19-3306; Rev 0; 5/04

2-Channel Temperature Monitor with Dual Automatic PWM Fan-Speed Controller and Five GPIOs

General Description

The MAX6678 monitors its own temperature and the temperatures of two external diode-connected transistors, which typically reside on the die of a CPU or other integrated circuit. The device reports temperature values in digital form using a 2-wire serial interface. The MAX6678 provides a programmable alarm output to generate interrupts, throttle signals, or overtemperature shutdown signals.

The 2-wire serial interface accepts standard System Management Bus (SMBus)™ write byte, read byte, send byte, and receive byte commands to read the temperature data and program the alarm thresholds. The temperature data controls a PWM output signal to adjust the speed of a cooling fan, thereby minimizing noise when the system is running cool, but providing maximum cooling when power dissipation increases.

Five GPIO pins provide additional flexibility. The GPIO power-up states are set by connecting the GPIO preset inputs to ground or V_{CC}.

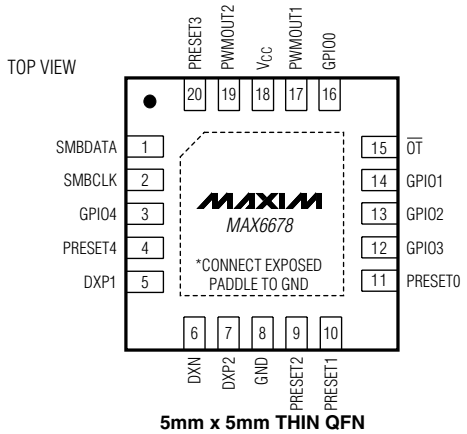
The MAX6678 is available in a 20-pin QSOP package and a 5mm x 5mm thin QFN package. It operates from 3.0V to 5.5V and consumes just 500µA of supply current.

Applications

Desktop Computers
Notebook Computers
Workstations
Servers
Networking Equipment

SMBus is a trademark of Intel Corp.

Pin Configurations



5mm x 5mm THIN QFN

Pin Configurations continued at end of data sheet.

Features

- ♦ **Two Thermal-Diode Inputs**
- ♦ **Local Temperature Sensor**
- ♦ **Five GPIO Input/Outputs**
- ♦ **Two PWM Outputs for Fan Drive (Open Drain; May Be Pulled Up to +5V)**
- ♦ **Programmable Fan-Control Characteristics**
- ♦ **Automatic Fan Spin-Up Ensures Fan Start**
- ♦ **Controlled Rate of Change Ensures Unobtrusive Fan-Speed Adjustments**
- ♦ **1°C Remote Temperature Accuracy (+60°C to +145°C)**
- ♦ **Temperature Monitoring Begins at POR for Fail-Safe System Protection**
- ♦ **$\overline{OT}$ Output for Throttling or Shutdown**
- ♦ **Four Versions Available, Each with a Different Address**
- ♦ **5mm x 5mm TQFN Package**

Ordering Information

PART	TEMP RANGE	PIN-PACKAGE	SMBus ADDRESS
MAX6678AEP90	-40°C to +125°C	20 QSOP	1001000
MAX6678AEP92	-40°C to +125°C	20 QSOP	1001001
MAX6678AEP94	-40°C to +125°C	20 QSOP	1001010
MAX6678AEP96	-40°C to +125°C	20 QSOP	1001011
MAX6678ATP90	-40°C to +125°C	20 Thin QFN-EP*	1001000
MAX6678ATP92	-40°C to +125°C	20 Thin QFN-EP*	1001001
MAX6678ATP94	-40°C to +125°C	20 Thin QFN-EP*	1001010
MAX6678ATP96	-40°C to +125°C	20 Thin QFN-EP*	1001011

**EP = Exposed paddle.*

Typical Operating Circuit appears at end of data sheet.

For pricing, delivery, and ordering information, please contact Maxim/Dallas Direct! at 1-888-629-4642, or visit Maxim's website at www.maxim-ic.com.

2-Channel Temperature Monitor with Dual Automatic PWM Fan-Speed Controller and Five GPIOs

ABSOLUTE MAXIMUM RATINGS

V_{CC} to GND .....-0.3V to +6V
$\overline{OT}$, SMBDATA, SMBCLK, PWMOUT_, GPIO_ to GND .....-0.3V to +6V
DXP_ to GND .....-0.3V to + (V_{CC} + 0.3V)
DXN to GND .....-0.3V to +0.8V
PRESET_ to GND .....-0.3V to + (V_{CC} + 0.3V)
SMBDATA, $\overline{OT}$, PWMOUT_ Current.....-1mA to +50mA
DXN Current .....±1mA
ESD Protection (all pins, Human Body Model) 2000V

Continuous Power Dissipation (T_A = +70°C)
20-Pin QSOP (derate 9.1mW/°C above +70°C)..... 727mW
20-Pin TQFN (derate 34.5mW/°C above +70°C) 2759mW
Operating Temperature Range .....-40°C to +125°C
Junction Temperature.....+150°C
Storage Temperature Range .....-65°C to +150°C
Lead Temperature (soldering, 10s) .....+300°C

Stresses beyond 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 beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

ELECTRICAL CHARACTERISTICS

(V_{CC} = +3.0V to +5.5V, T_A = -40°C to +125°C, unless otherwise noted. Typical values are at V_{CC} = +3.3V, T_A = +25°C.)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
Operating Supply Voltage Range	V_{CC}			+3.0		+5.5	V
Operating Current	I_S	Interface inactive, ADC active			0.5	1	mA
External Temperature Error, V_{CC} = 3.3V		V_{CC} = 3.3V	+25°C ≤ T_R ≤ +125°C, T_A = 60°C			±1	°C
			0°C ≤ T_R ≤ +145°C, +25°C ≤ T_A ≤ +100°C			±3	
			0°C ≤ T_R ≤ +145°C, 0°C ≤ T_A ≤ +125°C			±4	
Internal Temperature Error		V_{CC} = +3.3V	+25°C ≤ T_R ≤ +100°C			±2.5	°C
			0°C ≤ T_A ≤ +125°C			±4	
Temperature Resolution				1			°C
				8			Bits
Conversion Time				200	250	300	ms
PWM Frequency Tolerance		(Note 1)		-20		+20	%
Remote-Diode Sourcing Current		High level		80	100	120	µA
		Low level		8	10	12	
DXN Source Voltage					0.7		V
DIGITAL INPUTS AND OUTPUTS							
Output Low Voltage (Sink Current) ($\overline{OT}$, GPIO_, SMBDATA, PWMOUT_)	V_{OL}	I_{OUT} = 6mA				0.4	V
Output High Leakage Current ($\overline{OT}$, GPIO_, SMBDATA, PWMOUT_)	I_{OH}					1	µA
Logic-Low Input Voltage (SMBDATA, SMBCLK, PRESET_, GPIO_)	V_{IL}	V_{CC} = 3V to 3.6V				0.8	V
		V_{CC} = 3.6V to 5.5V				0.8	
Logic-High Input Voltage (SMBDATA, SMBCLK, PRESET_, GPIO_)	V_{IH}	V_{CC} = 3V to 3.6V		2.1			V
		V_{CC} = 3.6V to 5.5V		2.1			
Input Leakage Current						1	µA
Input Capacitance	C_{IN}				5		pF
SMBus TIMING							
Serial Clock Frequency	f_{SCLK}					100	kHz

ELECTRICAL CHARACTERISTICS (continued)

(V_{CC} = +3.0V to +5.5V, T_A = -40°C to +125°C, unless otherwise noted. Typical values are at V_{CC} = +3.3V, T_A = +25°C.)

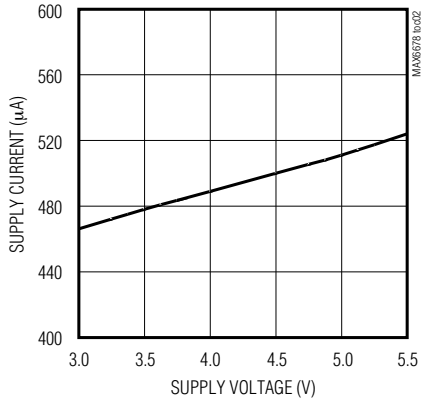
PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Clock Low Period	t_{LOW}	10% to 10%	4			µs
Clock High Period	t_{HIGH}	90% to 90%	4.7			µs
Bus Free Time Between Stop and Start Conditions	t_{BUF}		4.7			µs
SMBus Start Condition Setup Time	$t_{SU:STA}$	90% of SMBCLK to 90% of SMBDATA	4.7			µs
Start Condition Hold Time	$t_{HD:STO}$	10% of SMBDATA to 10% of SMBCLK	4			µs
Stop Condition Setup Time	$t_{SU:STO}$	90% of SMBCLK to 10% of SMBDATA	4			µs
Data Setup Time	$t_{SU:DAT}$	10% of SMBDATA to 10% of SMBCLK	250			ns
Data Hold Time	$t_{HD:DAT}$	10% of SMBCLK to 10% of SMBDATA	300			ns
SMBus Fall Time	t_F				300	ns
SMBus Rise Time	t_R				1000	ns
SMBus Timeout	$t_{TIMEOUT}$		29	37	55	ms
Startup Time After POR	t_{POR}				500	ms

Note 1: Deviation from programmed value in Table 6.

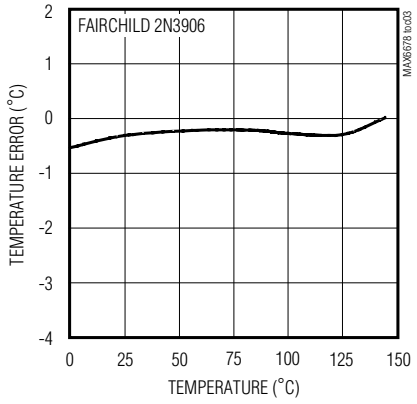
Typical Operating Characteristics

(T_A = +25°C, unless otherwise noted.)

OPERATING SUPPLY CURRENT vs. SUPPLY VOLTAGE



REMOTE TEMPERATURE ERROR vs. REMOTE-DIODE TEMPERATURE

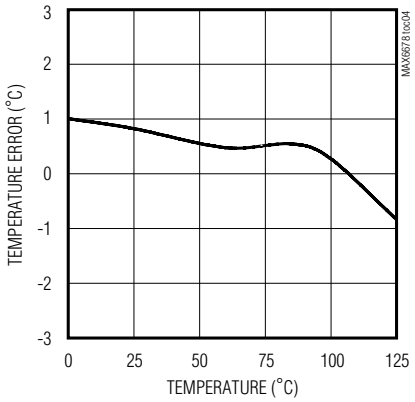


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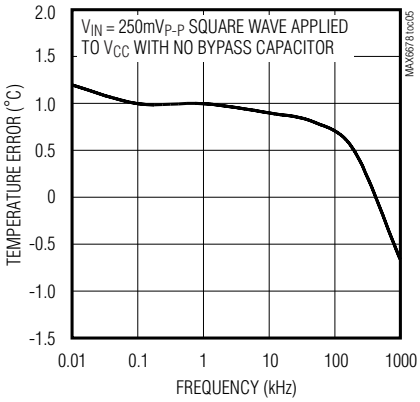
Typical Operating Characteristics (continued)

(T_A = +25°C, unless otherwise noted.)

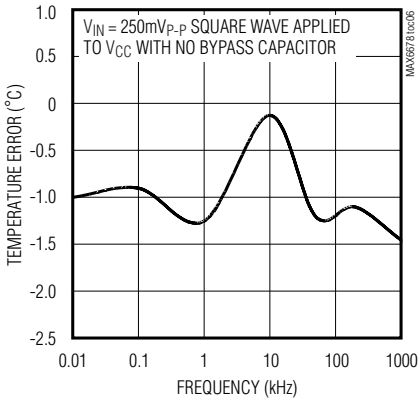
LOCAL TEMPERATURE ERROR vs. DIE TEMPERATURE



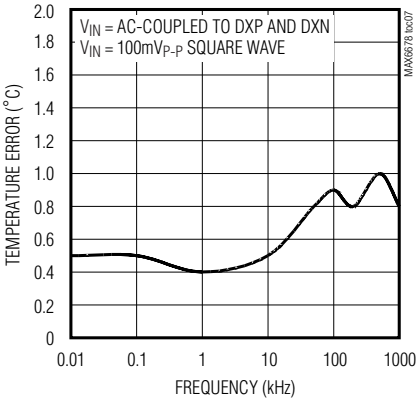
REMOTE TEMPERATURE ERROR vs. POWER-SUPPLY NOISE FREQUENCY



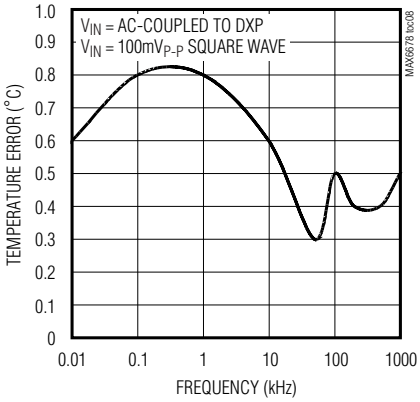
LOCAL TEMPERATURE ERROR vs. POWER-SUPPLY NOISE FREQUENCY



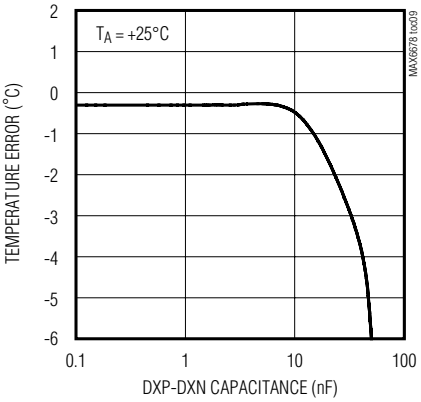
REMOTE TEMPERATURE ERROR vs. COMMON-MODE NOISE FREQUENCY



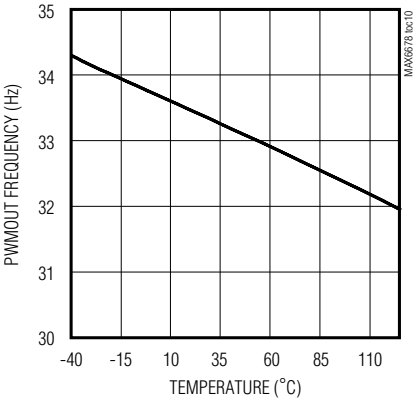
REMOTE TEMPERATURE ERROR vs. DIFFERENTIAL NOISE FREQUENCY



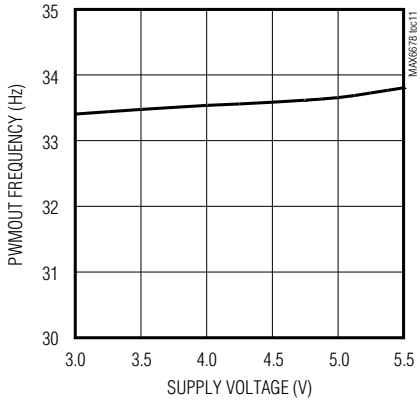
TEMPERATURE ERROR vs. DXP-DXN CAPACITANCE



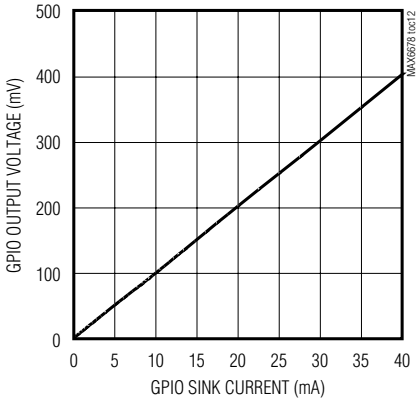
PWMOUT FREQUENCY vs. DIE TEMPERATURE



PWMOUT FREQUENCY vs. SUPPLY VOLTAGE



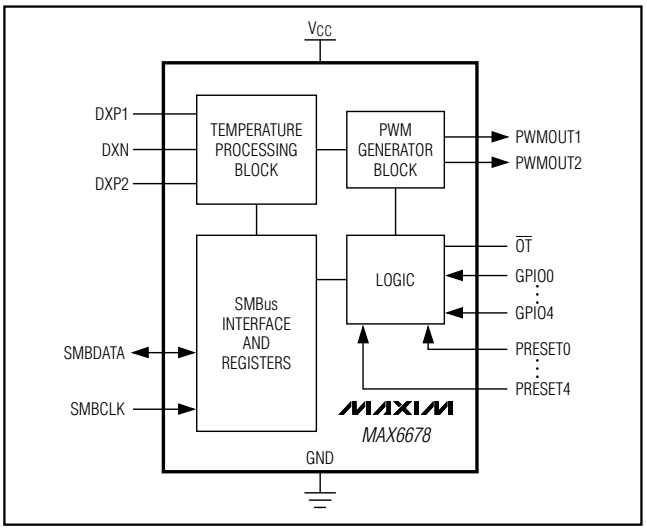
GPIO OUTPUT VOLTAGE vs. GPIO SINK CURRENT



Pin Description

PIN		NAME	DESCRIPTION
THIN QFN	QSOP		
1	3	SMBDATA	SMBus Serial-Data Input/Output, Open Drain. Can be pulled up to 5.5V, regardless of V_{CC}. Open circuit when V_{CC} = 0.
2	4	SMBCLK	SMBus Serial-Clock Input. Can be pulled up to 5.5V, regardless of V_{CC}. Open circuit when V_{CC} = 0.
3, 12, 13, 14, 16	5, 14, 15, 16, 18	GPIO0–GPIO4	Active-Low, Open-Drain GPIO Pins. Can be pulled up to 5.5V, regardless of V_{CC}. Open circuit when V_{CC} = 0.
4, 9, 10, 11, 20	2, 6, 11, 12, 13	PRESET0–PRESET4	GPIO Preset Inputs. Connect to GND or V_{CC} to set POR value of GPIO0–GPIO4.
5, 7	7, 9	DXP1, DXP2	Combined Current Source and A/D Positive Input for Remote Diode. Connect to anode of remote-diode-connected temperature-sensing transistor. Do not leave floating; connect to DXN if no remote diode is used. Place a 2200pF capacitor between DXP_ and DXN for noise filtering.
6	8	DXN	Combined Remote-Diode Cathode Input. Connect cathode of the remote-diode-connected transistor to DXN.
8	10	GND	Ground. Connect to a clean ground reference.
15	17	$\overline{OT}$	Active-Low, Open-Drain Over-Temperature Output. Typically used for system shutdown or clock throttling. Can be pulled up to 5.5V regardless of V_{CC}. Open circuit when V_{CC} = 0.
17, 19	1, 19	PWMOUT1, PWMOUT2	Open-Drain Output to Power Transistor Driving Fan. Connect to the gate of a MOSFET or base of a transistor. PWMOUT_ requires a pullup resistor. The pullup resistor can be connected to a supply voltage as high as 5.5V, regardless of the MAX6678's supply voltage.
18	20	V_{CC}	Power-Supply Input. 3.3V nominal. Bypass V_{CC} to GND with 0.1µF capacitor.

Block Diagram



Detailed Description

The MAX6678 temperature sensor and fan controller accurately measures the temperature of either two remote pn junctions or one remote pn junction and its own die. The device reports temperature values in digital form using a 2-wire serial interface. The remote pn junction is typically the emitter-base junction of a common-collector pnp on a CPU, FPGA, or ASIC. The MAX6678 operates from supply voltages of 3.0V to 5.5V and consumes 500µA (typ) of supply current. The temperature data controls a PWM output signal to adjust the speed of a cooling fan. The device also features an overtemperature alarm output to generate interrupts, throttle signals, or shutdown signals.

Five GPIO input/outputs provide additional flexibility. The GPIO power-up states are set by connecting the GPIO preset inputs to ground or V_{CC}.

2-Channel Temperature Monitor with Dual Automatic PWM Fan-Speed Controller and Five GPIOs

Write Byte Format

S	ADDRESS	WR	ACK	COMMAND	ACK	DATA	ACK	P
—	7 bits	—	—	8 bits	—	8 bits	—	1

Slave address: equivalent to chip-select line of a 3-wire interface

Command byte: selects which register you are writing to

Data byte: data goes into the register set by the command byte (to set thresholds, configuration masks, and sampling rate)

Read Byte Format

S	ADDRESS	WR	ACK	COMMAND	ACK	S	ADDRESS	RD	ACK	DATA	///	P
—	7 bits	—	—	8 bits	—	—	7 bits	—	—	8 bits	—	—

Slave address: equivalent to chip-select line

Command byte: selects which register you are reading from

Slave address: repeated due to change in data-flow direction

Data byte: reads from the register set by the command byte

Send Byte Format

S	ADDRESS	WR	ACK	COMMAND	ACK	P
—	7 bits	—	—	8 bits	—	—

Command byte: sends command with no data, usually used for one-shot command

Receive Byte Format

S	ADDRESS	RD	ACK	DATA	///	P
—	7 bits	—	—	8 bits	—	—

Data byte: reads data from the register commanded by the last read byte or write byte transmission; also used for SMBus alert response return address

S = Start condition *Shaded = Slave transmission*
P = Stop condition */// = Not acknowledged*

Figure 1. SMBus Protocols

SMBus Digital Interface

From a software perspective, the MAX6678 appears as a set of byte-wide registers. This device uses a standard SMBus 2-wire/I^2C-compatible serial interface to access the internal registers. The MAX6678 has four different slave addresses available; therefore, a maximum of four MAX6678 devices can share the same bus.

The MAX6678 employs four standard SMBus protocols: write byte, read byte, send byte, and receive byte (Figures 1, 2, and 3). The shorter receive byte protocol allows quicker transfers, provided that the correct data register was previously selected by a read byte instruction. Use caution with the shorter protocols in multimaster systems, since a second master could overwrite the command byte without informing the first master.

Temperature data can be read from registers 00h and 01h. The temperature data format for these registers is 8 bits, with the LSB representing 1°C (Table 1) and the MSB representing +128°C. The MSB is transmitted first. All values below 0°C clip to 00h.

Table 2 details the register address and function, whether they can be read or written to, and the power-on reset (POR) state. See Tables 2–6 for all other register functions and the *Register Descriptions* section.

Temperature Reading

The MAX6678 contains two external temperature measurement inputs to measure the die temperature of CPUs or other ICs having on-chip temperature-sensing diodes, or discrete diode-connected transistors as shown in the *Typical Operating Circuits*. For best accuracy, the discrete diode-connected transistor should be a small-signal device with its collector and base connected together. The on-chip ADC converts the sensed temperature and outputs the temperature data in the format shown in Table 1. Temperature channel 2 can be used to measure either a remote thermal diode or the internal temperature of the MAX6678. Bit D1 of register 02h (Table 2) selects local or remote sensing for temperature channel 2 (1 = local). The temperature measurement resolution is 1°C for both local and remote temperatures. The temperature accuracy is within ±1°C for remote temperature measurements from +60°C to +100°C.

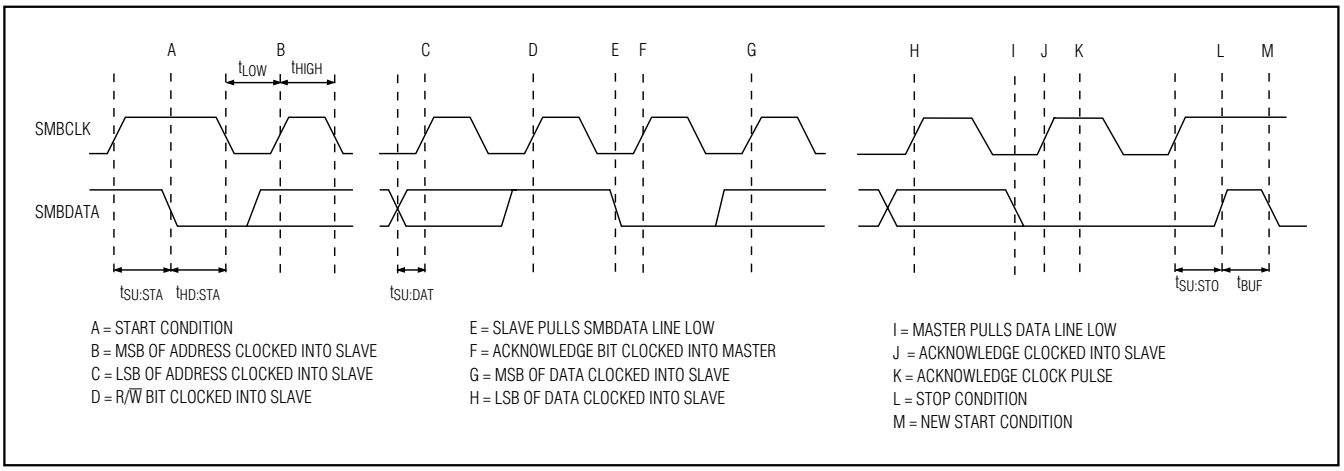


Figure 2. SMBus Write Timing Diagram

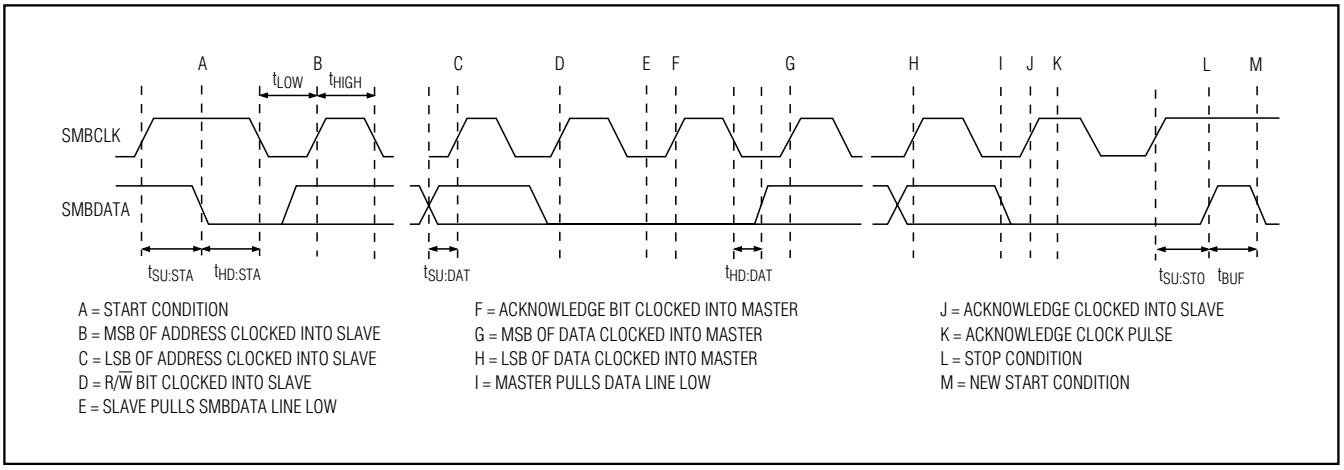


Figure 3. SMBus Read Timing Diagram

The DXN input is biased at 0.60V above ground by an internal diode to set up the analog-to-digital inputs for a differential measurement. The worst case DXP-DXN differential input voltage range is from 0.25V to 0.95V. Excess resistance in series with the remote diode causes about +0.5°C error per ohm. Likewise, a 200µV offset voltage forced on DXP-DXN causes about 1°C error.

High-frequency EMI is best filtered at DXP and DXN with an external 2200pF capacitor. This value can be increased to about 3300pF (max), including cable capacitance. Capacitance higher than 3300pF introduces errors due to the rise time of the switched current source.

Table 1. Temperature Data Byte Format

TEMP (°C)	ROUNDED TEMP (°C)	DIGITAL OUTPUT
241	+241	1111 0001
240	+240	1111 0000
126	+126	0111 1110
25	+25	0001 1001
0.50	+1	0000 0001
0.00	0	0000 0000
Diode fault (open)	—	1110 1111
Diode fault (short)	—	1111 1111

2-Channel Temperature Monitor with Dual Automatic PWM Fan-Speed Controller and Five GPIOs

PWM Output

1) The PWMOUT_ signals are normally used in one of three ways to control the fan's speed: PWMOUT_ drives the gate of a MOSFET or the base of a bipolar transistor in series with the fan's power supply. The *Typical Application Circuit* shows the PWMOUT_ driving an n-channel MOSFET. In this case, the PWM invert bit (D4 in register 02h) is set to 1. Figure 4 shows PWMOUT_ driving a p-channel MOSFET and the PWM invert bit must be set to zero.
2) PWMOUT_ is converted (using an external circuit) into a DC voltage that is proportional to duty cycle. This duty-cycle-controlled voltage becomes the power supply for the fan. This approach is less efficient than 1), but can result in quieter fan operation. Figure 5 shows an example of a circuit that converts the PWM signal to a DC voltage. Because this circuit produces a full-scale output voltage when PWMOUT = 0V, bit D4 in register 02h should be set to zero.
3) PWMOUT_ directly drives the logic-level PWM speed-control input on a fan that has this type of input. This approach requires fewer external components and combines the efficiency of 1) with the low noise of 2). An example of PWMOUT_ driving a fan with a speed-control input is shown in Figure 6. Bit D4 in register 02h should be set to 1 when this configuration is used.

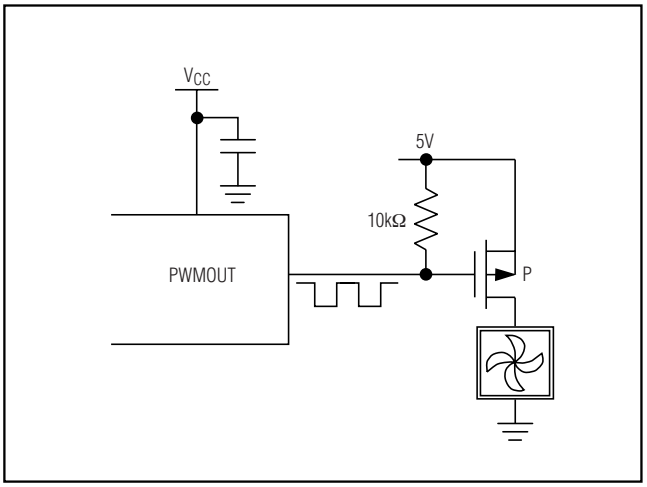


Figure 4. Driving a P-Channel MOSFET for Top-Side PWM Fan Drive

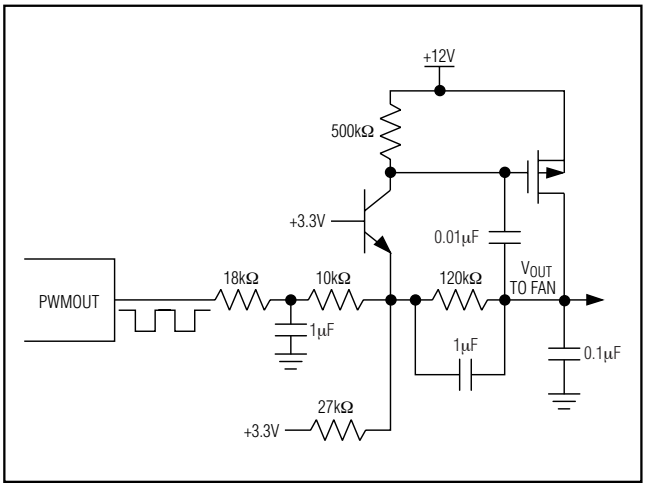


Figure 5. Driving a Fan with a PWM-to-DC Circuit

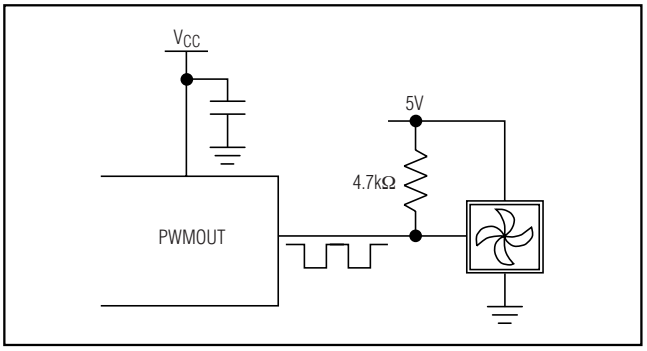


Figure 6. Controlling a PWM Input Fan with the MAX6678's PWM Output (Typically, the 35kHz PWM Frequency Is Used)

Whenever the fan has to start turning from a motionless state, PWMOUT_ is forced high for 2s. After this spin-up period, the PWMOUT_ duty cycle settles to the predetermined value. Whenever spin-up is disabled (bit 2 in the configuration byte = 1) and the fan is off, the duty cycle changes immediately from zero to the nominal value, ignoring the duty-cycle rate-of-change setting.

The frequency-select register controls the frequency of the PWM signal. When the PWM signal modulates the power supply of the fan, a low PWM frequency (usually 33Hz) should be used to ensure the circuitry of the brushless DC motor has enough time to operate. When driving a fan with a PWM-to-DC circuit as in Figure 5, the highest available frequency (35kHz) should be used to minimize the size of the filter capacitors. When using a fan with a PWM control input, the frequency normally should be high as well, although some fans have PWM inputs that accept low-frequency drive.

The duty cycle of the PWM can be controlled in two ways:

1) Manual PWM control by setting the duty cycle of the fan directly through the fan target duty-cycle registers (0Bh and 0Ch).
2) Automatic PWM control by setting the duty cycle based on temperature.

Manual PWM Duty-Cycle Control

Clearing the bits that select the temperature channels for fan control (D5 and D4 for PWMOUT1 and D3 and D2 for PWMOUT2) in the fan-configuration register (11h) enables manual fan control. In this mode, the duty cycle written to the fan target duty-cycle register directly controls the corresponding fan. The value is clipped to a maximum of 240. Any value entered above that is changed to 240 automatically. In this control mode, the value in the maximum duty-cycle register is ignored and does not affect the duty cycle used to control the fan.

Automatic PWM Duty-Cycle Control

In the automatic control mode, the duty cycle is controlled by the local or remote temperature according to the settings in the control registers. Below the fan-start temperature, the duty cycle is either 0% or is equal to the fan-start duty cycle, depending on the value of bit D3 in the configuration byte register. Above the fan-start temperature, the duty cycle increases by one duty cycle step each time the temperature increases by one temperature step. The target duty cycle is calculated based on the following formula; for temperature > FanStartTemperature:

$$DC = FSDC + (T - FST) \times \frac{DCSS}{TS}$$

where:

DC = DutyCycle

FSDC = FanStartDutyCycle

T = Temperature

FST = FanStartTemperature

DCSS = DutyCycleStepSize

TS = TempStep

Duty cycle is recalculated after each temperature conversion if temperature is increasing. If the temperature begins to decrease, the duty cycle is not recalculated until the temperature drops by 5°C from the last peak temperature. The duty cycle remains the same until the temperature drops 5°C from the last peak temperature or the temperature rises above the last peak temperature. For example, if the temperature goes up to +85°C and starts decreasing, duty cycle is not recalculated until the temperature reaches +80°C or the temperature rises above +85°C. If the temperature decreases further, the duty cycle is not updated until it reaches +75°C.

For temperature < FanStartTemperature and D2 of configuration register = 0:

DutyCycle = 0

For temperature < FanStartTemperature and D2 of configuration register = 1:

DutyCycle = FanStartDutyCycle

Once the temperature crosses the fan-start temperature threshold, the temperature has to drop below the fan-start temperature threshold minus the hysteresis before the duty cycle returns to either 0% or the fan-start duty cycle. The value of the hysteresis is set by D7 of the fan-configuration register.

The duty cycle is limited to the value in the fan maximum duty-cycle register. If the duty-cycle value is larger than the maximum fan duty cycle, it is set to the maximum fan-duty cycle as in the fan maximum duty-cycle register. The temperature step is bit D6 of the fan-configuration register (0Dh).

Notice if temperature crosses FanStartTemperature going up with an initial DutyCycle of zero, a spin-up of 2s applies before the duty-cycle calculation controls the value of the fan's duty cycle.

FanStartTemperature for a particular channel follows the channel, not the fan. When a fan switches channels, the start temperature also changes to that of the new channel.

If DutyCycle is an odd number, it is automatically rounded down to the closest even number.

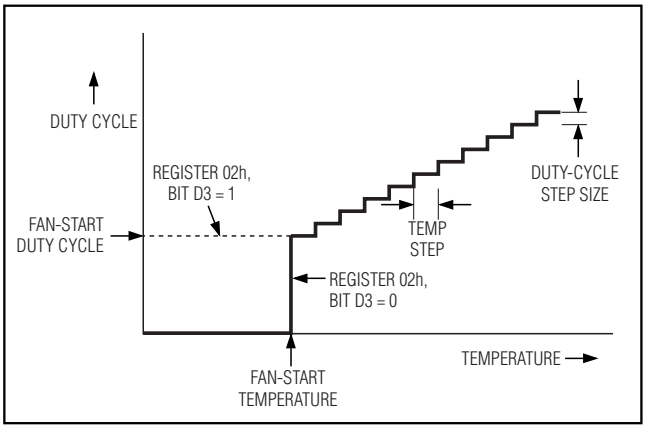


Figure 7. Automatic PWM Duty Control

2-Channel Temperature Monitor with Dual Automatic PWM Fan-Speed Controller and Five GPIOs

Duty-Cycle Rate-of-Change Control

To reduce the audibility of changes in fan speed, the rate of change of the duty cycle is limited by the values set in the duty-cycle rate-of-change register. Whenever the target duty cycle is different from the instantaneous duty cycle, the duty cycle increases or decreases at the rate determined by the duty-cycle rate-of-change byte until it reaches the target duty cycle. By setting the rate of change to the appropriate value, the thermal requirements of the system can be balanced against good acoustic performance. Slower rates of change are less noticeable to the user, while faster rates of change can help minimize temperature variations. Remember that the fan controller is part of a complex control system. Because several of the parameters are generally not known, some experimentation may be necessary to arrive at the best settings.

Power-Up Defaults

At power-up, or when the POR bit in the configuration byte register is set, the MAX6678 has the default settings indicated in Table 2. Some of these settings are summarized below:

- Temperature conversions are active.
- Channel 1 and channel 2 are set to report the remote temperature channel measurements.
- Channel 1 $\overline{OT}$ limit = +110°C.
- Channel 2 $\overline{OT}$ limit = +80°C.
- Manual fan mode.
- Fan duty cycle = 0.
- PWM invert bit = 0.
- PWMOUT_ are high.
- When using an NMOS or npn transistor, the fan starts at full speed on power-up.

$\overline{OT}$ Output

When temperature exceeds the $\overline{OT}$ temperature threshold and $\overline{OT}$ is not masked, the $\overline{OT}$ status register indicates a fault and $\overline{OT}$ output becomes active. If $\overline{OT}$ for the respective channel is masked off, the $\overline{OT}$ status register continues to be set, but the $\overline{OT}$ output does not become active.

The fault flag and the output can be cleared only by reading the $\overline{OT}$ status register and the temperature register of that channel. If the $\overline{OT}$ status bit is cleared, $\overline{OT}$ reasserts on the next conversion if the temperature still exceeds the $\overline{OT}$ temperature threshold.

GPIO Inputs/Outputs and Presets

The MAX6678 contains five GPIO pins (GPIO0 through GPIO4). When set as an output, the GPIO pin connects to the drains of internal n-channel MOSFETs. When the n-channel MOSFET is off, the pullup resistor (see the *Typical Operating Circuit*) provides a logic-level high output. When a GPIO pin is configured as an input, read the state of GPIO_ from the GPIO value register (15h). The MAX6678 powers up with GPIO0, GPIO1, and GPIO2 high impedance and GPIO3 and GPIO4 pulled low. After 2ms, the GPIOs go to their assigned preset values. The preset values are set by connecting the associated PRESET inputs to either GND or V_{CC}. With PRESET"N" connected to GND, GPIO"N" pulls low; with PRESET"N" connected to V_{CC}, GPIO"N" pulls high through the pullup resistor. After power-up, the functions and states of the GPIOs can be read and controlled using registers 15h and 16h.

Register Descriptions

The MAX6678 contains 26 internal registers. These registers store temperature, allow control of the PWM outputs, determine if the MAX6678 is measuring from the internal or remote temperature sensors, and set the GPIO as inputs or outputs.

Temperature Registers (00h and 01h)

These registers contain the results of temperature measurements. The value of the MSB is +128°C, and the value of the LSB is +1°C. Temperature data for remote diode 1 is in the temperature channel 1 register. Temperature data for remote diode 2 OR the local sensor (selectable by bit D1 in the configuration byte) is stored in the temperature channel 2 register.

Configuration Byte (02h)

The configuration byte register controls timeout conditions and various PWMOUT signals. The POR state of the configuration byte register is 00h. See Table 3 for configuration byte definitions.

Channel 1 and Channel 2 $\overline{OT}$ Limits (03h and 04h)

Set channel 1 (03h) and channel 2 (04h) temperature thresholds with these two registers. Once the temperature is above the threshold, the $\overline{OT}$ output is asserted low (for the temperature channels that are not masked). The POR state of the channel 1 $\overline{OT}$ limit register is 6Eh, and the POR state of the channel 2 $\overline{OT}$ limit register is 50h.

Table 2. Register Map

READ/ WRITE	REGISTER NO. /ADDRESS	POR STATE	FUNCTION	D7	D6	D5	D4	D3	D2	D1	D0
R	00h	0000 0000	Temperature channel 1	MSB (+128°C)	—	—	—	—	—	—	LSB (+1°C)
R	01h	0000 0000	Temperature channel 2	MSB (+128°C)	—	—	—	—	—	—	LSB (+1°C)
R/W	02h	0001 1000	Configuration byte	Reserved; set to 0	Reserved; set to 0	Timeout: 0 = enabled, 1 = disabled	PWMOUT 1 PWM invert	PWMOUT 2 PWM invert	Min duty cycle: 0 = 0%, 1 = fan - start duty cycle	Temp channel 2 source: 1 = local, 0 = remote 2	Spin-up disable
R/W	03h	0110 1110	Temperature channel 1 OT limit	MSB	—	—	—	—	—	—	LSB (+1°C)
R/W	04h	0101 0000	Temperature channel 2 OT limit	MSB	—	—	—	—	—	—	LSB (+1°C)
R	05h	00xx xxxx	$\overline{OT}$ status	Channel 1: 1 = fault	Channel 2: 1 = fault	—	—	—	—	—	—
R/W	06h	00xx xxxx	$\overline{OT}$ mask	Channel 1: 1 = masked	Channel 2: 1 = masked	—	—	—	—	—	—
R/W	07h	0110 000x (96 = 40%)	PWMOUT1 start duty cycle	MSB (128/240)	—	—	—	—	—	LSB (2/240)	—
R/W	08h	0110 000x (96 = 40%)	PWMOUT2 start duty cycle	MSB (128/240)	—	—	—	—	—	LSB (2/240)	—
R/W	09h	1111 000x (240 = 100%)	PWMOUT1 max duty cycle	MSB (128/240)	—	—	—	—	—	LSB (2/240)	—
R/W	0Ah	1111 000x (240 = 100%)	PWMOUT2 max duty cycle	MSB (128/240)	—	—	—	—	—	LSB (2/240)	—
R/W	0Bh	0000 000x	PWMOUT1 target duty cycle	MSB (128/240)	—	—	—	—	—	LSB (2/240)	—
R/W	0Ch	0000 000x	PWMOUT2 target duty cycle	MSB (128/240)	—	—	—	—	—	LSB (2/240)	—
R	0Dh	0000 000x	PWMOUT1 instantaneous duty cycle	MSB (128/240)	—	—	—	—	—	LSB (2/240)	—

****GPIO0 through GPIO4 POR values set by Preset0 through Preset4.*

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Table 2. Register Map (continued)

READ/ WRITE	REGISTER NO. /ADDRESS	POR STATE	FUNCTION	D7	D6	D5	D4	D3	D2	D1	D0
R	0Eh	0000 000x	PWMOUT2 instantaneous duty cycle	MSB (128/240)	—	—	—	—	—	LSB (2/240)	—
R/W	0Fh	0000 0000	Temperature channel 1 fan-start temperature	MSB	—	—	—	—	—	—	LSB
R/W	10h	0000 0000	Temperature channel 2 fan-start temperature	MSB	—	—	—	—	—	—	LSB
R/W	11h	0000 000x	Fan configuration	Hysteresis: 0 = 5°C, 1 = 10°C	Temp step: 0 = 1°C, 1 = 2°C	PWMOUT 1 control: 1 = channel1	PWMOUT 1 control: 1 = channel 2	PWMOUT 2 control: 1 = channel 1	PWMOUT 2 control: 1 = channel 2	—	—
R/W	12h	1011 01xx	Duty-cycle rate of change	PWMOUT 1 MSB	—	PWMOUT 1 LSB	PWMOUT 2 MSB	—	PWMOUT 2 LSB	—	—
R/W	13h	0101 0101	Duty-cycle step size	PWMOUT 1 MSB	—	—	PWMOUT 1 LSB	PWMOUT 2 MSB	—	—	PWMOUT 2 LSB
R/W	14h	010x xxxx	PWM frequency select	Select A	Select B	Select C	—	—	—	—	—
R/W	15h	xxx0 0000	GPIO function	—	—	—	GPIO4: 0 = output, 1 = input	GPIO3: 0 = output, 1 = input	GPIO2: 0 = output, 1 = input	GPIO1: 0 = output, 1 = input	GPIO0: 0 = output, 1 = input
R/W	16h	xxx***	GPIO value	—	—	—	GPIO4	GPIO3	GPIO2	GPIO1	GPIO0
R	FDh	0000 0001	Read device revision	0	0	0	0	0	0	0	1
R	FEh	1000 0110	Read device ID	1	0	0	0	0	1	1	0
R	FFh	0100 1101	Read manufacturer ID	0	1	0	0	1	1	0	1

****GPIO0 through GPIO4 POR values set by Preset0 through Preset4.*

$\overline{OT}$ Status (05h)

Read the $\overline{OT}$ status register to determine which channel recorded an overtemperature condition. Bit D7 is high if the fault reading occurred from channel 1. Bit D6 is high if the fault reading occurred in channel 2. The $\overline{OT}$ status register is cleared only by reading its contents. After reading the $\overline{OT}$ status register, a temperature register read must be done. Reading the contents of the register also makes the $\overline{OT}$ output high impedance. If the fault is still present on the next temperature measurement cycle, the corresponding bits and the $\overline{OT}$ output are set again. The POR state of the $\overline{OT}$ status register is 00h.

$\overline{OT}$ Mask (06h)

Set bit D7 to 1 in the $\overline{OT}$ mask register to prevent the $\overline{OT}$ output from asserting on faults in channel 1. Set bit D6 to 1 to prevent the $\overline{OT}$ output from asserting on faults in channel 2. The POR state of the $\overline{OT}$ mask register is 00h.

Table 3. Configuration Byte Definition (02h)

BIT	NAME	POR STATE	FUNCTION
7	Reserved; set to 0	—	—
6	Reserved; set to 0	—	—
5	TIMEOUT	0	Set TIMEOUT to zero to enable SMBus timeout for prevention of bus lockup. Set to 1 to disable this function.
4	FAN1 PWM INVERT	0	Set FAN PWM INVERT to zero to force PWMOUT1 low when the duty cycle is 100%. Set to 1 to force PWMOUT1 high when the duty cycle is 100%.
3	FAN2 PWM INVERT	0	Set FAN PWM INVERT to zero to force PWMOUT2 low when the duty cycle is 100%. Set to 1 to force PWMOUT2 high when the duty cycle is 100%.
2	MIN DUTY CYCLE	0	Set MIN DUTY CYCLE to zero for a 0% duty cycle when the measured temperature is below the fan-temperature threshold in automatic mode. When the temperature equals the fan-temperature threshold, the duty cycle is the value in the fan-start duty-cycle register, and it increases with increasing temperature. Set MIN DUTY CYCLE to 1 to force the PWM duty cycle to the value in the fan-start duty-cycle register when the measured temperature is below the fan-temperature threshold. As the temperature increases above the temperature threshold, the duty cycle increases as programmed.
1	TEMPERATURE SOURCE SELECT	0	Selects either local or remote 2 as the source for temperature channel 2 register data. When D1 = 0, the MAX6678 measures remote 2 and when D1 = 1, the MAX6678 measures the internal die temperature.
0	SPIN-UP DISABLE	0	Set SPIN-UP DISABLE to 1 to disable spin-up. Set to zero for normal fan spin-up.

PWMOUT Start Duty Cycle (07h and 08h)

The PWMOUT start duty-cycle register determines the PWM duty cycle where the fan starts spinning. Bit D2 in the configuration byte register (MIN DUTY CYCLE) determines the starting duty cycle. If the MIN DUTY CYCLE bit is 1, the duty cycle is the value written to the fan-start duty-cycle register at all temperatures below the fan-start temperature. If the MIN DUTY CYCLE bit is zero, the duty cycle is zero below the fan-start temperature and has this value when the fan-start temperature is reached. A value of 240 represents 100% duty cycle. Writing any value greater than 240 causes the fan speed to be set to 100%. The POR state of the fan-start duty-cycle register is 96h, 40%.

PWMOUT Max Duty Cycle (09h and 0Ah)

The PWMOUT maximum duty-cycle register sets the maximum allowable PWMOUT duty cycle between 2/240 (0.83% duty cycle) and 240/240 (100% duty cycle). Any values greater than 240 are recognized as 100% maximum duty cycle. The POR state of the PWMOUT maximum duty-cycle register is F0h, 100%. In manual control mode, this register is ignored.

PWMOUT Target Duty Cycle (0Bh and 0Ch)

In automatic fan-control mode, this register contains the present value of the target PWM duty cycle, as determined by the measured temperature and the duty-cycle step size. The actual duty cycle requires time before it equals the target duty cycle if the duty-cycle rate-of-change register is set to a value other than zero. In manual fan-control mode, write the desired value of the PWM duty cycle directly into this register. The POR state of the fan-target duty-cycle register is 00h.

PWMOUT1 Instantaneous Duty Cycle, PWMOUT2 Instantaneous Duty Cycle (0Dh, 0Eh)

These registers always contain the duty cycle of the PWM signals presented at the PWM output.

The POR state of the PWMOUT instantaneous duty-cycle register is 00h.

Channel 1 and Channel 2 Fan-Start Temperature (0Fh and 10h)

These registers contain the temperatures at which fan control begins (in automatic mode). See the *Automatic PWM Duty-Cycle Control* section for details on setting the fan-start thresholds. The POR state of the channel 1 and channel 2 fan-start temperature registers is 00h.

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Table 4. Setting the Time Between Duty-Cycle Increments

D7:D5, D4:D2	TIME BETWEEN INCREMENTS (s)	TIME FROM 33% TO 100% (s)
000	0	0
001	0.0625	5
010	0.125	10
011	0.25	20
100	0.5	40
101	1	80
110	2	160
111	4	320

Fan Configuration (11h)

The fan-configuration register controls the hysteresis level, temperature step size, and whether the remote or local diode controls the PWMOUT2 signal (see Table 2). Set bit D7 of the fan-configuration register to zero to set the hysteresis value to 5°C. Set bit D7 to 1 to set the hysteresis value to 10°C. Set bit D6 to zero to set the fan-control temperature step size to 1°C. Set bit D6 to 1 to set the fan-control temperature step size to +2°C. Bits D5 to D2 select which PWMOUT_ channel 1 or channel 2 controls (see Table 2). If both are selected for a given PWMOUT_, the highest PWM value is used. If neither is selected, the fan is controlled by the value written to the fan-target duty-cycle register. Also in this mode, the value written to the target duty-cycle register is not limited by the value in the maximum duty-cycle register. It is, however, clipped to 240 if a value above 240 is written. The POR state of the fan-configuration register is 00h.

Duty-Cycle Rate of Change (12h)

Bits D7, D6, and D5 (channel 1) and D4, D3, and D2 (channel 2) of the duty-cycle rate-of-change register set the time between increments of the duty cycle. Each increment is 2/240 of the duty cycle (see Table 4). This allows the time from 33% to 100% duty cycle to be adjusted from 5s to 320s. The rate-of-change control is always active in manual mode. To make instant changes, set bits D7, D6, and D5 (channel 1) or D4, D3, and D2 (channel 2) = 000. The POR state of the duty-cycle rate-of-change register is B4h (1s between increments).

Table 5. Setting the Duty-Cycle Change

D7:D4, D3:D0	CHANGE IN DUTY CYCLE PER TEMPERATURE STEP	TEMPERATURE RANGE FOR FAN CONTROL (1°C STEP, 33% TO 100%)
0000	0	0
0001	2/240	80
0010	4/240	40
0011	6/240	27
0100	8/240	20
0101	10/240	16
…	…	...
1000	16	10
...	...	...
1111	31	5

Duty-Cycle Step Size (13h)

Bits D7–D4 (channel 1) and bits D3–D0 (channel 2) of the duty-cycle step-size register change the size of the duty-cycle change for each temperature step. The POR state of the duty-cycle step size register is 55h (see Table 5).

PWM Frequency Select (14h)

Set bits D7, D6, and D5 (select A, B, and C) in the PWM frequency-select register to control the PWMOUT frequency (see Table 6). The POR state of the PWM frequency-select register is 40h, 33Hz. The lower frequencies are usually used when driving the fan's power-supply pin as in the *Typical Application Circuit*, with 33Hz being the most common choice. The 35kHz frequency setting is used for controlling fans that have logic-level PWM input pins for speed control. The minimum duty-cycle resolution is decreased from 2/240 to 4/240 at the 35kHz frequency setting. For example, a result that would return a value of 6/240 is truncated to 4/240.

Table 6. PWM Frequency Select

PWM FREQUENCY (Hz)	SELECT A	SELECT B	SELECT C
20	0	0	0
33	0	1	0
50	1	0	0
100	1	1	0
35k	X	X	1

Note: *At 35kHz, duty-cycle resolution is decreased from a resolution of 2/240 to 4/240.*

GPIO Function Register (15h)

The GPIO function register (15h) sets the GPIO_ states. Write a zero to set a GPIO as an output. Write a one to set a GPIO as an input.

GPIO Value Register (16h)

The GPIO value register (16h) contains the state of each GPIO input when a GPIO is configured as an input. When configured as an output, write a one or zero to set the value of the GPIO output.

Applications Information

Remote-Diode Considerations

Temperature accuracy depends upon having a good-quality, diode-connected, small-signal transistor. Accuracy has been experimentally verified for all the devices listed in Table 7. The MAX6678 can also directly measure the die temperature of CPUs and other ICs with on-board temperature-sensing diodes.

The transistor must be a small-signal type with a relatively high forward voltage. This ensures that the input voltage is within the A/D input voltage range. The forward voltage must be greater than 0.25V at 10µA at the highest expected temperature. The forward voltage must be less than 0.95V at 100µA at the lowest expected temperature. The base resistance has to be less than 100Ω. Tight specification of forward-current gain (+50 to +150, for example) indicates that the manufacturer has good process control and that the devices have consistent characteristics.

Effect of Ideality Factor

The accuracy of the remote-temperature measurements depends on the ideality factor (n) of the remote "diode" (actually a transistor). The MAX6678 is optimized for n = 1.008, which is the typical value for the Intel Pentium® III and the AMD Athlon™ MP model 6. If a sense transistor with a different ideality factor is used, the output data is different. Fortunately, the difference is predictable.

Assume a remote-diode sensor designed for a nominal ideality factor $n_{NOMINAL}$ is used to measure the temperature of a diode with a different ideality factor, n_1. The measured temperature T_M can be corrected using:

$$T_M = T_{ACTUAL}\left(\frac{n_1}{n_{NOMINAL}}\right)$$

where temperature is measured in Kelvin.

As mentioned above, the nominal ideality factor of the MAX6678 is 1.008.

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Athlon is a trademark of AMD.

As an example, assume the MAX6678 is configured with a CPU that has an ideality factor of 1.002. If the diode has no series resistance, the measured data is related to the real temperature as follows:

$$T_{ACTUAL} = T_M\left(\frac{n_{NOMINAL}}{n_1}\right) = T_M\left(\frac{1.008}{1.002}\right) = T_M(1.00599)$$

For a real temperature of +85°C (358.15K), the measured temperature is +82.87°C (356.02K), which is an error of -2.13°C.

Effect of Series Resistance

Series resistance in a sense diode contributes additional errors. For nominal diode currents of 10µA and 100µA, change in the measured voltage is:

$$\Delta V_M = R_S(100\mu A - 10\mu A) = 90\mu A \times R_S$$

Since 1°C corresponds to 198.6µV, series resistance contributes a temperature offset of:

$$\frac{90\frac{\mu V}{\Omega}}{198.6\frac{\mu V}{^\circ C}} = 0.453\frac{^\circ C}{\Omega}$$

Assume that the diode being measured has a series resistance of 3Ω. The series resistance contributes an offset of:

$$3\Omega \times 0.453\frac{^\circ C}{\Omega} = 1.36^\circ C$$

The effects of the ideality factor and series resistance are additive. If the diode has an ideality factor of 1.002 and series resistance of 3Ω, the total offset can be calculated by adding error due to series resistance with error due to ideality factor:

1.36°C - 2.13°C = -0.77°C

for a diode temperature of +85°C.

In this example, the effect of the series resistance and the ideality factor partially cancel each other.

For best accuracy, the discrete transistor should be a small-signal device with its collector connected to GND and base connected to DXN. Table 7 lists examples of discrete transistors that are appropriate for use with the MAX6678.

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ADC Noise Filtering

The integrating ADC has inherently good noise rejection, especially of low-frequency signals such as 60Hz/120Hz power-supply hum. Micropower operation places constraints on high-frequency noise rejection. Lay out the PC board carefully with proper external noise filtering for high-accuracy remote measurements in electrically noisy environments.

Filter high-frequency electromagnetic interference (EMI) at DXP and DXN with an external 2200pF capacitor connected between the two inputs. This capacitor can be increased to about 3300pF (max), including cable capacitance. A capacitance higher than 3300pF introduces errors due to the rise time of the switched-current source.

Twisted Pairs and Shielded Cables

For remote-sensor distances longer than 8in, or in particularly noisy environments, a twisted pair is recommended. Its practical length is 6ft to 12ft (typ) before noise becomes a problem, as tested in a noisy electronics laboratory. For longer distances, the best solution is a shielded twisted pair like that used for audio microphones. For example, Belden 8451 works well for distances up to 100ft in a noisy environment. Connect the twisted pair to DXP and DXN and the shield to ground, and leave the shield's remote end unterminated. Excess capacitance at DXN or DXP limits practical remote-sensor distances (see the *Typical Operating Characteristics*).

For very long cable runs, the cable's parasitic capacitance often provides noise filtering, so the recommended 2200pF capacitor can often be removed or reduced in value. Cable resistance also affects remote-sensor accuracy. A 1Ω series resistance introduces about +1/2°C error.

PC Board Layout Checklist

1) Place the MAX6678 as close as practical to the remote diode. In a noisy environment, such as a computer motherboard, this distance can be 4in to 8in, or more, as long as the worst noise sources (such as CRTs, clock generators, memory buses, and ISA/PCI buses) are avoided.
2) Do not route the DXP/DXN lines next to the deflection coils of a CRT. Also, do not route the traces across a fast memory bus, which can easily introduce +30°C error, even with good filtering. Otherwise, most noise sources are fairly benign.

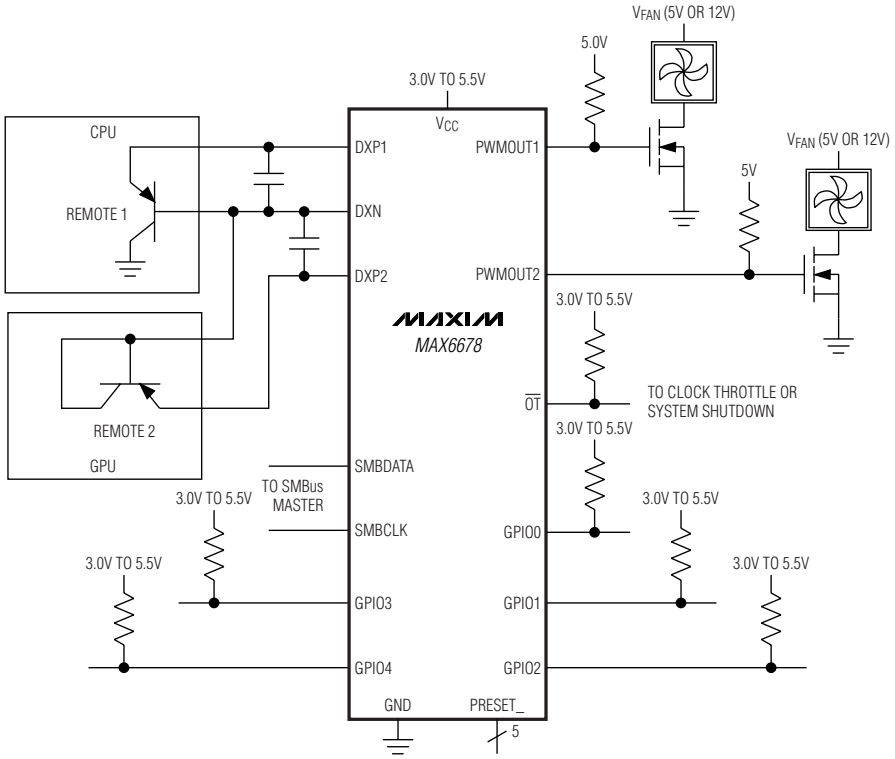
Table 7. Remote-Sensor Transistor Manufacturers

MANUFACTURER	MODEL NO.
Central Semiconductor (USA)	CMPT3906
Rohm Semiconductor (USA)	SST3906
Samsung (Korea)	KST3906-TF
Siemens (Germany)	SMBT3906

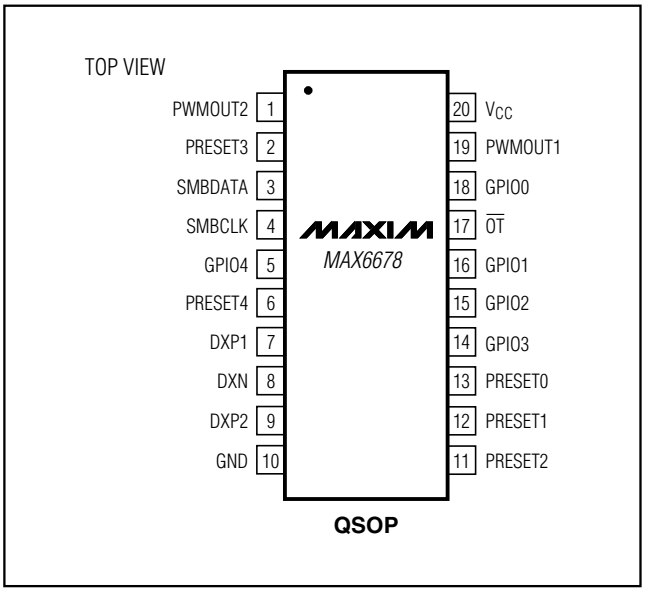
3) Route the DXP and DXN traces parallel and close to each other, away from any high-voltage traces such as +12VDC. Avoid leakage currents from PC board contamination. A 20MΩ leakage path from DXP ground causes approximately +1°C error.
4) Connect guard traces to GND on either side of the DXP/DXN traces. With guard traces, placing routing near high-voltage traces is no longer an issue.
5) Route as few vias and crossunders as possible to minimize copper/solder thermocouple effects.
6) When introducing a thermocouple, make sure that both the DXP and the DXN paths have matching thermocouples. In general, PC board-induced thermocouples are not a serious problem. A copper solder thermocouple exhibits 3µV/°C, and it takes approximately 200µV of voltage error at DXP/DXN to cause a +1°C measurement error, so most parasitic thermocouple errors are swamped out.
7) Use wide traces. Narrow traces are more inductive and tend to pick up radiated noise. The 10-mil widths and spacings recommended are not absolutely necessary (as they offer only a minor improvement in leakage and noise), but use them where practical.
8) Placing an electrically clean copper ground plane between the DXP/DXN traces and traces carrying high-frequency noise signals helps reduce EMI.

2-Channel Temperature Monitor with Dual Automatic PWM Fan-Speed Controller and Five GPIOs

Typical Application Circuit



Pin Configurations (continued)



Chip Information

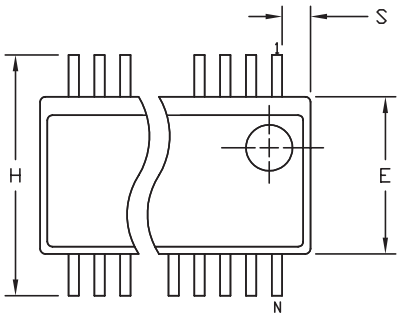
TRANSISTOR COUNT: 23,618
PROCESS: BiCMOS

2-Channel Temperature Monitor with Dual Automatic PWM Fan-Speed Controller and Five GPIOs

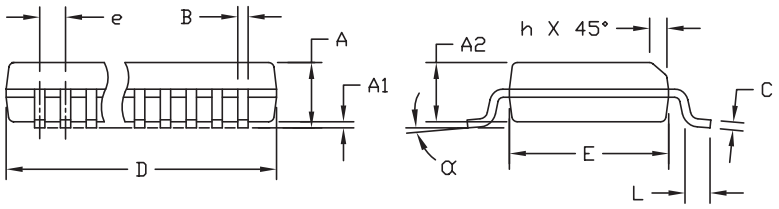
Package Information

(The package drawing(s) in this data sheet may not reflect the most current specifications. For the latest package outline information, go to **www.maxim-ic.com/packages**.)

QSOP.EPS



DIM	INCHES MIN	INCHES MAX	MILLIMETERS MIN	MILLIMETERS MAX
A	.061	.068	1.55	1.73
A1	.004	.0098	0.102	0.249
A2	.055	.061	1.40	1.55
B	.008	.012	0.20	0.30
C	.0075	.0098	0.191	0.249
D	SEE VARIATIONS			
E	.150	.157	3.81	3.99
e	.025 BSC		0.635 BSC	
H	.230	.244	5.84	6.20
h	.010	.016	0.25	0.41
L	.016	.035	0.41	0.89
N	SEE VARIATIONS			
α	0°	8°	0°	8°



VARIATIONS:

	INCHES MIN.	INCHES MAX.	MILLIMETERS MIN.	MILLIMETERS MAX.	N	
D	.189	.196	4.80	4.98	16	AB
S	.0020	.0070	0.05	0.18		
D	.337	.344	8.56	8.74	20	AD
S	.0500	.0550	1.270	1.397		
D	.337	.344	8.56	8.74	24	AE
S	.0250	.0300	0.635	0.762		
D	.386	.393	9.80	9.98	28	AF
S	.0250	.0300	0.635	0.762		

NOTES:
1). D & E DO NOT INCLUDE MOLD FLASH OR PROTRUSIONS.
2). MOLD FLASH OR PROTRUSIONS NOT TO EXCEED .006" PER SIDE.
3). CONTROLLING DIMENSIONS: INCHES.
4). MEETS JEDEC MO137.

DALLAS SEMICONDUCTOR MAXIM
PROPRIETARY INFORMATION

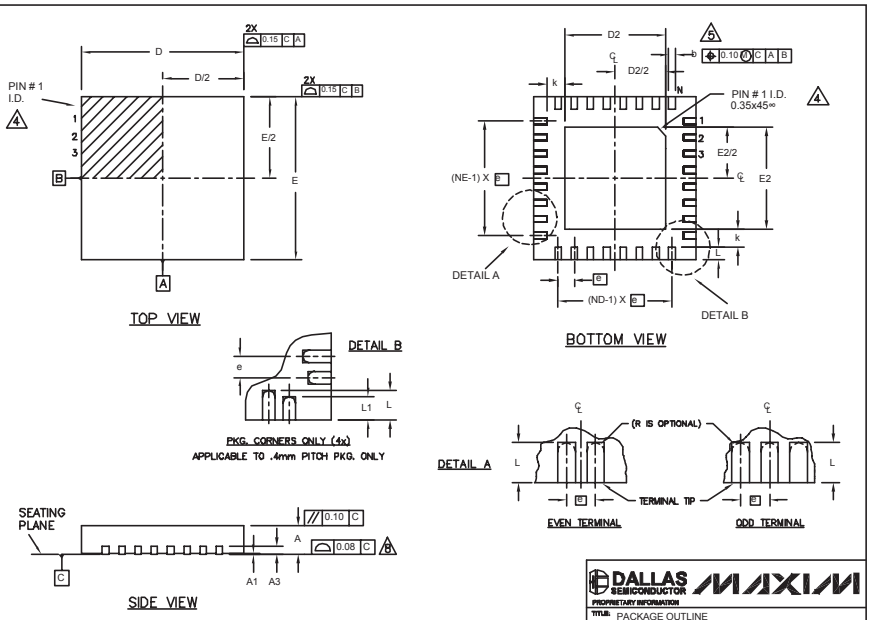
TITLE:
PACKAGE OUTLINE, QSOP .150", .025" LEAD PITCH

APPROVAL	DOCUMENT CONTROL NO.	REV.	
	21-0055	E	1/1

Package Information (continued)

(The package drawing(s) in this data sheet may not reflect the most current specifications. For the latest package outline information, go to **www.maxim-ic.com/packages**.)

QFN THIN.EPS



COMMON DIMENSIONS															
PKG.	16L 5x5			20L 5x5			28L 5x5			32L 5x5			40L 5x5		
SYMBOL	MIN.	NOM.	MAX.	MIN.	NOM.	MAX.	MIN.	NOM.	MAX.	MIN.	NOM.	MAX.	MIN.	NOM.	MAX.
A	0.70	0.75	0.80	0.70	0.75	0.80	0.70	0.75	0.80	0.70	0.75	0.80	0.70	0.75	0.80
A1	0	0.02	0.05	0	0.02	0.05	0	0.02	0.05	0	0.02	0.05	0	-	0.05
A3	0.20 REF.			0.20 REF.			0.20 REF.			0.20 REF.			0.20 REF.		
b	0.25	0.30	0.35	0.25	0.30	0.35	0.20	0.25	0.30	0.20	0.25	0.30	0.15	0.20	0.25
D	4.90	5.00	5.10	4.90	5.00	5.10	4.90	5.00	5.10	4.90	5.00	5.10	4.90	5.00	5.10
E	4.90	5.00	5.10	4.90	5.00	5.10	4.90	5.00	5.10	4.90	5.00	5.10	4.90	5.00	5.10
e	0.80 BSC.			0.65 BSC.			0.50 BSC.			0.50 BSC.			0.40 BSC.		
k	0.25	-	-	0.25	-	-	0.25	-	-	0.25	-	-	0.25	0.35	0.45
L	0.30	0.40	0.50	0.45	0.55	0.65	0.45	0.55	0.65	0.30	0.40	0.50	0.40	0.50	0.60
L1	-	-	-	-	-	-	-	-	-	-	-	-	0.30	0.40	0.50
N	16			20			28			32			40		
ND	4			5			7			8			10		
NE	4			5			7			8			10		
JEDEC	WHHB			WHHC			WHHD-1			WHHD-2			-		

EXPOSED PAD VARIATIONS							
PKG. CODES	D2			E2			DOWN BONDS ALLOWED
	MIN.	NOM.	MAX.	MIN.	NOM.	MAX.	
T1655-1	3.00	3.10	3.20	3.00	3.10	3.20	NO
T1655-2	3.00	3.10	3.20	3.00	3.10	3.20	YES
T2055-2	3.00	3.10	3.20	3.00	3.10	3.20	NO
T2055-3	3.00	3.10	3.20	3.00	3.10	3.20	YES
T2055-4	3.00	3.10	3.20	3.00	3.10	3.20	NO
T2855-1	3.15	3.25	3.35	3.15	3.25	3.35	NO
T2855-2	2.60	2.70	2.80	2.60	2.70	2.80	NO
T2855-3	3.15	3.25	3.35	3.15	3.25	3.35	YES
T2855-4	2.60	2.70	2.80	2.60	2.70	2.80	YES
T2855-5	2.60	2.70	2.80	2.60	2.70	2.80	NO
T2855-6	3.15	3.25	3.35	3.15	3.25	3.35	NO
T2855-7	2.60	2.70	2.80	2.60	2.70	2.80	YES
T3255-2	3.00	3.10	3.20	3.00	3.10	3.20	NO
T3255-3	3.00	3.10	3.20	3.00	3.10	3.20	YES
T3255-4	3.00	3.10	3.20	3.00	3.10	3.20	NO
T4055-1	3.20	3.30	3.40	3.20	3.30	3.40	YES

NOTES:

1. DIMENSIONING & TOLERANCING CONFORM TO ASME Y14.5M-1994.
2. ALL DIMENSIONS ARE IN MILLIMETERS. ANGLES ARE IN DEGREES.
3. N IS THE TOTAL NUMBER OF TERMINALS.
4. THE TERMINAL #1 IDENTIFIER AND TERMINAL NUMBERING CONVENTION SHALL CONFORM TO JESD 95-1 SPP-012. DETAILS OF TERMINAL #1 IDENTIFIER ARE OPTIONAL, BUT MUST BE LOCATED WITHIN THE ZONE INDICATED. THE TERMINAL #1 IDENTIFIER MAY BE EITHER A MOLD OR MARKED FEATURE.
5. DIMENSION b APPLIES TO METALLIZED TERMINAL AND IS MEASURED BETWEEN 0.25 mm AND 0.30 mm FROM TERMINAL TIP.
6. ND AND NE REFER TO THE NUMBER OF TERMINALS ON EACH D AND E SIDE RESPECTIVELY.
7. DEPOPULATION IS POSSIBLE IN A SYMMETRICAL FASHION.
8. COPLANARITY APPLIES TO THE EXPOSED HEAT SINK SLUG AS WELL AS THE TERMINALS.
9. DRAWING CONFORMS TO JEDEC MO220, EXCEPT EXPOSED PAD DIMENSION FOR T2855-1, T2855-3 AND T2855-6.
10. WARPAGE SHALL NOT EXCEED 0.10 mm.



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