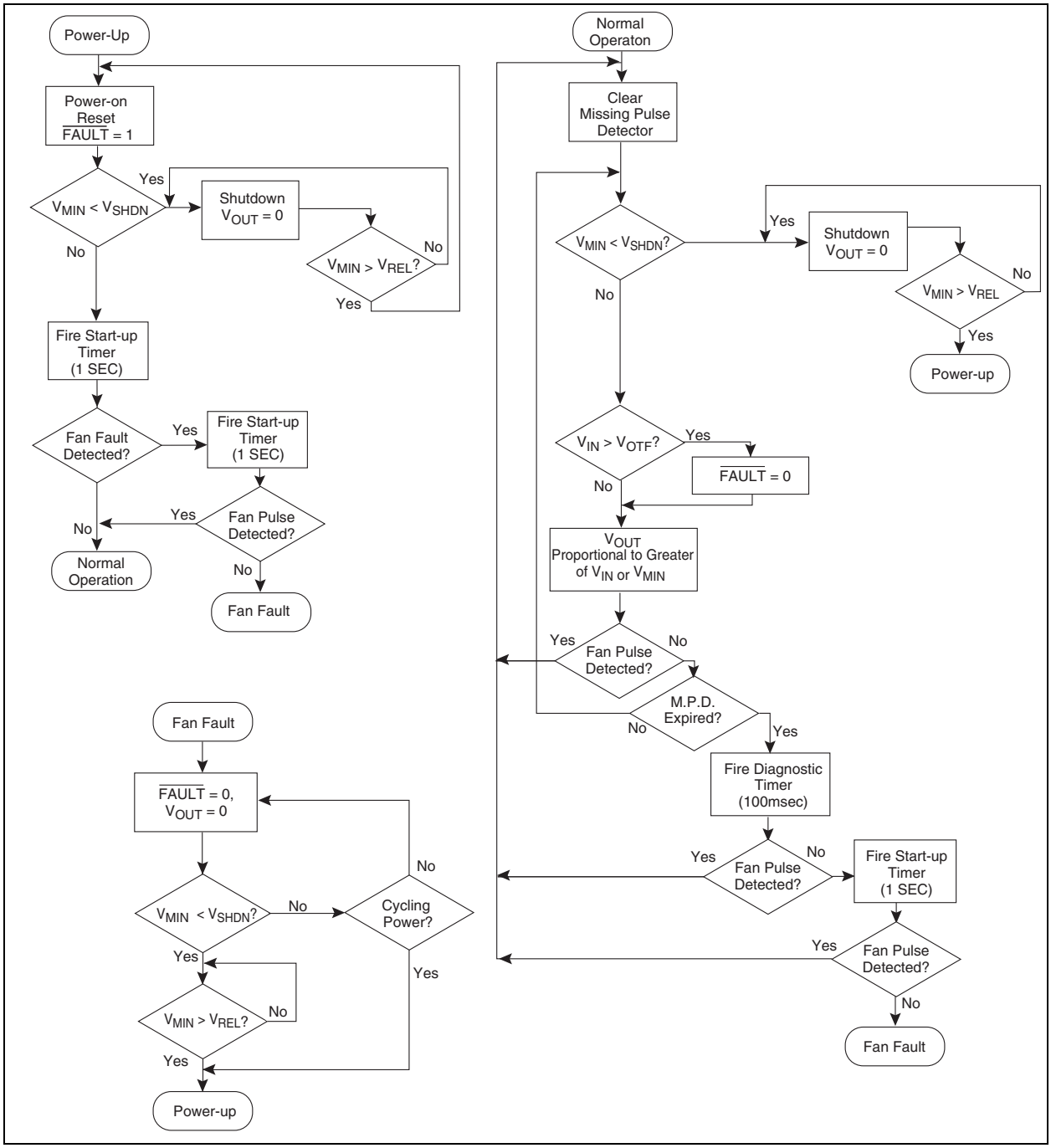



***FIGURE 4-1:*** *TC642 Behavioral Algorithm Flowchart.*


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## 5.0 TYPICAL APPLICATIONS

Designing with the TC642 involves the following:

(1) The temp sensor network must be configured to deliver 1.25V to 2.65V on $V_{IN}$ for 0% to 100% of the temperature range to be regulated.

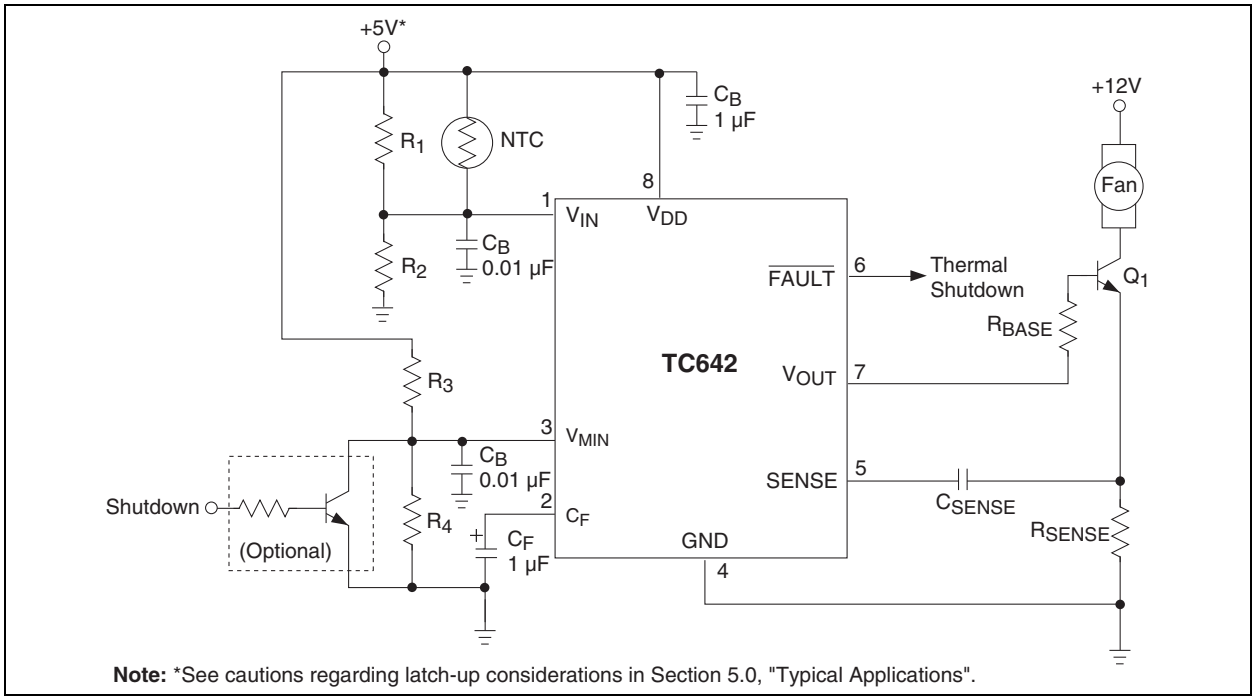
(2) The minimum fan speed ($V_{MIN}$) must be set.

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

(4) The SENSE network, $R_{SENSE}$ and $C_{SENSE}$, 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 TC642 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 TC642 should consult the documentation for both TC642EV (DS21403) and TC642DEMO (DS21401).




**Note:** *See cautions regarding latch-up considerations in Section 5.0, "Typical Applications".

***FIGURE 5-1:*** *Typical Application Circuit.*

### 5.1 Temperature Sensor Design

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

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.

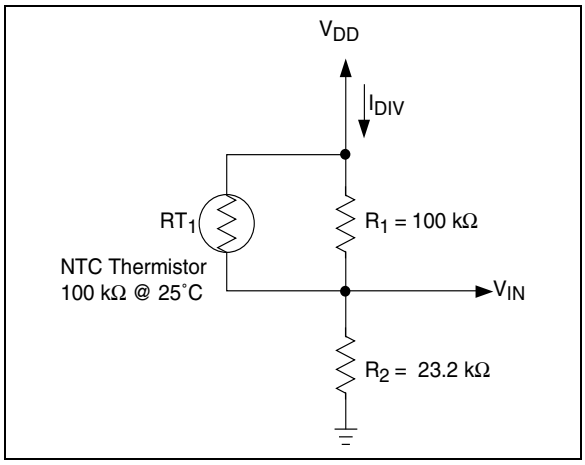



***FIGURE 5-2:*** *Temperature Sensing Circuit.*

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, while $R_2$ 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 TC642. 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. With this change, $R_2$ is adjusted according to the formulas below. It is suggested that a maximum temperature range of 50°C be used with this circuit due to thermistor linearity limitations.

The following two equations permit solving for the two unknown variables, $R_1$ and $R_2$. More information regarding thermistors can be found in AN679, "Temperature Sensing Technologies", and AN685, "Thermistors in Single Supply Temperature Sensing Circuits", which can be downloaded from Microchip's web site at: www.microchip.com.

**EQUATION**

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

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

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

## 5.2 Minimum Fan Speed

A voltage divider on $V_{MIN}$ sets the minimum PWM duty cycle and, thus, the minimum fan speed. As with the $V_{IN}$ input, 1.25V to 2.65V typically corresponds to 0% to 100% duty cycle. Assuming that fan speed is linearly related to duty cycle, the minimum speed voltage is given by the equation:

**EQUATION**

$$V_{MIN} = \frac{Minimum\ Speed}{Full\ Speed}\ x\ (1.4) + 1.25V$$

For example, if 2500 RPM equates to 100% fan speed, and a minimum speed of 1000 RPM is desired, then the $V_{MIN}$ voltage is:

**EQUATION**

$$V_{MIN} = \frac{1000}{2500}\ x\ (1.4) + 1.25V = 1.81V$$

The $V_{MIN}$ voltage may be set using a simple resistor divider, as shown in Figure 5-3. Per Section 1.0, "Electrical Characteristics", the leakage current at the $V_{MIN}$ pin is no more than 1 µA. It would be very conservative to design for a divider current, $I_{DIV}$, of 100 µA. If $V_{DD}$ = 5.0V then;

**EQUATION**

$$I_{DIV} = 100\mu A = \frac{5.0V}{R_1 + R_2},\ therefore$$

$$R_1 + R_2 = \frac{5.0V}{100\mu A} = 50{,}000\Omega = 50k\Omega$$

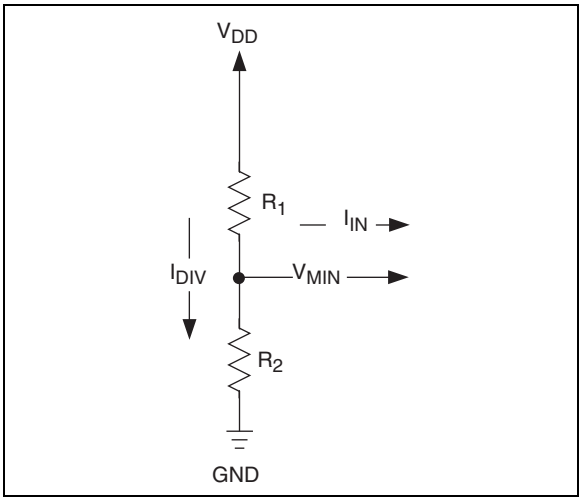



***FIGURE 5-3:*** *$V_{IN}$ Circuit.*


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

**EQUATION**

$$V_{MIN} = \frac{V_{DD} \, x \, R_2}{R_1 + R_2}$$

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

**EQUATION**

$$R_1 = R_2 \, x \, \frac{V_{DD} - V_{MIN}}{V_{MIN}}$$

In this example, $R_1 = (1.762) R_2$. Substituting this relationship back into the previous equation yields the resistor values:

$$R_2 = 18.1 \text{ k}\Omega, \text{ and } R_1 = 31.9 \text{ k}\Omega$$

In this case, the standard values of 31.6 kΩ and 18.2 kΩ 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 TC642 "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 TC642 may fail to capture a pulse within the 32-cycle missing pulse detector window. When 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 $V_{MIN}$ 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 TC642 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.

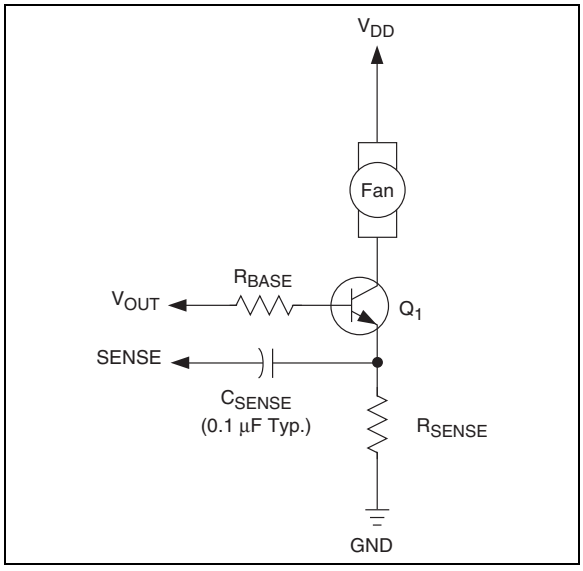



***FIGURE 5-4:*** *SENSE Network.*

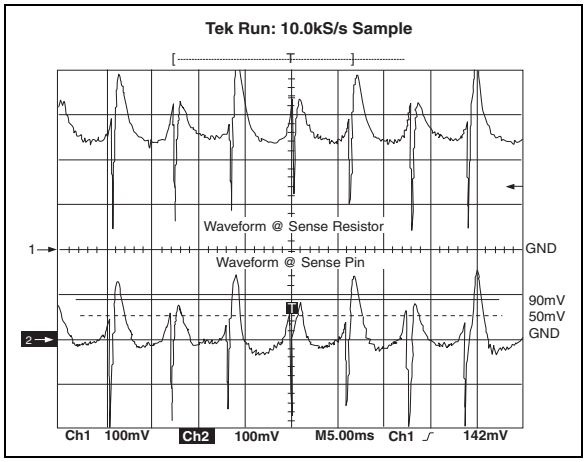



***FIGURE 5-5:*** *SENSE Waveforms.*

Table 5-1 lists recommended values for $R_{SENSE}$ 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: $R_{SENSE}$ VS. FAN CURRENT**

| Nominal Fan Current (mA) | $R_{SENSE}$ (Ω) |
|---|---|
| 50 | 9.1 |
| 100 | 4.7 |
| 150 | 3.0 |
| 200 | 2.4 |
| 250 | 2.0 |
| 300 | 1.8 |
| 350 | 1.5 |
| 400 | 1.3 |
| 450 | 1.2 |
| 500 | 1.0 |

## 5.5 Output Drive Transistor Selection

The TC642 is designed to drive an external transistor or MOSFET for modulating power to the fan. This is shown as $Q_1$ in Figures 3-1, 5-1, 5-4, 5-6, 5-7, 5-8 and 5-9. The $V_{OUT}$ pin has a minimum source current of 5 mA and a minimum sink current of 1 mA. Bipolar transistors or MOSFETs may be used as the power switching element, as shown in Figure 5-7. When high current gain is needed to drive larger fans, two transistors may be used in a Darlington configuration. Three possible circuit topologies are shown in Figure 5-7: (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 TC642'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".

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 $Q_1$ are: (1) the breakdown voltage ($V_{(BR)CEO}$ or $V_{DS}$ (MOSFET)) must be large enough to withstand the highest voltage applied to the fan (**Note:** This will occur when the fan is off); (2) 5 mA of base drive current must be enough to saturate the transistor when conducting the full fan current (transistor must have sufficient gain); (3) the $V_{OUT}$ voltage must be high enough to sufficiently drive the gate of the MOSFET to minimize the $R_{DS(on)}$ of the device; (4) rated fan current draw must be within the transistor's/MOSFET's current handling capability; and (5) power dissipation must be kept within the limits of the chosen device.

A base-current limiting resistor is required with bipolar transistors (Figure 5-6).

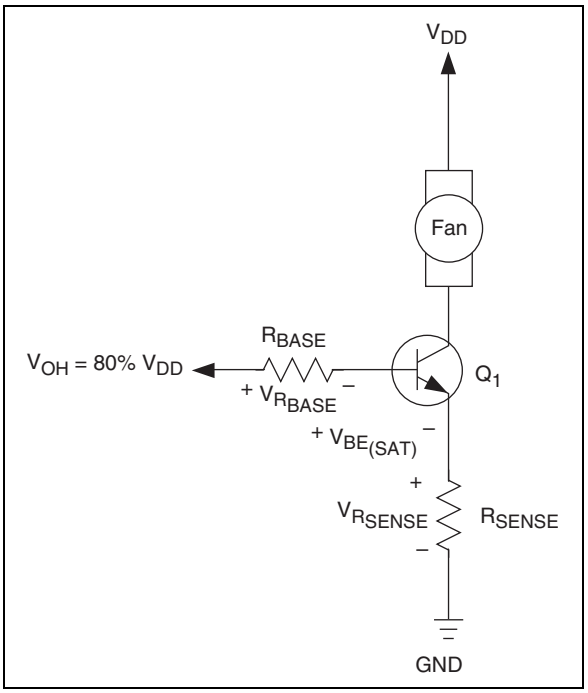



***FIGURE 5-6:*** *Circuit For Determining $R_{BASE}$.*

The correct value for this resistor can be determined as follows:

$$V_{OH} = V_{R_{SENSE}} + V_{BE(SAT)} + V_{R_{BASE}}$$
$$V_{R_{SENSE}} = I_{FAN} \times R_{SENSE}$$
$$V_{R_{BASE}} = R_{BASE} \times I_{BASE}$$
$$I_{BASE} = I_{FAN} / h_{FE}$$

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

**EQUATION**

$$R_{BASE} = \frac{V_{OH} - V_{BE(SAT)} - V_{R_{SENSE}}}{I_{BASE}}$$


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Some applications require the fan to be powered from the negative 12V supply to keep motor noise out of the positive voltage power supplies. As is shown in Figure 5-8, zener diode $D_1$ offsets the -12V power supply voltage, holding transistor $Q_1$ off when $V_{OUT}$ is low.

When $V_{OUT}$ is high, the voltage at the anode of $D_1$ increases by $V_{OUT}$, causing $Q_1$ to turn on. Operation is otherwise consistent with the case of fan operation from +12V.

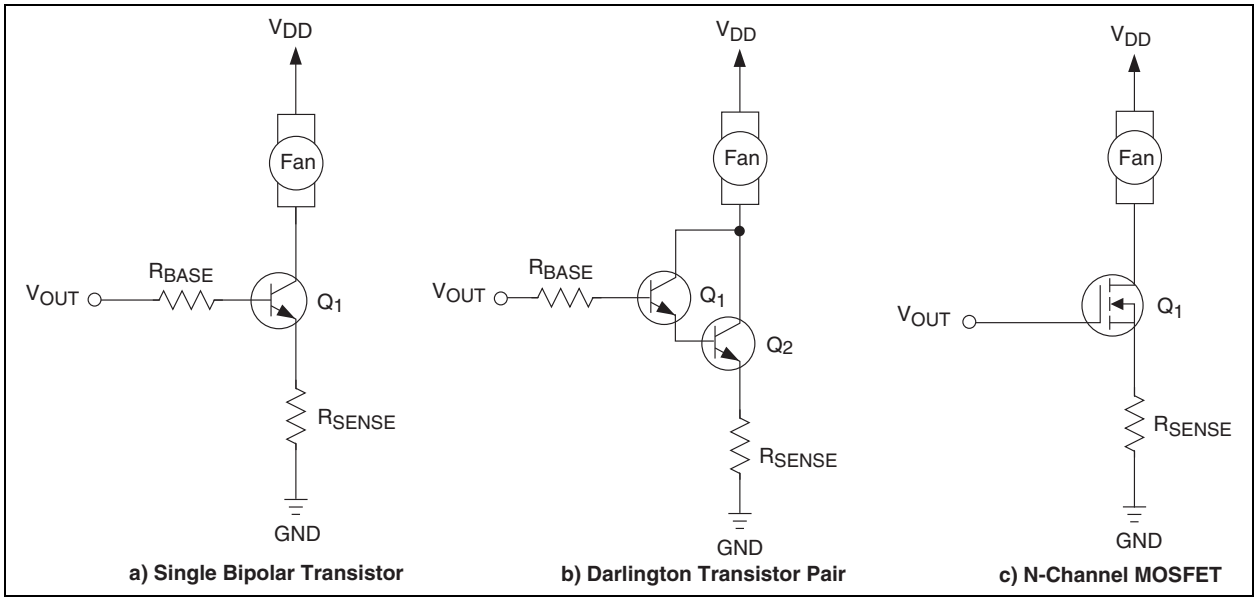



***FIGURE 5-7:*** *Output Drive Transistor Circuit Topologies.*

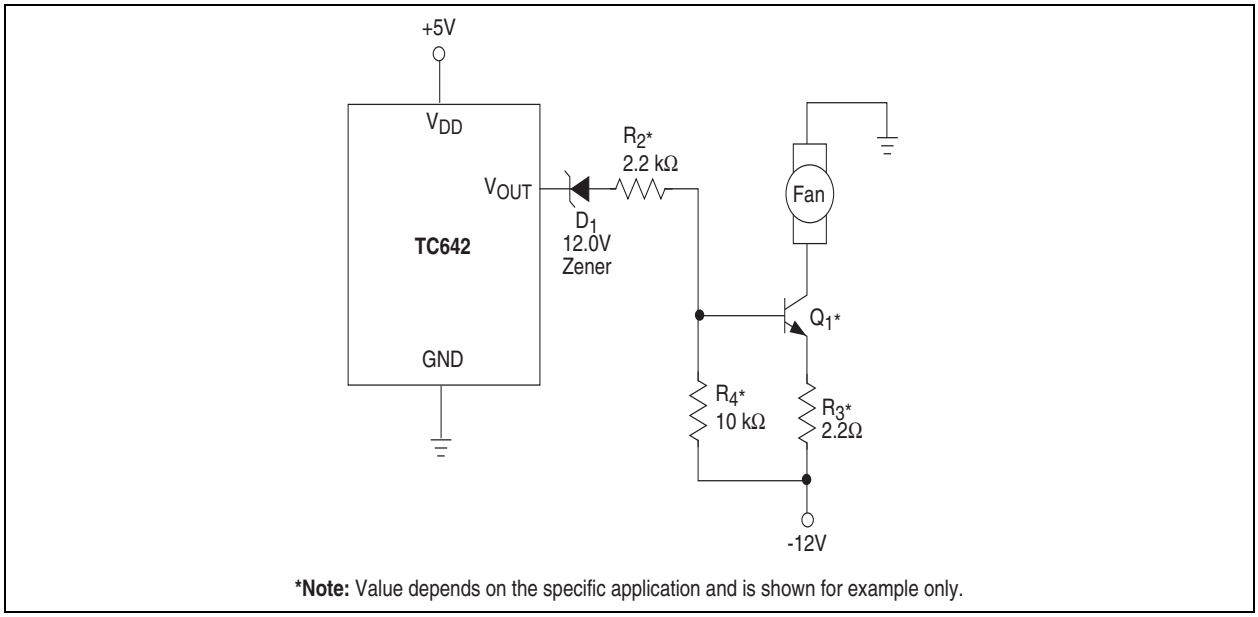



***FIGURE 5-8:*** *Powering the Fan From a -12V Supply.*

**TABLE 5-2: TRANSISTORS AND MOSFETS FOR $Q_1$ ($V_{DD}$ = 5V)**

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

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

## 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, $V_{MIN}$ divider or shutdown circuit) is powered by a supply different from that of the TC642. Care should be taken to ensure that the TC642's $V_{DD}$ supply powers up first. If possible, the networks attached to $V_{IN}$ and $V_{MIN}$ should connect to the $V_{DD}$ supply at the same physical location as the IC itself. Even if the IC and any external networks are powered by the same supply, physical separation of the connecting points can result in enough parasitic capacitance and/or inductance in the power supply connections to delay one power supply "routing" versus another.


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## 5.7 Power Supply Routing and Bypassing

Noise present on the $V_{IN}$ and $V_{MIN}$ inputs may cause erroneous operation of the $\overline{FAULT}$ output. As a result, these inputs should be bypassed with a 0.01 µF capacitor mounted as close to the package as is possible. This is particularly true of $V_{IN}$, which is usually driven from a high impedance source (such as a thermistor). In addition, the $V_{DD}$ input should be bypassed with a 1 µF capacitor. Grounds should be kept as short as possible. To keep fan noise off the TC642 ground pin, individual ground returns for the TC642 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 $T_{MIN}$ (25°C) and 4.65 kΩ at $T_{MAX}$ (45°C) (see Figure 5-9).

$R_1$ = 20.5 kΩ
$R_2$ = 3.83 kΩ

**Step 2.** Set minimum fan speed $V_{MIN}$ = 1.8V. Limit the divider current to 100 µA from which $R_5$ = 33 kΩ and $R_6$ = 18 kΩ.

**Step 3.** Design the output circuit.

Maximum fan motor current = 250 mA.
$Q_1$ beta is chosen at 50 from which
$R_7$ = 800 Ω.

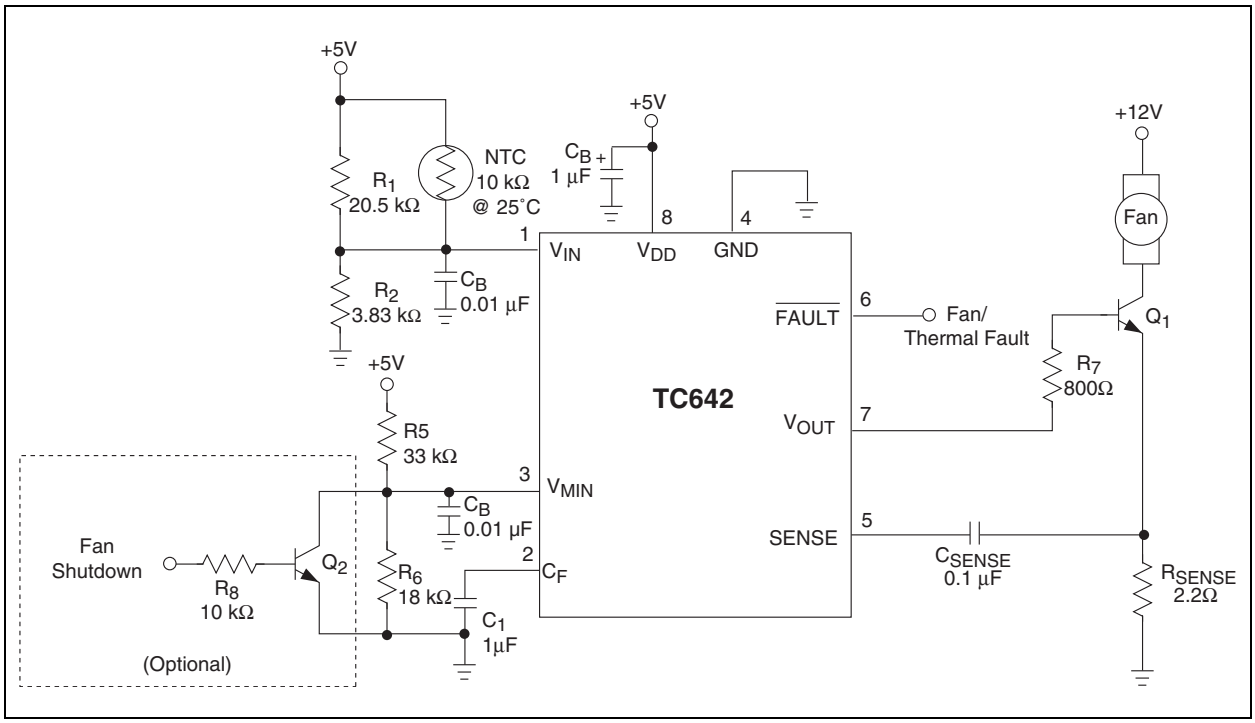



***FIGURE 5-9:*** *Design Example.*

## 5.8 TC642 as a Microcontroller Peripheral

In a system containing a microcontroller or other host intelligence, the TC642 can be effectively managed as a CPU peripheral. Routine fan control functions can be performed by the TC642 without processor intervention. The microcontroller receives temperature data from one or more points throughout the system. It calculates a fan operating speed based on an algorithm specifically designed for the application at hand. The processor controls fan speed using complementary port bits I/O1 through I/O3. Resistors $R_1$ through $R_6$ (5% tolerance) form a crude 3-bit DAC that translates the 3-bit code from the processor's outputs into a 1.6V DC control signal. A monolithic DAC or digital pot may be used instead of the circuit shown in Figure 5-10.

With $V_{MIN}$ set to 1.8V, the TC642 has a minimum operating speed of approximately 40% of full rated speed when the processor's output code is 000[B]. Output codes 001[B] to 111[B] operate the fan from roughly 40% to 100% of full speed. An open-drain output from the processor (I/O0) can be used to reset the TC642 following detection of a fault condition. The $\overline{FAULT}$ output can be connected to the processor's interrupt input, or to an I/O pin, for polled operation.

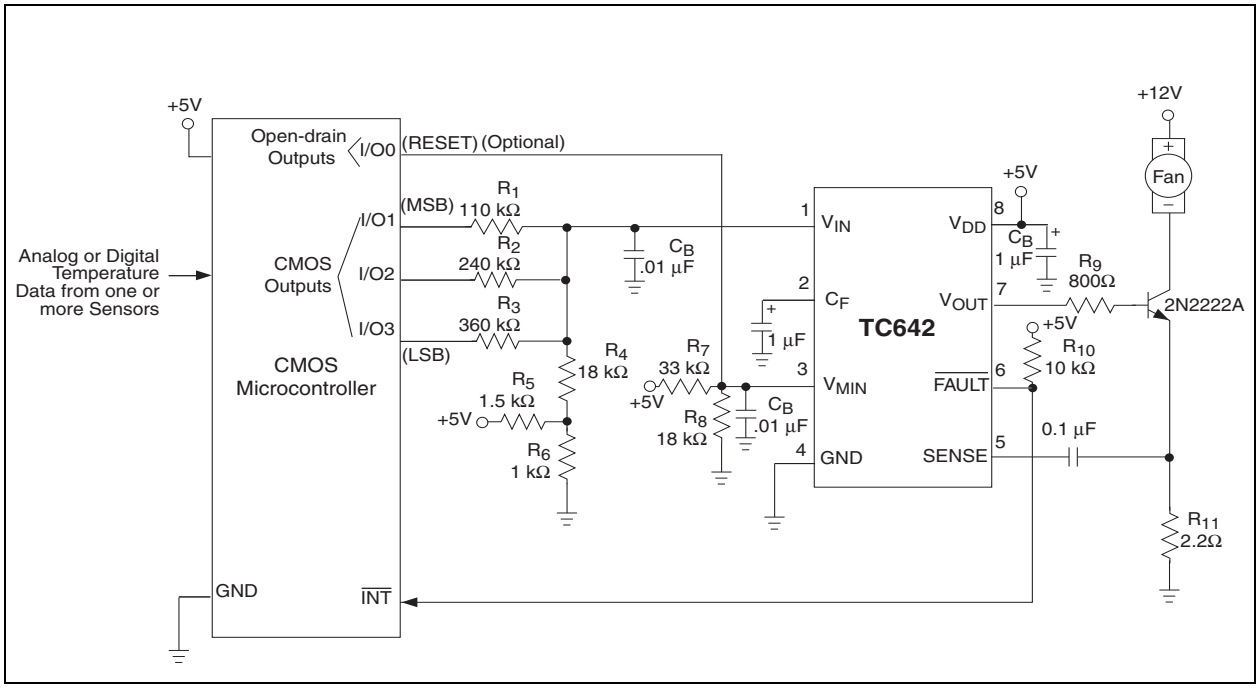


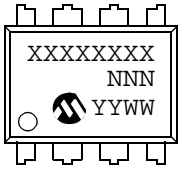

***FIGURE 5-10:*** *TC642 as a Microcontroller Peripheral.*


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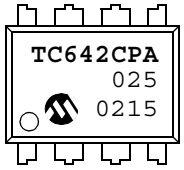
## 6.0 PACKAGING INFORMATION

### 6.1 Package Marking Information

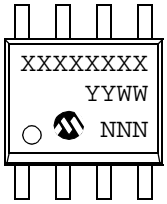
8-Lead PDIP (300 mil)



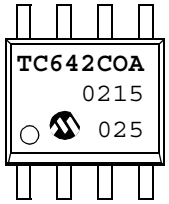

Example:



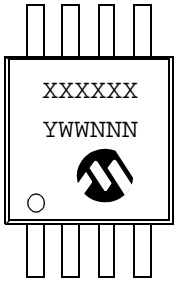

8-Lead SOIC (150 mil)



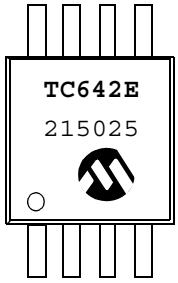

Example:




8-Lead MSOP




Example:



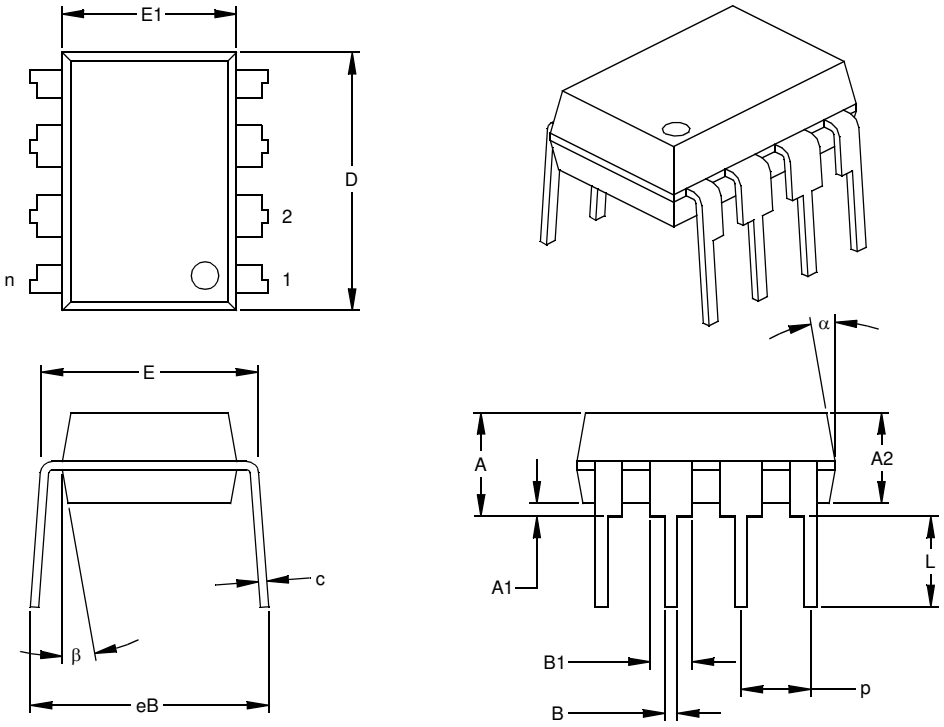

| | | |
|---|---|---|
| **Legend:** | XX...X | Customer specific information* |
| | YY | Year code (last 2 digits of calendar year) |
| | WW | Week code (week of January 1 is week ‘01’) |
| | NNN | Alphanumeric traceability code |

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




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

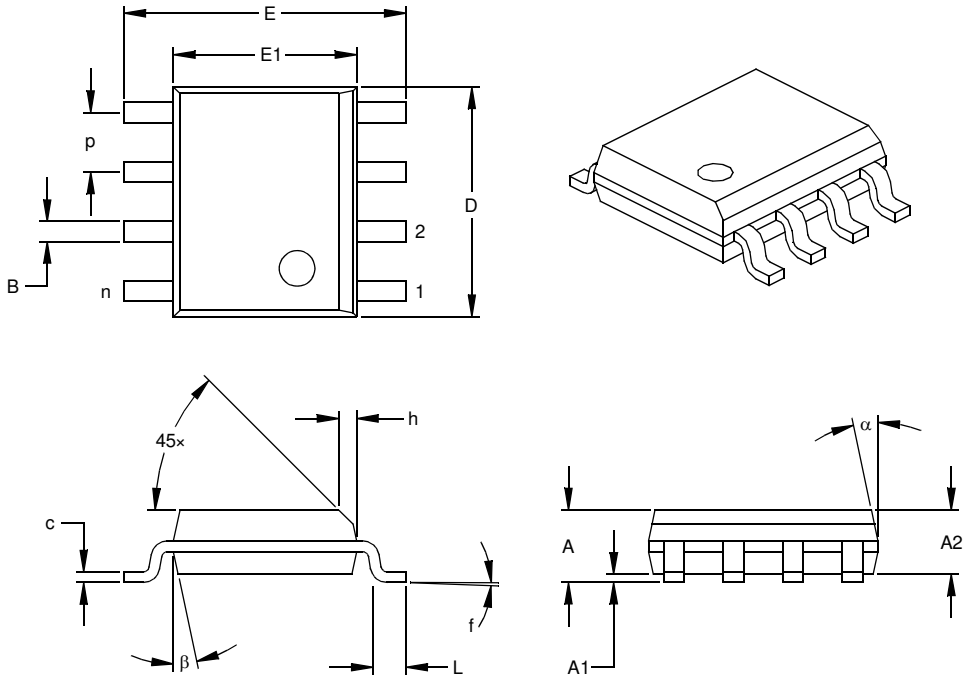
* Controlling Parameter
§ Significant Characteristic

**Notes:**
Dimensions D and E1 do not include mold flash or protrusions. Mold flash or protrusions shall not exceed .010" (0.254mm) per side.
JEDEC Equivalent: MS-001
Drawing No. C04-018


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

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



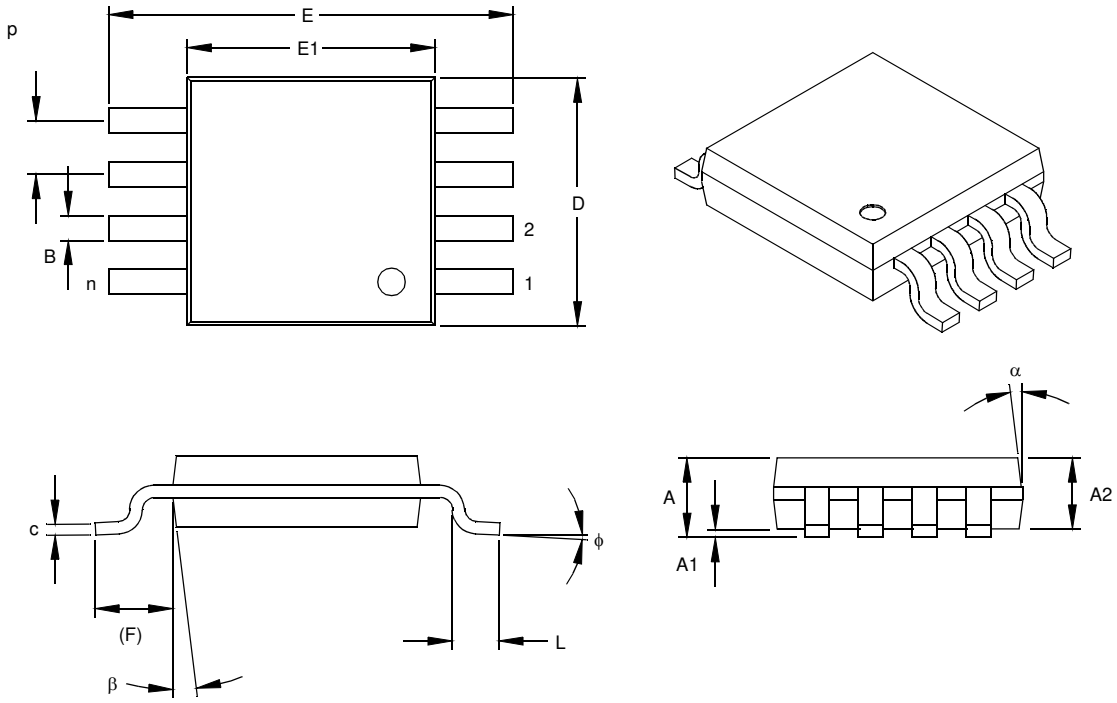

| Units | | INCHES* | | | MILLIMETERS | | |
|---|---|---|---|---|---|---|---|
| Dimension Limits | | MIN | NOM | MAX | MIN | NOM | MAX |
| Number of Pins | n | | 8 | | | 8 | |
| Pitch | p | | .050 | | | 1.27 | |
| Overall Height | A | .053 | .061 | .069 | 1.35 | 1.55 | 1.75 |
| Molded Package Thickness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

* Controlling Parameter
§ Significant Characteristic

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

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

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




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

*Controlling Parameter
§ Significant Characteristic

Notes:

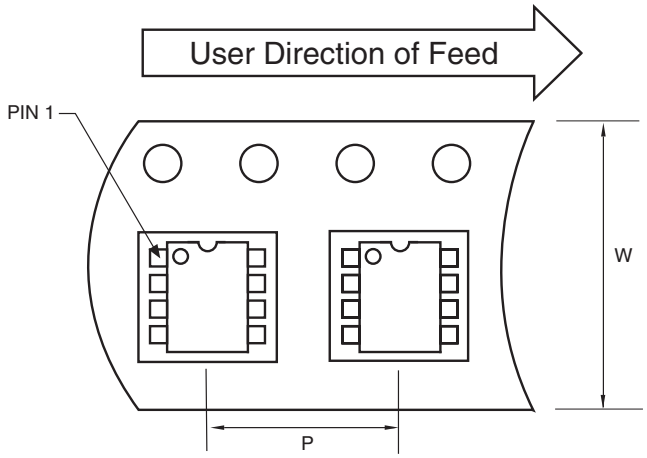
Dimensions D and E1 do not include mold flash or protrusions. Mold flash or protrusions shall not exceed. 010" (0.254mm) per side.

Drawing No. C04-111


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## 6.2 Taping Form

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

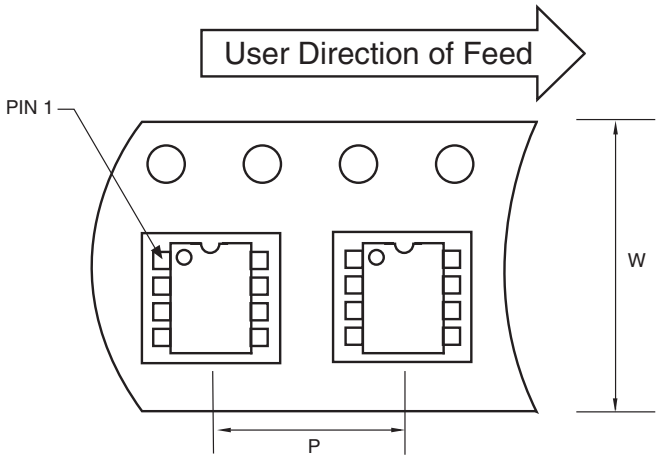



Standard Reel Component Orientation
for 713 Suffix Device

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

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

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




Standard Reel Component Orientation
for 713 Suffix Device

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

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

## 7.0 REVISION HISTORY

### Revision D (December 2012)

Added a note to each package outline drawing.


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

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

7. How would you improve this document?


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## PRODUCT IDENTIFICATION SYSTEM

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| PART NO. | X | /XX |
|---|---|---|
| Device | Temperature Range | Package |

| | | |
|---|---|---|
| Device: | TC642: | PWM Fan Speed Controller w/ Fault Detection |
| Temperature Range: | C = 0°C to +70°C<br>V = 0°C to +85°C<br>E = -40°C to +85°C | |
| Package: | PA = Plastic DIP (300 mil Body), 8-lead *<br>OA = Plastic SOIC, (150 mil Body), 8-lead<br>UA = Plastic Micro Small Outline (MSOP), 8-lead ** | |

* PDIP is only offered in the C and V temp ranges
** MSOP is only available in the V and E temp ranges

**Examples:**

a) TC642COA: PWM Fan Speed Controller w/ Fault Detection, SOIC package.

b) TC642COA713: PWM Fan Speed Controller w/ Fault Detection, SOIC package, Tape and Reel.

c) TC642CPA: PWM Fan Speed Controller w/ Fault Detection, PDIP package.

d) TC642EUA: PWM Fan Speed Controller w/ Fault Detection, MSOP package.

### Sales and Support

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