Fan Speed Controller with Auto-Shutdown

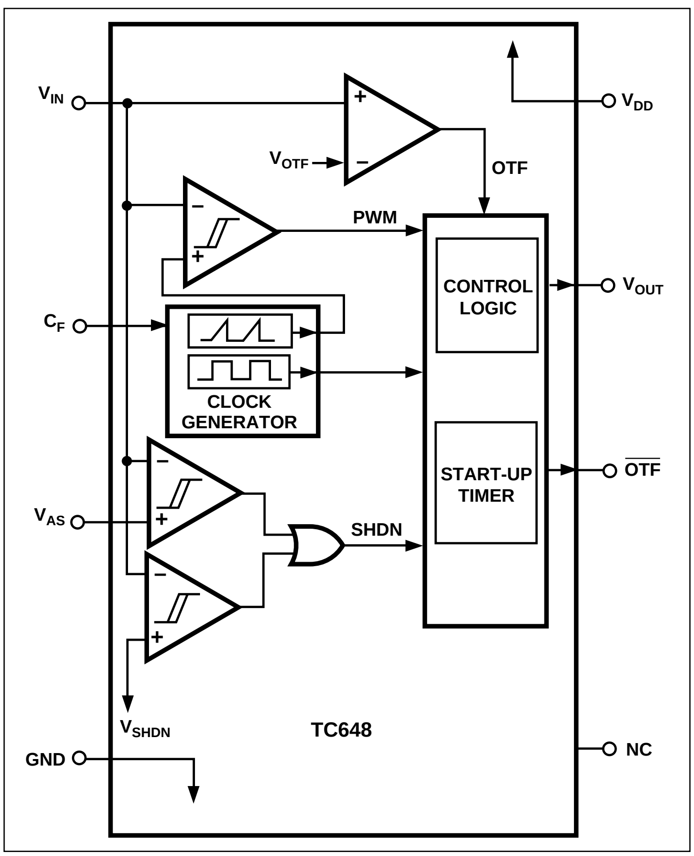
FEATURES

- **Temperature Proportional Fan Speed for Acoustic Control and Longer Fan Life**
- **Efficient PWM Fan Drive**
- **3.0V to 5.5V Supply Range; Fan Voltage Independent of TC648 Supply Voltage - Supports Any Fan Voltage!**
- **Over-Temperature Fault Detection**
- **Automatic Shutdown Mode for "Green" Systems**
- **Supports Low Cost NTC/PTC Thermistors**
- **Space-Saving 8-Pin PDIP and SOIC Packages**

APPLICATIONS

- **Power Supplies**
- **Computers**
- **Telecom Equipment**
- **Portable Computers**
- **UPS's, Power Amps, etc.**
- **General Purpose Fan Speed Control**

FUNCTIONAL BLOCK DIAGRAM



GENERAL DESCRIPTION

The TC648 is a switch mode fan speed controller for use with brushless DC motors. Temperature proportional speed control is accomplished using pulse width modulation (PWM). A thermistor (or other voltage output temperature sensor) connected to the V_{IN} input furnishes the required control voltage of 1.25V to 2.65V (typical) for 0% to 100% PWM duty cycle. The TC648 can be configured to operate in either Auto-Shutdown or Minimum Speed mode. In Auto-Shutdown mode, fan operation is automatically suspended when measured temperature (V_{IN}) is lower than a user-programmed minimum setting (V_{AS}). The fan is automatically restarted and proportional speed control restored when V_{IN} exceeds V_{AS} (plus hysteresis). Operation in Minimum Speed mode is similar to Auto-Shutdown mode, except the fan is operated at a user-programmed minimum setting when measured temperature is low. An integrated Start-Up Timer ensures reliable motor start-up at turn-on, or when coming out of Shutdown mode.

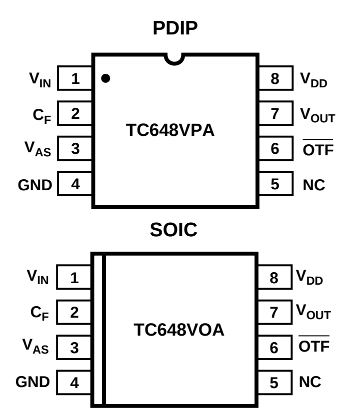
The over-temperature fault ($\overline{OTF}$) is asserted when the PWM reaches 100% duty cycle, indicating a possible thermal runaway situation.

The TC648 is packaged in a space-saving 8-pin plastic DIP and SOIC package and is available in the industrial temperature range.

ORDERING INFORMATION

Part No.	Package	Temp. Range
TC648VOA	8-Pin SOIC	0°C to +85°C
TC648VPA	8-Pin Plastic DIP	0°C to +85°C
TC642EV	Evaluation Kit for TC64x Family	
TC642DEMO	Demo Board for TC64x Family	

PIN CONFIGURATIONS



ABSOLUTE MAXIMUM RATINGS*

Package Power Dissipation ($T_A \leq 70°C$)
- Plastic DIP 730mW
- Small Outline (SOIC) 470mW
- Micro SOP (MSOP) 333mW

Derating Factors .... 8mW/°C
Supply Voltage 6V
Input Voltage, Any Pin .... (GND – 0.3V) to (V_{CC} + 0.3V)
Operating Temperature Range .... – 0°C to +125°C
Maximum Chip Temperature .... +150°C
Storage Temperature Range .... – 65°C to +150°C
Lead Temperature (Soldering, 10 sec) .... +300°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.

D.C. ELECTRICAL CHARACTERISTICS: $T_{MIN} \leq T_A \leq T_{MAX}$, V_{DD} = 3.0V to 5.5V, unless otherwise specified.

Symbol	Parameter	Test Conditions	Min	Typ	Max	Units
V_{DD}	Supply Voltage		3.0	—	5.5	V
I_{DD}	Supply Current, Operating	Pin 7 Open, C_F = 1µF, $V_{IN} = V_{C(MAX)}$	—	0.5	1	mA
$I_{DD(SHDN)}$	Supply Current, Auto-Shutdown Mode	Pins 6, 7 Open, C_F = 1µF, V_{IN} = 0.35V, Note 1	—	25	—	µA
I_{IN}	V_{IN}, V_{AS} Input Leakage	Note 1	– 1	—	+1	µA
V_{OUT} Output						
t_R	V_{OUT} Rise Time	I_{OH} = 5mA, Note 1	—	—	50	µsec
t_F	V_{OUT} Fall Time	I_{OL} = 1mA, Note 1	—	—	50	µsec
t_{RESET}	Pulse Width On V_{IN} to Enabled RESET		30	—	—	µsec
I_{OL}	Sink Current at V_{OUT} Output	V_{OL} = 10% of V_{DD}	1	—	—	mA
I_{OH}	Source Current at V_{OUT} Output	V_{OH} = 80% of V_{DD}	5	—	—	mA
V_{IN}, V_{AS} Inputs						
$V_{C(MAX)}$, V_{OTF}	Voltage at V_{IN} for 100% Duty Cycle and Overtemp. Fault		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_{HAS}	Hysteresis on Auto-Shutdown Comparator		—	70	—	mV
Pulse-Width Modulator/Start-up Timer						
F	PWM Frequency	C_F = 1.0µF,	26	30	34	Hz
$t_{STARTUP}$	Start-up Time	C_F = 1.0µF	—	32/F	—	Sec
$\overline{OTF}$ Output						
V_{OL}	Output Low Voltage	I_{OL} = 2.5mA	—	—	0.3	V

NOTE: 1. Ensured by design, not tested.

PIN DESCRIPTION

Pin No. (PDIP/SOIC)	Symbol	Description
1	V_{IN}	Analog input. The thermistor network (or other temperature sensor) connects to this input. A voltage range of 1.25V to 2.65V (typical) on this pin drives an active duty cycle of 0% to 100% on the V_{OUT} pin. See Applications section for more details.
2	C_F	Analog output. Positive terminal for the PWM ramp generator timing capacitor. The recommended C_F is 1µF for 30Hz PWM operation.
3	V_{AS}	Analog input. An external resistor divider connected to this input sets the Auto-Shutdown threshold between. Auto-Shutdown occurs when $V_{IN} \leq V_{AS}$. During Shutdown, supply current falls to 25µA (typical).The fan is automatically restarted when $V_{IN} \geq (V_{AS} + V_{HAS})$. See the *Applications* section for more details.
4	GND	Ground Terminal.
5	NC	This pin is not connected to the die.
6	$\overline{OTF}$	Digital (open collector) output. This line goes low to indicate an over-temperature condition.
7	V_{OUT}	Digital output. This active high complimentary output drives the base of an external NPN transistor via an appropriate base resistor. This output has asymmetrical drive. See Electrical Characteristics section.
8	V_{DD}	Power supply input. May be independent of fan power supply. See *Electrical Characteristics* section.

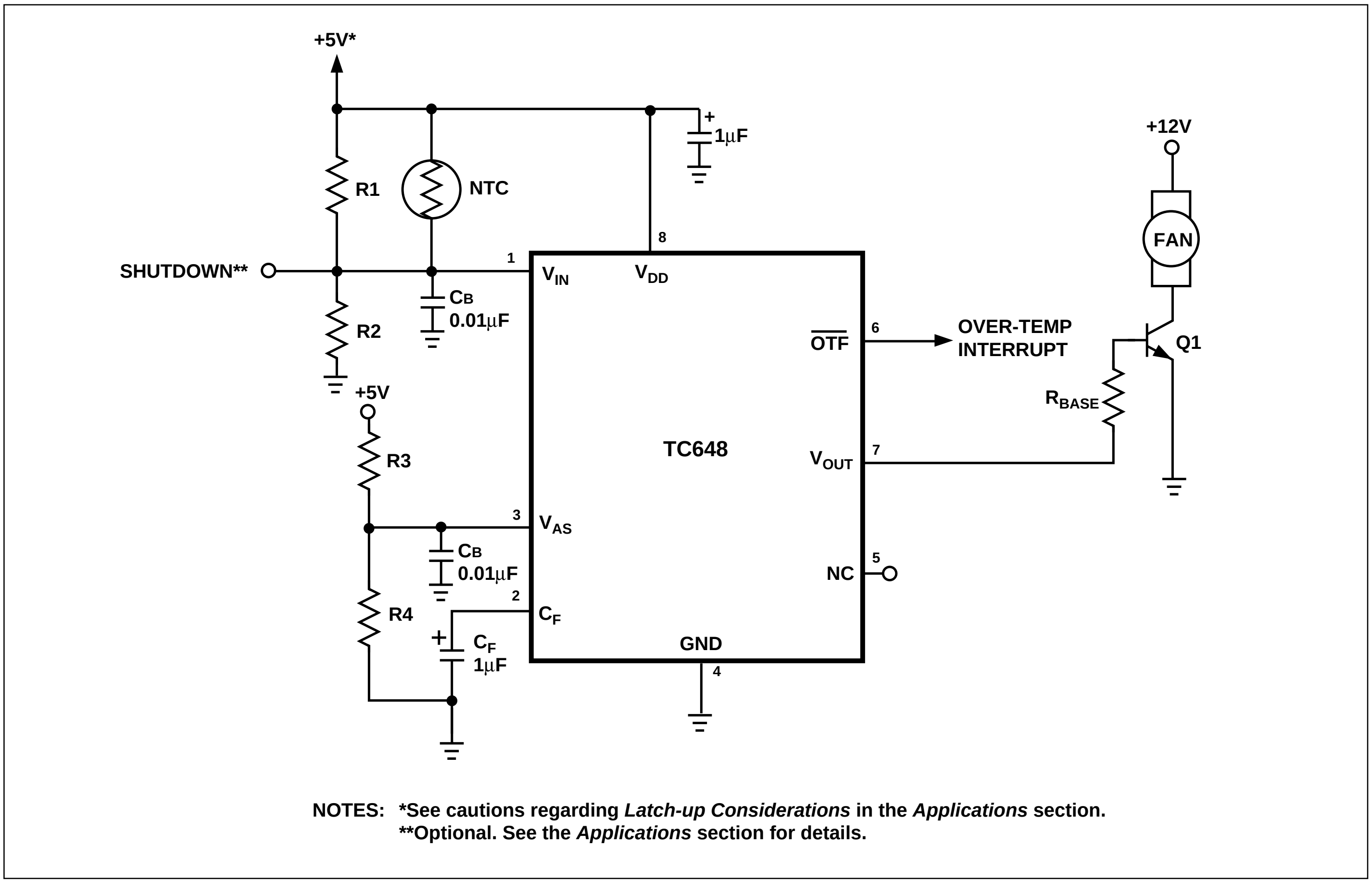


Figure 1. Typical Application Circuit

DETAILED DESCRIPTION

PWM

The PWM circuit consists of a ramp generator and threshold detector. The frequency of the PWM is determined by the value of the capacitor connected to the C_F pin. A frequency of 30Hz is recommended for most applications ($C_F = 1.0\mu F$). The PWM is also the timebase for the Start-up Timer (see paragraphs below). The PWM voltage control range is 1.25V to 2.65V (typical) for 0% to 100% output duty cycle.

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 below. This output has an asymmetric complementary drive and is optimized for driving NPN-transistors or N-channel MOSFETs. Since the system relies on PWM rather than linear power control, the dissipation in the power switch is kept to a minimum. Generally, very small devices (TO-92 or SOT packages) will suffice.

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, chip reset and when coming out of Auto-Shutdown mode. If the PWM frequency is 30Hz ($C_F = 1\mu F$) the resulting start-up time will be about one second.

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

$\overline{OTF}$ is asserted when the PWM control voltage applied to V_{IN} becomes greater than that needed to drive 100% duty cycle (see *Electrical Characteristics*). This indicates that the fan is at maximum drive, and the potential exists for system overheating. Either heat dissipation in the system has gone beyond the cooling system's design limits, or some subtle fault exists such as fan bearing failure or an airflow obstruction. This output may be treated as a "System Overheat" warning and used to trigger system shutdown or some other corrective action. $\overline{OTF}$ will become inactive when $V_{IN} < V_{OTF}$.

Auto-Shutdown Mode

If the voltage on V_{IN} becomes less than the voltage on V_{AS}, the fan is automatically shut off (Auto-Shutdown mode). The TC648 exits Auto-Shutdown mode when the voltage on V_{IN} becomes higher than the voltage on V_{AS} by V_{HAS}, the Auto-Shutdown Hysteresis Voltage (see Figure 7). The Start-up Timer is triggered, and normal operation is resumed on exiting Auto-Shutdown mode. This V_{AS} input should be grounded if Auto-Shutdown mode is not used.

Chip Reset in Minimum Speed Mode

In Minimum Speed mode (V_{AS} is grounded), and Auto-Shutdown feature is disabled; the TC648 can still be reset to give a one second start-up pulse by forcing V_{IN} to a logic low for a period of t_{RESET} and releasing it to a normal operational level (between 1.25V to 2.65V). After the Start-up Timer is triggered, the V_{OUT} output duty cycle is proportional to V_{IN} level as usual.

SYSTEM BEHAVIOR

The flowcharts describing the TC648's behavioral algorithm are shown in Figure 2. They can be summarized as follows:

Power-Up

(1) Assuming the device is not being held in Shutdown mode ($V_{IN} > V_{AS}$);

(2) Turn V_{OUT} output on for 32 cycles of the PWM clock. This insures that the fan will start from a dead stop.

(3) End.

Normal Operation

Normal Operation is an endless loop which may only be exited by entering Shutdown mode. The loop can be thought of as executing at the frequency of the oscillator and PWM.

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

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

(3) Is the device in Auto-Shutdown mode? If so, $V_{OUT} = 0$ until $V_{IN} > (V_{AS} + V_{HAS})$, then execute power-up sequence.

(4) End.

APPLICATIONS INFORMATION

Designing with the TC648 involves the following:

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

(2) The Auto-Shutdown temperature must be set with a voltage divider on V_{AS} (if used).

(3) The output drive transistor and base resistor must be selected.

(4) If Reset capability is desired, the drive requirements of the external signal or circuit must be considered.

The TC642DEMO demonstration and prototyping board and the TC642EV Evaluation Kit provide working examples of TC648 circuits and prototyping aids. The TC642DEMO is a printed circuit board optimized for small size and ease of inclusion into system prototypes. The TC642EV is a larger board intended for benchtop development and analysis. At the very least, anyone contemplating a design using the TC648 should consult the documentation for both the TC642EV and TC642DEMO.

An Excel-based spreadsheet is included with the TC642EV that is helpful in designing the thermistor network for the TC64x fan controllers. THMSTR5.XLS is compatible with Office 95, while THMSTR7.XLS is compatible with Office 97. This utility also is available for downloading from the Microchip website at www.Microchip.com.

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 of Figure 3 is a convenient way to provide this signal.

Figure 1 illustrates a simple temperature-dependent voltage divider circuit. T_1 is a conventional NTC thermistor, and R1 and R2 are standard resistors. The supply voltage, V_{DD}, is divided between R2 and the parallel combination of T_1 and R1. For convenience, the parallel combination of T_1 and R1 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. A thermistor with a 25°C resistance on the order of 100kΩ will result in reasonable values for R1, R2, and I_{DIV}. In order to determine R1 and R2, we must specify the fan duty-cycle, i.e. V_{IN} at any two temperatures. Equipped with these two points on the system's operating curve and the thermistor data, we can write the defining equations:

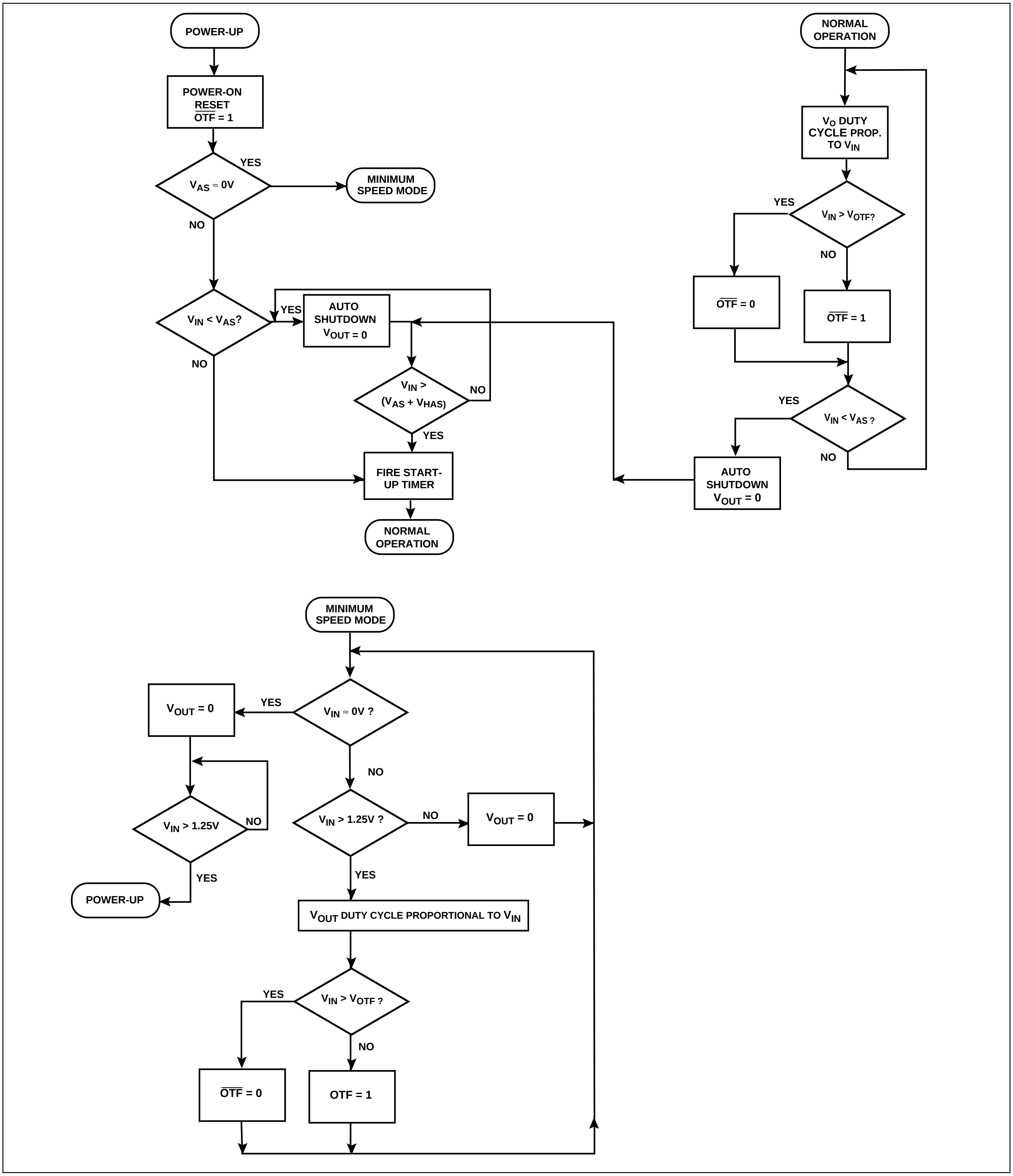


Figure 2. TC648 Behavioral Algorithm Flowcharts

$$\frac{2.65V - 1.25V}{t_2 - t_1} = \frac{V_{AS} - 1.25}{t_{AS} - t_1}$$

$$V_{AS} = \left(\frac{1.4V}{t_2 - t_1}\right)(t_{AS} - t_1) + 1.25$$

Equation 5.

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:

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

Equation 6.

The V_{AS} voltage may be set using a simple resistor divider as shown in Figure 6. Per the *Electrical Characteristics*, the leakage current at the V_{AS} pin is no more than 1µ. It is conservative to design for a divider current, I_{DIV}, of 100µA. If V_{DD} = 5.0V then…

$$I_{DIV} = 1e^{-4}\,A = \frac{5.0V}{R1 + R2}\text{, therefore}$$

$$R1 + R2 = \frac{5.0V}{1e^{-4}A} = 50{,}000\Omega = 50k\Omega$$

Equation 7.

We can further specify R1 and R2 by the condition that the divider voltage is equal to our desired V_{AS}. This yields the equation**:**

$$V_{AS} = V_{DD} \times \frac{R2}{R1 + R2}$$

Equation 8.

Solving for the relationship between R1 and R2 results in:

$$R1 = R2 \times \frac{V_{DD} - V_{AS}}{V_{AS}} = R2 \times \frac{5 - 1.53}{1.53}$$

Equation 9.

In the case of this example, R1 = (2.27) R2. Substituting this relationship back into Equation 7 yields the resistor values:

R2 = 15.3kΩ, and
R1 = 34.7kΩ

In this case, the standard values of 35kΩ and 15kΩ are very close to the calculated values and would be more than adequate.

Output Drive Transistor Selection

The TC648 is designed to drive an external transistor for modulating power to the fan. This is shown as "Q1" in Figures 1, 7, 8, and 10. The V_{OUT} pin has a minimum source current of 5mA and a minimum sink current of 1mA at V_{DD} = 5.0V. Bipolar transistors or MOSFETs may be used as the power switching element as shown below. 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 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 TC648's PWM control scheme versus linear speed control is that the 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 200mA, a single transistor usually suffices. Above 200mA, 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". The minimum gain (h_{FE}) of the transistor in question must be adequate to fully saturate the transistor when passing the full fan current and being driven within the 5mA I_{OH} of the V_{OUT} output.

Table 1 gives examples of some commonly available transistors. This table is a guide only. There are many transistor types which might work equally as well as those listed. The only critical issues when choosing a device to use as Q1 are: (1) the breakdown voltage, $V_{CE(BR)}$, must be large enough to stand off the highest voltage applied to the fan (NOTE: this may be when the fan is off!); (2) the gain (h_{FE}) must be high enough for the device to remain fully saturated while conducting the maximum expected fan current and being driven with no more than 5mA of base/gate drive at maximum temperature; (3) rated fan current draw must be within the transistor's current handling capability; and (4) power dissipation must be kept within the limits of the chosen device.

Table 1. Transistors for Q1

Device	$V_{BE(SAT)}$	MIN h_{FE}	$V_{BR(CEO)}$	I_C	R_{BASE} (Ω)
MPS2222	1.3	100	30	150	800
MPS2222A	1.2	100	40	150	800
2N4400	0.95	50	40	150	820
2N4401	0.95	100	40	150	820
MPS6601	1.2	50	25	500	780
MPS6602	1.2	50	40	500	780

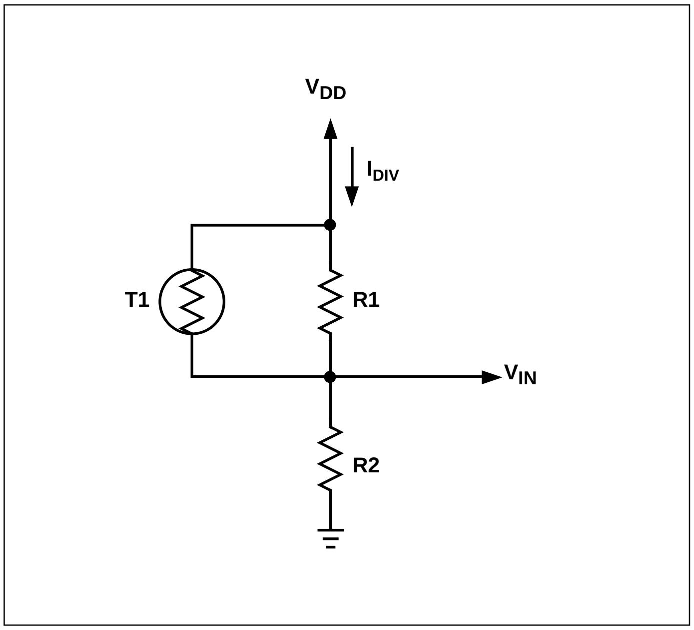


Figure 5. Temperature Sensing Circuit

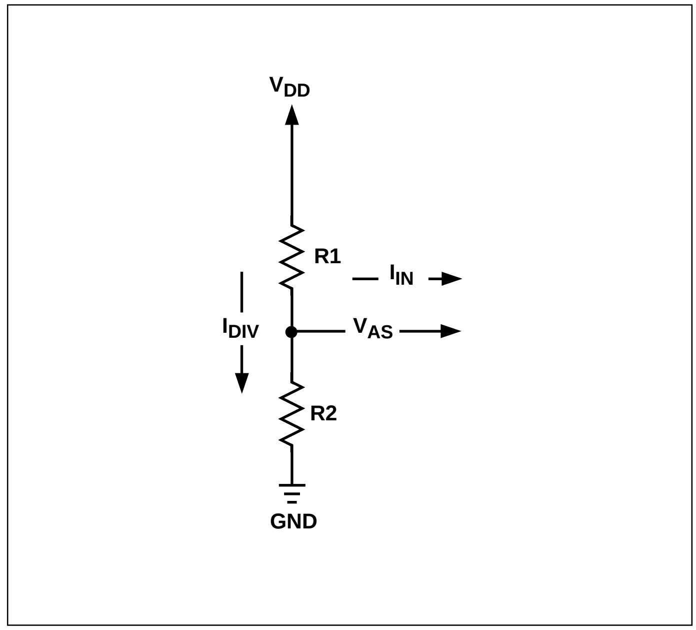


Figure 6. V_{AS} Circuit

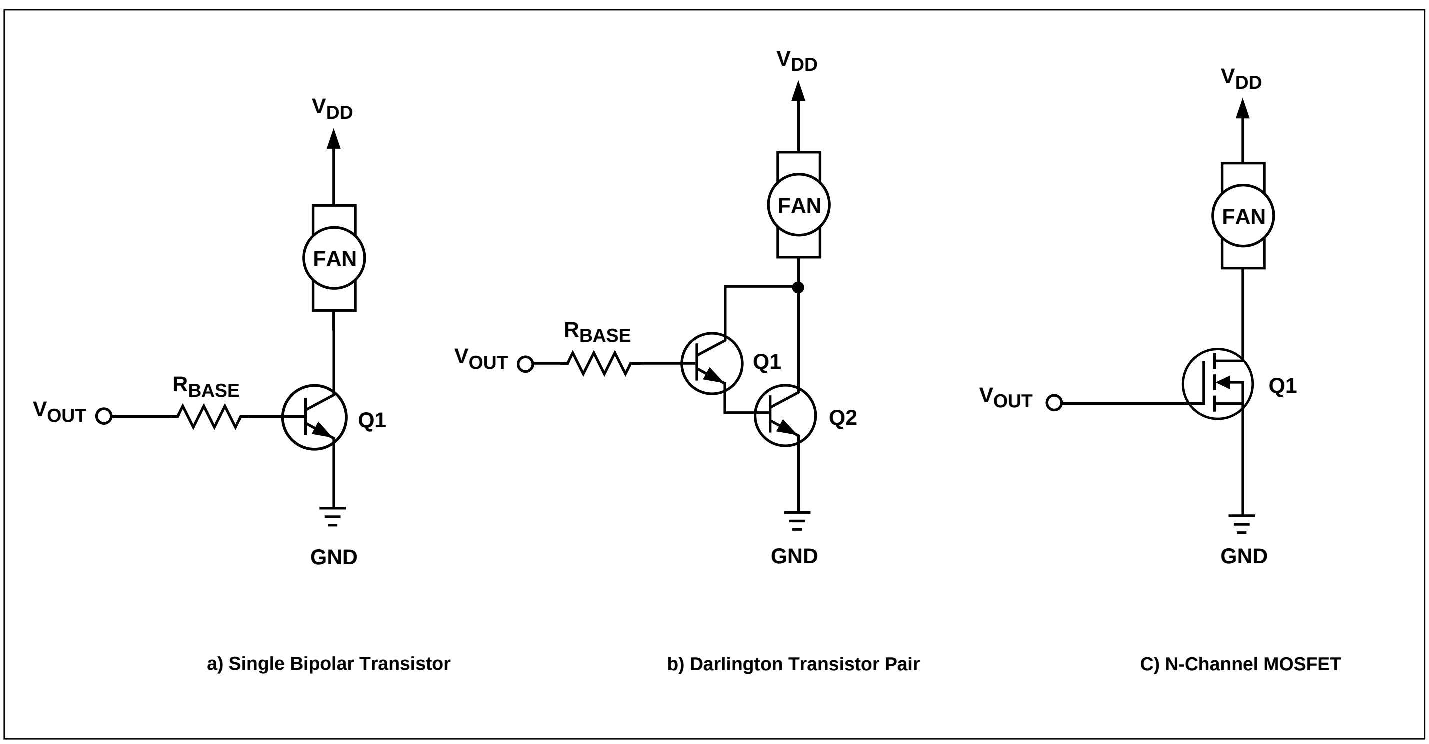


Figure 7. Output Drive Transistor Circuit Topologies

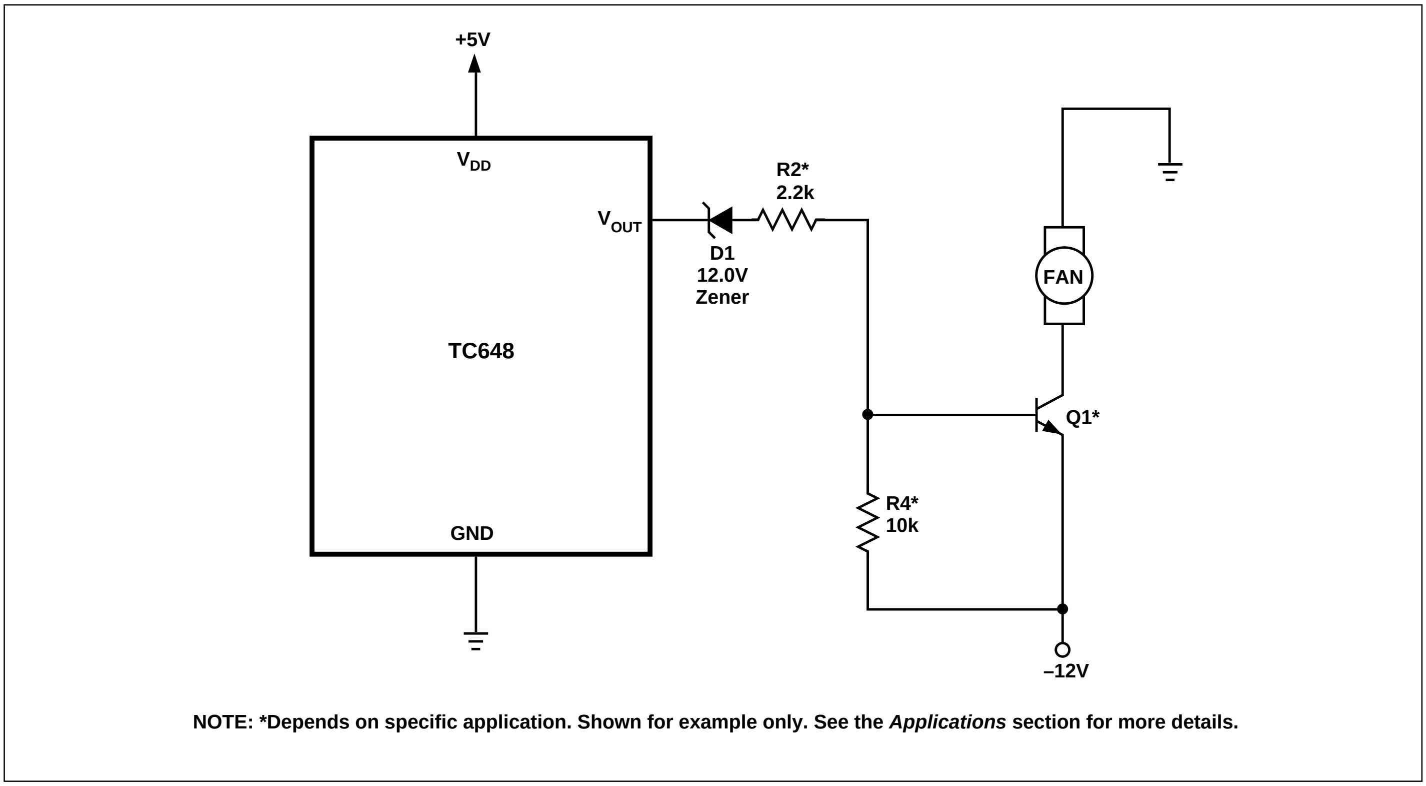


Figure 8. Powering the Fan from a Negative Supply

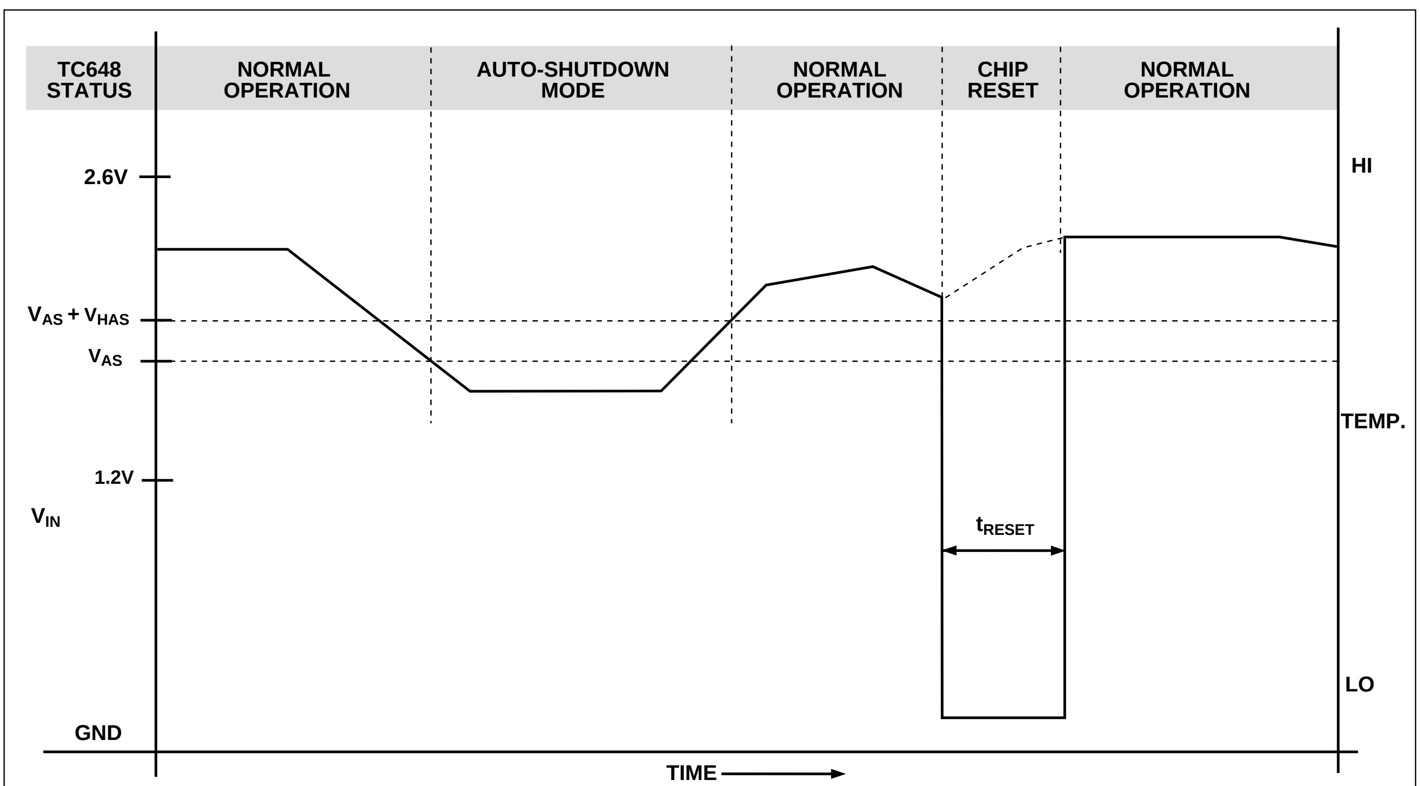


Figure 9. TC648 Nominal Operation

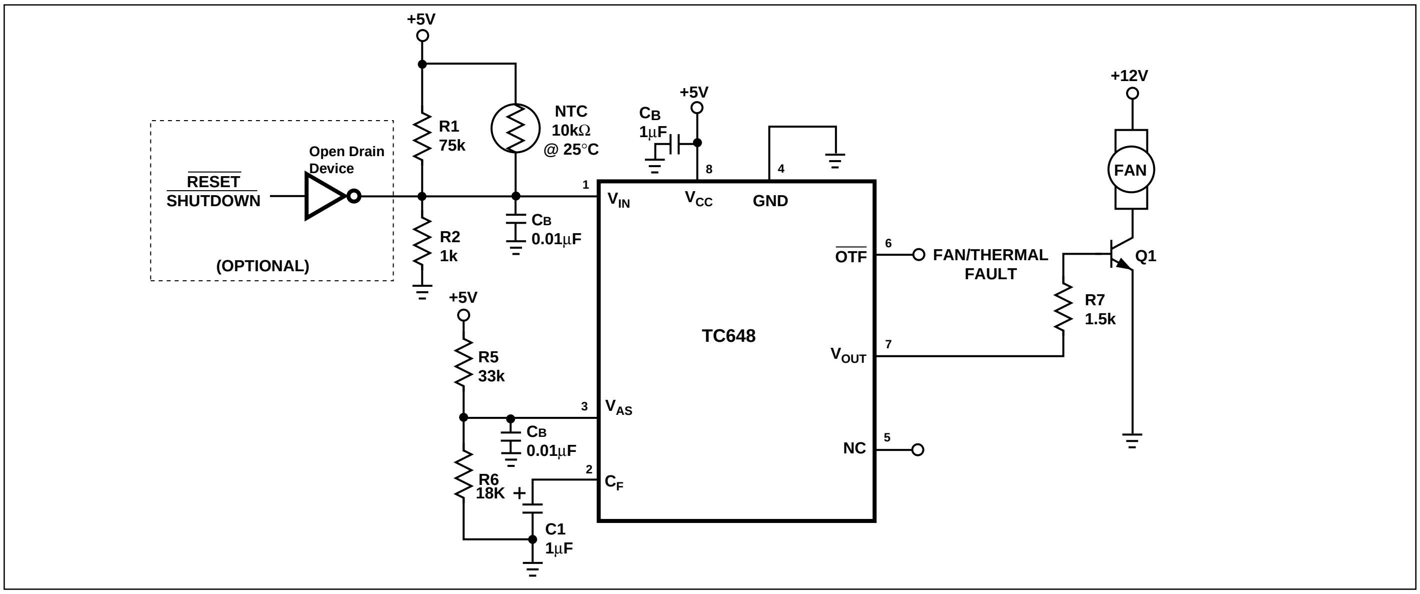


Figure 10. Design Example

Auto-Shutdown Mode Design Example (Figure 10)

Step 1. Calculate R1 and R2 based on using an NTC having a resistance of 4.6kΩ at T_{MIN} and 1.1kΩ at T_{MAX}.

R1 = 75kΩ
R2 = 1kΩ

Step 2. Set Auto-Shutdown level

V_{AS} = 1.8V
Limit the divider current to 100µA
R5 = 33k
R6 = 18k

Step 3. Design the output circuit

Maximum fan motor current = 250mA.
Q1 beta is chosen at 100 from which
R7 = 1.5kΩ.

Minimum Speed Mode Design Example

Given:

Minimum speed = 40%(1.8V)
T_{MIN} = 30°C, T_{MAX} = 95°C
Thermistor = 100K at 25°C
RT_{MIN} = 79.4K, RT_{MAX} = 6.5K

Step 1: Calculate R1 Equation 2:
R1 = 7.9K (Use closest standard value: 7.5K)

Calculate R2 using Equation 3:
R2 = 4.05K (Use closest standard value: 3.9K)

Step 2: Verify V_{MAX} using Equation 4:
V_{MAX} = 2.64V

TC648 as a Microcontroller Peripheral (Figure 11)

In a system containing a microcontroller or other host intelligence, the TC648 can be effectively managed as a CPU peripheral. Routine fan control functions can be performed by the TC648 without processor intervention. The micro-controller receives temperature data from one or more points thoughout 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/01 through I/03. 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 to 2.6V DC control signal. (A monolithic DAC or digital pot may be used instead of the circuit shown.)

With V_{AS} set at 1.8V, the TC648 enters Auto-Shutdown when the processor's output code is 000[B]. Output codes 001[B] to 111[B] operate the fan from roughly 40% to 100% of full speed. An open drain output from the processor (I/O_0) can be used to reset the TC648 following detection of a fault condition. The $\overline{OTF}$ output can be connected to the processor's interrupt input, or to another I/O pin for polled operation.

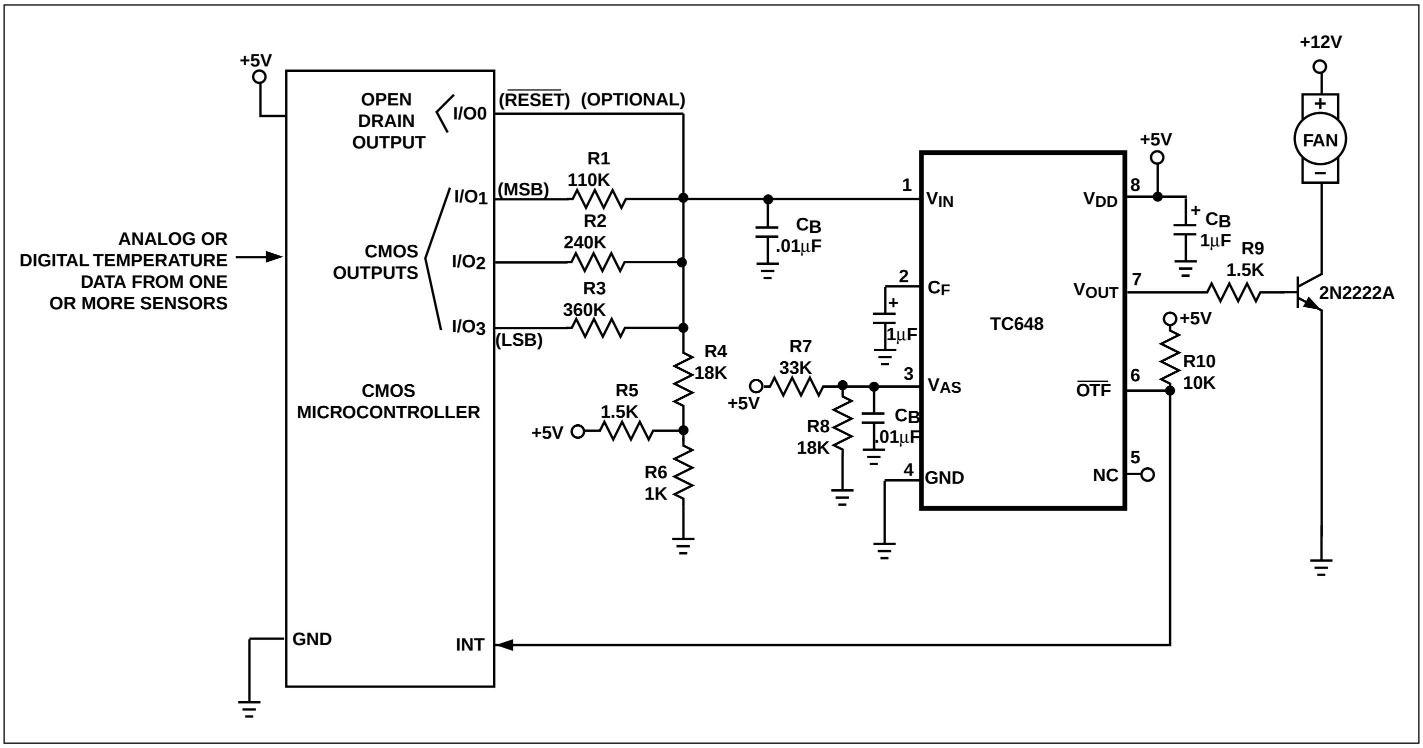
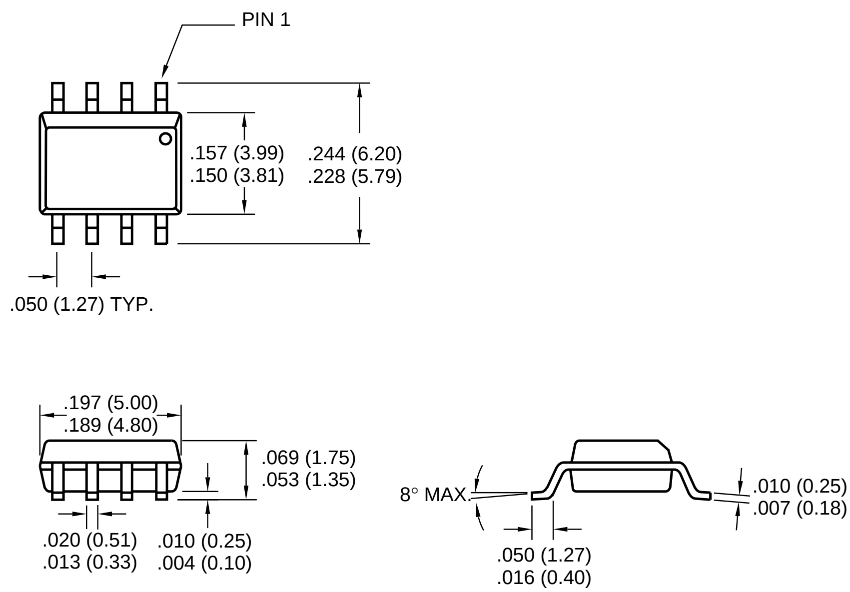


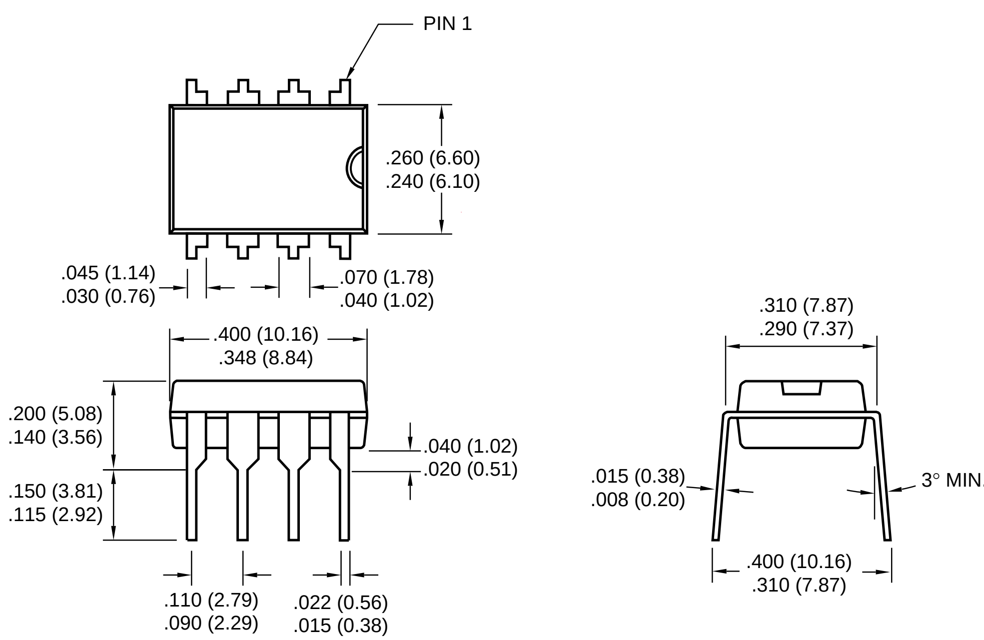
Figure 11. TC648 as a Microcontroller Peripheral

PACKAGE DIMENSIONS (con't.)

8-Pin SOIC (Narrow)



8-Pin PDIP (Narrow)



Dimensions: inches (mm)

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01/09/01