N 211

±1°C M R C

The NVT211 is a dual-channel digital thermometer and undertemperature/overtemperature alarm, intended for use in thermal management systems. It is register-compatible with the NCT1008 and NCT72. A feature of the NVT211 is series resistance cancellation, where up to 1.5 kΩ (typical) of resistance in series with the temperature monitoring diode can be automatically cancelled from the temperature result, allowing noise filtering. The NVT211 has a configurable $\overline{\text{ALERT}}$ output and an extended, switchable temperature measurement range.

The NVT211 can measure the temperature of a remote thermal diode accurate to ±1°C and the ambient temperature accurate to ±3°C. The temperature measurement range defaults to 0°C to +127°C, compatible with the NCT1008 and NCT72, but it can be switched to a wider measurement range of −64°C to +191°C.

The NVT211 communicates over a 2-wire serial interface, compatible with system management bus (SMBus/I^2C) standards. The default SMBus/I^2C address of the NVT211 is 0x4C. An NVT211D is available with an SMBus/I^2C address of 0x4D. This is useful if more than one NVT211 is used on the same SMBus/I^2C.

An $\overline{\text{ALERT}}$ output signals when the on-chip or remot-23.2(ormot-23.2(3mperatoi523.2(df)-198.4(same8.(392ess)2 Tc15437 Tw[put)-2361.

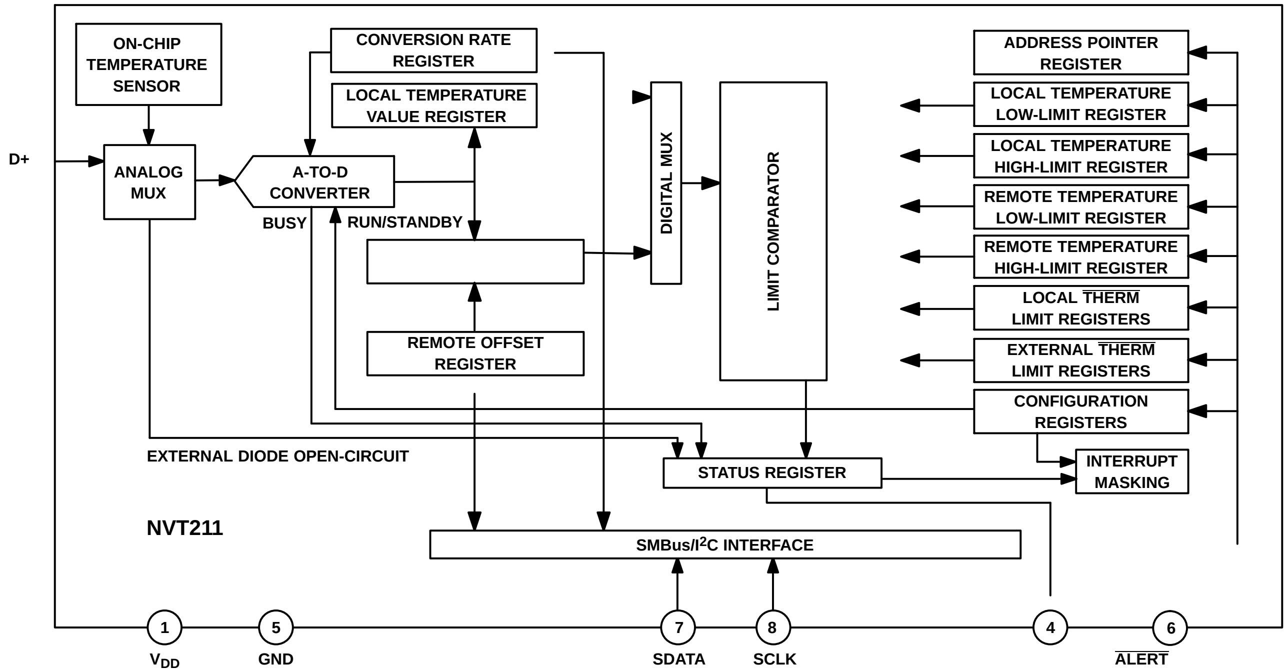


Figure 1. Functional Block Diagram

Table 3. SMBus/I²C TIMING SPECIFICATIONS (Note 1)

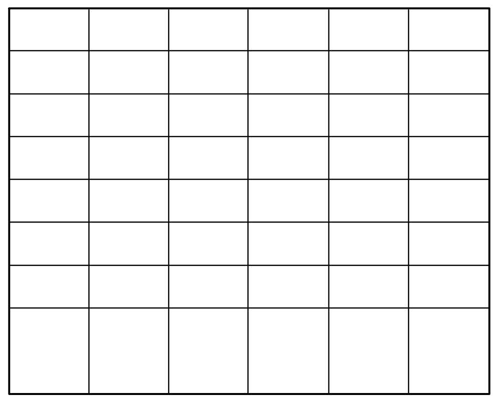
Parameter	Limit at T_{MIN} and T_{MAX}	Unit	Description
f_{SCLK}	400	kHz max	–
t_{LOW}	1.3	μs min	Clock Low Period, between 10% Points
t_{HIGH}	0.6	μs min	Clock High Period, between 90% Points
t_R	300	ns max	Clock/Data Rise Time
t_F	300	ns max	Clock/Data Fall Time
$t_{SU; STA}$	600	ns min	Start Condition Setup Time
$t_{HD; STA}$			

Table 4. ELECTRICAL CHARACTERISTICS (T_A = –40°C to +125°C, V_{DD} = 2.8 V to 3.6 V, unless otherwise noted)

Parameter	Conditions	Min	Typ	Max	Unit
Power Supply					
Supply Voltage, V_{DD}		2.8	3.30	3.6	V
Average Operating Supply Current, I_{DD}	0.0625 Conversions/Sec Rate (Note 1, 2) Standby Mode	– –	240 5.0	350 30	μA
Undervoltage Lockout Threshold	V_{DD} input, disables ADC, rising edge	–	2.55	–	V
Power-on Reset Threshold		1.0	–	2.56	V
Temperature-to-Digital Converter					
Local Sensor Accuracy 3.0 V to 3.6 V	0°C ≤ T_A ≤ +70°C 0°C ≤ T_A ≤ +85°C	– –	– –	±1.0 ±1.5	°C
Local Sensor Accuracy 2.8 V to 3.6 V	–20°C ≤ T_A ≤ +110°C	–	–	±2.5	°C
Resolution		–	1.0	–	°C
Remote Diode Sensor Accuracy 3.0 V to 3.6 V	0°C ≤ T_A ≤ +70°C, –55°C ≤ T_D (Note 3) ≤ +150°C 0°C ≤ T_A ≤ +85°C, –55°C ≤ T_D (Note 3) ≤ +150°C –40°C ≤ T_A ≤ +100°C, –55°C ≤ T_D (Note 3) ≤ +150°C	– – –	– – –	±1.0 ±1.5 ±2.5	°C
Remote Diode Sensor Accuracy 2.8 V to 3.6 V	0°C ≤ T_A ≤ +70°C, –20°C ≤ T_D ≤ +110°C –20°C ≤ T_A ≤ +110°C, T_D = +40°C	– –	– –	±1.5 ±2.25	°C
Resolution		–	0.25	–	°C
Remote Sensor Source Current	High Level (Note 3) Middle Level (Note 3) Low Level (Note 3)	– – –	220 82 13.5	– – –	μA
Conversion Time	From Stop Bit to Conversion Complete, One-shot Mode with Averaging Switched On	–	40	52	ms
	One-shot Mode with Averaging Off (that is, Conversion Rate = 16-, 32-, or 64-conversions per Second)	–	6.0	8.0	ms
Maximum Series Resistance Cancelled	Resistance Split Evenly on both the D+ and D– Inputs	–	1.5	–	kΩ
Open-drain Digital Outputs ($\overline{\text{THERM}}$, $\overline{\text{ALERT}}$/$\overline{\text{THERM2}}$)					
Output Low Voltage, V_{OL}	I_{OUT} = –6.0 mA	–	–	0.4	V
High Level Output Leakage Current, I_{OH}	$V_{OUT} = V_{DD}$	–	0.1	1.0	μA
SMBus/I^{2}C Interface (Note 4 and 5)					
Logic Input High Voltage, V_{IH} SCLK, SDATA		1.4	–	–	V
Logic Input Low Voltage, V_{IL} SCLK, SDATA		–	–	0.8	V
Hysteresis		–	500	–	mV
SDA Output Low Voltage, V_{OL}		–	–	0.4	mA
Logic Input Current, I_{IH}, I_{IL}		–1.0	–	+1.0	μA
SMBus/I^{2}C Input Capacitance, SCLK, SDATA		–	5.0	–	pF
SMBus/I^{2}C Clock Frequency		–	–	400	kHz
SMBus/I^{2}C Timeout (Note 6)	User Programmable	–	25	64	ms
SCLK Falling Edge to SDATA Valid Time	Master Clocking in Data	–	–	1.0	μs

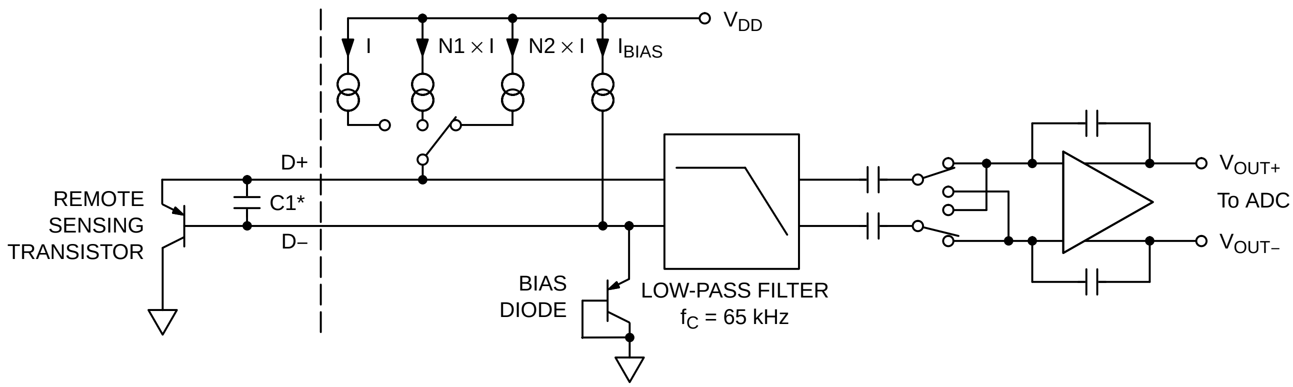
1. See Table 8 for information on other conversion rates.
2. $\overline{\text{THERM}}$ and $\overline{\text{ALERT}}$ pulled to V_{DD}.
3. Guaranteed by characterization, but not production tested.
4. Guaranteed by design, but not production tested.
5. See SMBus/I^{2}C Timing Specifications section for more information.
6. Disabled by default. Detailed procedures to enable it are in the Serial Bus Interface section of the datasheet.

TYPICAL PERFORMANCE CHARACTERISTICS (Cont'd)



Theory of Operation

The NVT211 is a local and remote temperature sensor and



*CAPACITOR C1 IS OPTIONAL. IT IS ONLY NECESSARY IN NOISY ENVIRONMENTS. C1 = 1,000 pF MAX.

Figure 14. Input Signal Conditioning

Temperature Measurement Results

The results of the local and remote temperature measurements are stored in the local and remote temperature value registers and compared with limits programmed into the local and remote high and low limit registers.

The local temperature value is in Register 0x00 and has a resolution of 1°C. The external temperature value is stored in two registers, with the upper byte in Register 0x01 and the lower byte in Register 0x10. Only the two MSBs in the external temperature low byte are used giving the external temperature measurement a resolution of 0.25°C. Table 5 lists the data format for the external temperature low byte.

Table 5. EXTENDED TEMPERATURE RESOLUTION (REMOTE TEMPERATURE LOW BYTE)

Extended Resolution	Remote Temperature Low Byte
0.00°C	0 000 0000
0.25°C	0 100 0000
0.50°C	1 000 0000
0.75°C	1 100 0000

When reading the full external temperature value, read the LSB first. This causes the MSB to be locked (that is, the ADC does not write to it) until it is read. This feature ensures that the results read back from the two registers come from the same measurement.

Temperature Measurement Range

The temperature measurement range for both internal and external measurements is, by default, 0°C to +127°C. However, the NVT211 can be operated using an extended temperature range. The extended measurement range is −64°C to +191°C. Therefore, the NVT211 can be used to measure the full temperature range of an external diode, from −55°C to +150°C.

The extended temperature range is selected by setting Bit 2 of the configuration register to 1. The temperature range is 0°C to 127°C when Bit 2 equals 0. A valid result is available in the next measurement cycle after changing the temperature range.

In extended temperature mode, the upper and lower temperature that can be measured by the NVT211 is limited by the remote diode selection. The temperature registers can have values from −64°C to +191°C. However, most temperature sensing diodes have a maximum temperature range of −55°C to +150°C. Above +150°C, they may lose their semiconductor characteristics and approximate conductors instead. This results in a diode short. In this case, a read of the temperature result register gives the last good temperature measurement. Therefore, the temperature measurement on the external channel may not be accurate for temperatures that are outside the operating range of the remote sensor.

It should be noted that although both local and remote temperature measurements can be made while the part is in extended temperature mode, the NVT211 itself should not be exposed to temperatures greater than those specified in the absolute maximum ratings section. Further, the device is only guaranteed to operate as specified at ambient temperatures from −40°C to +120°C.

Temperature Data Format

The NVT211 has two temperature data formats. When the temperature measurement range is from 0°C to 127°C (default), the temperature data format for both internal and external temperature results is binary. When the measurement range is in extended mode, an offset binary data format is used for both internal and external results. Temperature values are offset by 64°C in the offset binary data format. Examples of temperatures in both data formats are shown in Table 6.

Table 6. TEMPERATURE DATA FORMAT

Table 7. CONFIGURATION REGISTER BIT ASSIGNMENTS

Bit	Name	Function	Power-on Default
7	MASK1	0 = $\overline{\text{ALERT}}$ Enabled 1 = $\overline{\text{ALERT}}$ Masked	0
6	RUN/STOP	0 = Run 1 = Standby	0
5	$\overline{\text{ALERT}}$/ $\overline{\text{THERM2}}$	0 = $\overline{\text{ALERT}}$ 1 = $\overline{\text{THERM2}}$	0
4, 3	Reserved		0
2	Temperature Range Select	0 = 0°C to 127°C 1 = Extended Range	0
1, 0	Reserved		0

Conversion Rate Register

The conversion rate register is Address 0x04 at read and Address 0x0A at write. The lowest four bits of this register are used to program the conversion rate by dividing the internal oscillator clock by 1, 2, 4, 8, 16, 32, 64, 128, 256, 512, or 1024 to give conversion times from 15.5 ms (Code 0x0A) to 16 seconds (Code 0x00). For example, a conversion rate of eight conversions per second means that beginning at 125 ms intervals, the device performs a conversion on the internal and the external temperature channels.

The conversion rate register can be written to and read back over the SMBus/I^2C. The higher four bits of this register are unused and must be set to 0. The default value of this register is 0x08, giving a rate of 16 conversions per second. Use of slower conversion times greatly reduces the device power consumption.

Table 8. CONVERSION RATE REGISTER CODES

Code	Conversion/Second	Time
0x00	0.0625	16 s
0x01	0.125	8 s
0x02	0.25	4 s
0x03	0.5	2 s
0x04	1	1 s
0x05	2	500 ms
0x06	4	250 ms
0x07	8	125 ms
0x08	16	62.5 ms
0x09	32	31.25 ms
0x0A	64	15.5 ms
0x0B to 0xFF	Reserved	–

Limit Registers

The NVT211 has eight limit registers: high, low, and $\overline{\text{THERM}}$ temperature limits for both local and remote temperature measurements. The remote temperature high and low limits span two registers each, to contain an upper and lower byte for each limit. There is also a $\overline{\text{THERM}}$ hysteresis register. All limit registers can be written to, and read back over, the SMBus/I^2C. See Table 12 for details of the limit register addresses and their power-on default values.

Table 12. LIST OF REGISTERS

Read Address (Hex)	Write Address (Hex)	Name	Power-on Default
Not Applicable	Not Applicable	Address Pointer	Undefined
00	Not Applicable	Local Temperature Value	0000 0000 (0x00)
01	Not Applicable	External Temperature Value High Byte	0000 0000 (0x00)
02	Not Applicable	Status	Undefined
03	09	Configuration	0000 0000 (0x00)
04	0A	Conversion Rate	0000 1000 (0x08)
05	0B	Local Temperature High Limit	0101 0101 (0x55) (85°C)
06	0C	Local Temperature Low Limit	0000 0000 (0x00) (0°C)
07	0D	External Temperature High Limit High Byte	0101 0101 (0x55) (85°C)
08	0E	External Temperature Low Limit High Byte	0000 0000 (0x00) (0°C)
Not Applicable	0F (Note 1)	One-shot	
10	Not Applicable	External Temperature Value Low Byte	0000 0000
11	11	External Temperature Offset High Byte	0000 0000
12	12	External Temperature Offset Low Byte	0000 0000
13	13	External Temperature High Limit Low Byte	0000 0000
14	14	External Temperature Low Limit Low Byte	0000 0000
19	19	External $\overline{THERM}$ Limit	0110 1100 (0x6C) (108°C)
20	20	Local $\overline{THERM}$ Limit	

write operation is limited only by what the master and slave devices can handle.

3. When all data bytes have been read or written, stop conditions are established. In write mode, the master pulls the data line high during the tenth clock pulse to assert a stop condition. In read mode, the master device overrides the acknowledge bit by pulling the data line high during the low period before the ninth clock pulse. This is known as no acknowledge. The master takes the data line low during the low period before the tenth clock pulse, then high during the tenth clock pulse to assert a stop condition.

   Any number of bytes of data are transferable over the serial bus in one operation, but it is not possible to mix read and write in one operation because the type of operation is determined at the beginning and cannot subsequently be changed without starting a new operation. For the NVT211, write operations contain either one or two bytes, while read operations contain one byte.

To write data to one of the device data registers, or to read data from it, the address pointer register must be set so that the correct data register is addressed. The first byte of a write operation always contains a valid address that is stored in the address pointer register. If data is to be written to the device, the write operation contains a second data byte that is written to the register selected by the address pointer register.

This procedure is illustrated in Figure 15. The device address is sent over the bus followed by R/$\overline{W}$ set to 0. This is followed by two data bytes. The first data byte is the address of the internal data register to be written to, which is stored in the address pointer register. The second data byte is the data to be written to the internal data register.

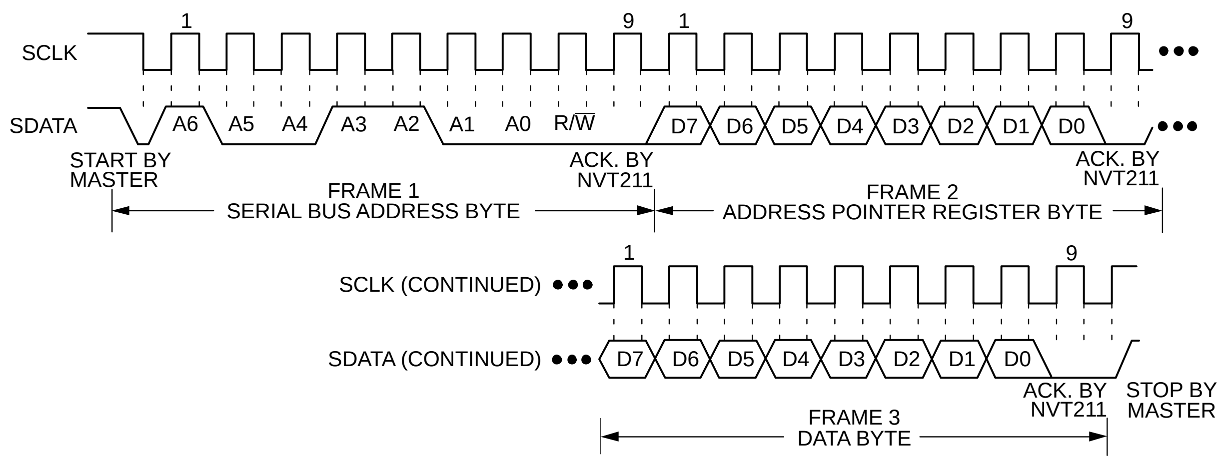


Figure 15. Writing a Register Address to the Address Pointer Register, then Writing Data to the Selected Register

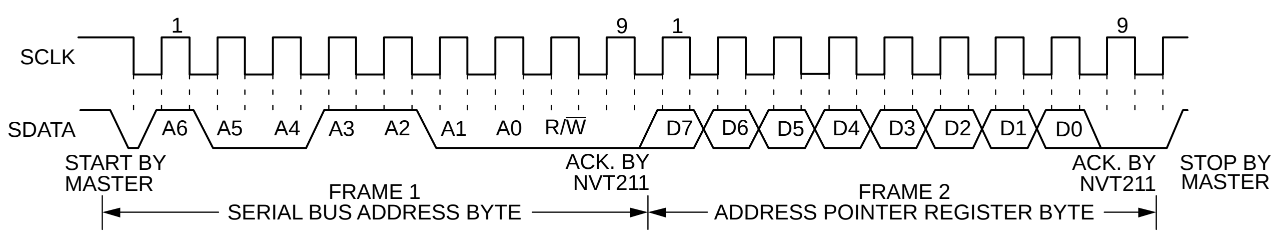


Figure 16. Writing to the Address Pointer Register Only

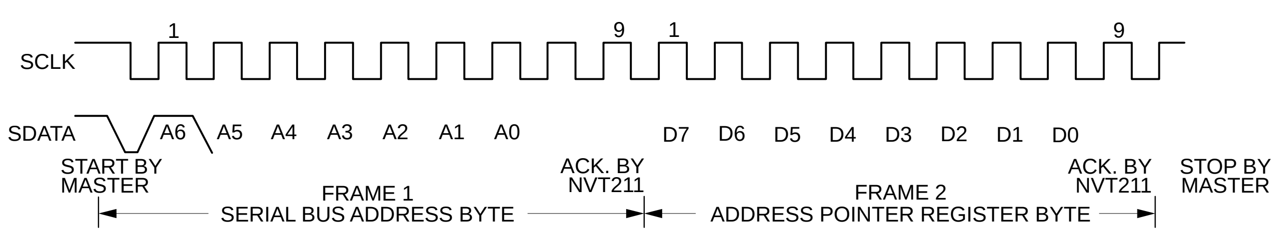


Figure 17. Reading Data from a Previously Selected Register

When reading data from a register there are two possibilities.

- If the address pointer register value of the NVT211 is unknown or not the desired value, it is first necessary to set it to the correct value before data can be read from the desired data register. This is done by writing to the NVT211 as before, but only the data byte containing the register read address is sent, because data is not to be written to the register see Figure 16.
  A read operation is then performed consisting of the serial bus address, $R/\overline{W}$ bit set to 1, followed by the data byte read from the data register see Figure 17.
- If the address pointer register is known to be at the desired address, data can be read from the corresponding data register without first writing to the address pointer register and the bus transaction shown in Figure 16 can be omitted.

Notes:

- It is possible to read a data byte from a data register without first writing to the address pointer register. However, if the address pointer register is already at the correct value, it is not possible to write data to a register without writing to the address pointer register because the first data byte of a write is always written to the address pointer register.
- Some of the registers have different addresses for read and write operations. The write address of a register must be written to the address pointer if data is to be written to that register, but it may not be possible to read data from that address. The read address of a register must be written to the address pointer before data can be read from that register.

$\overline{\text{ALERT}}$ Output

This is applicable when Pin 6 is configured as an $\overline{\text{ALERT}}$ output. The $\overline{\text{ALERT}}$ output goes low whenever an out-of-limit measurement is detected, or if the remote temperature sensor is open circuit. It is an open-drain output and requires a pullup resistor to V_{DD}. Several $\overline{\text{ALERT}}$ outputs can be wire-OR'ed together, so that the common line goes low if one or more of the $\overline{\text{ALERT}}$ outputs goes low.

The $\overline{\text{ALERT}}$ output can be used as an interrupt signal to a processor, or as an $\overline{\text{SMBALERT}}$. Slave devices on the SMBus/I^{2}C cannot normally signal to the bus master that they want to talk, but the $\overline{\text{SMBALERT}}$ function allows them to do so.

One or more $\overline{\text{ALERT}}$ outputs can be connected to a common $\overline{\text{SMBALERT}}$ line that is connected to the master. When the $\overline{\text{SMBALERT}}$ line is pulled low by one of the devices, the following procedure occurs (see Figure 18):

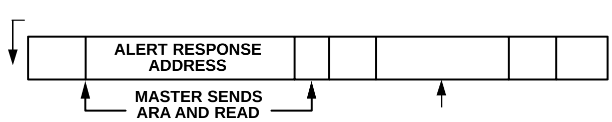


Figure 18. Use of $\overline{\text{SMBALERT}}$

The NVT211 Interrupt System

The NVT211 has two interrupt outputs, $\overline{\text{ALERT}}$ and $\overline{\text{THERM}}$. Both have different functions and behavior. $\overline{\text{ALERT}}$ is maskable and responds to violations of software programmed temperature limits or an open-circuit fault on the external diode. $\overline{\text{THERM}}$ is intended as a fail-safe interrupt output that cannot be masked.

If the external or local temperature exceeds the programmed high temperature limits, or equals or exceeds the low temperature limits, the $\overline{\text{ALERT}}$ output is asserted low. An open-circuit fault on the external diode also causes $\overline{\text{ALERT}}$ to assert. $\overline{\text{ALERT}}$ is reset when serviced by a master reading its device address, provided the error condition has gone away and the status register has been reset.

The $\overline{\text{THERM}}$ output asserts low if the external or local temperature exceeds the programmed $\overline{\text{THERM}}$ limits. $\overline{\text{THERM}}$ temperature limits should normally be equal to or greater than the high temperature limits. $\overline{\text{THERM}}$ is reset automatically when the temperature falls back within the $\overline{\text{THERM}}$ limit. A hysteresis value can be programmed; in which case, $\overline{\text{THERM}}$ resets when the temperature falls to the limit value minus the hysteresis value. This applies to both local and remote measurement channels. The power-on hysteresis default value is 10°C, but this can be reprogrammed to any value after powerup.

The hysteresis loop on the $\overline{\text{THERM}}$ outputs is useful when $\overline{\text{THERM}}$ is used, for example, as an on/off controller for a fan. The user's system can be set up so that when $\overline{\text{THERM}}$ asserts, a fan is switched on to cool the system. When $\overline{\text{THERM}}$ goes high again, the fan can be switched off. Programming a hysteresis value protects from fan jitter, where the temperature hovers around the $\overline{\text{THERM}}$ limit, and the fan is constantly switched.

Table 13. $\overline{\text{THERM}}$ HYSTERESIS

$\overline{\text{THERM}}$ Hysteresis	Binary Representation
0°C	0 000 0000
1°C	0 000 0001

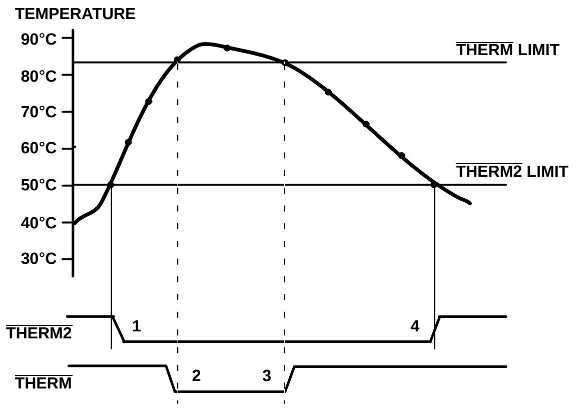


Figure 20. Operation of the $\overline{\text{THERM}}$ and $\overline{\text{THERM2}}$ Interrupts

- When the $\overline{\text{THERM2}}$ limit is exceeded, the $\overline{\text{THERM2}}$ signal asserts low.
- If the temperature continues to increase and exceeds the $\overline{\text{THERM}}$ limit, the $\overline{\text{THERM}}$ output asserts low.
- The $\overline{\text{THERM}}$ output deasserts (goes high) when the temperature falls to $\overline{\text{THERM}}$ limit minus hysteresis. In Figure 20, there is no hysteresis value shown.
- As the system cools further, and the temperature falls below the $\overline{\text{THERM2}}$ limit, the $\overline{\text{THERM2}}$ signal resets. Again, no hysteresis value is shown for $\overline{\text{THERM2}}$.

Both the external and internal temperature measurements cause $\overline{\text{THERM}}$ and $\overline{\text{THERM2}}$ to operate as described.

Application Information

Noise Filtering

For temperature sensors operating in noisy environments, the industry standard practice was to place a capacitor across the D+ and D− pins to help combat the effects of noise. However, large capacitances affect the accuracy of the temperature measurement, leading to a recommended maximum capacitor value of 1,000 pF. Although this capacitor reduces the noise, it does not eliminate it, making it difficult to use the sensor in a very noisy environment.

The NVT211 has a major advantage over other devices when it comes to eliminating the effects of noise on the external sensor. The series resistance cancellation feature allows a filter to be constructed between the external temperature sensor and the part. The effect of any filter resistance seen in series with the remote sensor is automatically cancelled from the temperature result.

The construction of a filter allows the NVT211 and the remote temperature sensor to operate in noisy environments. Figure 21 shows a low-pass R-C-R filter, where R = 100 Ω and C = 1 nF. This filtering reduces both common-mode and differential noise.

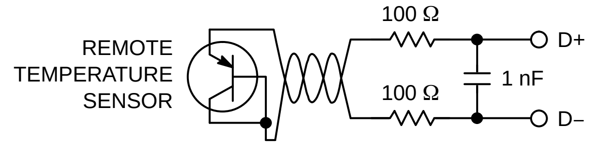


Figure 21. Filter between Remote Sensor and NVT211 Factors Affecting Diode Accuracy

Remote Sensing Diode

The NVT211 is designed to work with discrete transistors. Substrate transistors are generally PNP types with the collector connected to the substrate. Discrete types are either PNP or NPN transistors connected as diodes (base-shorted to collector). If an NPN transistor is used, the collector and base are connected to D+ and the emitter to D−. If a PNP transistor is used, the collector and base are connected to D− and the emitter to D+.

To reduce the error due to variations in discrete transistors,, where R = 100 causes a lag in the response of the sensor to a temperature

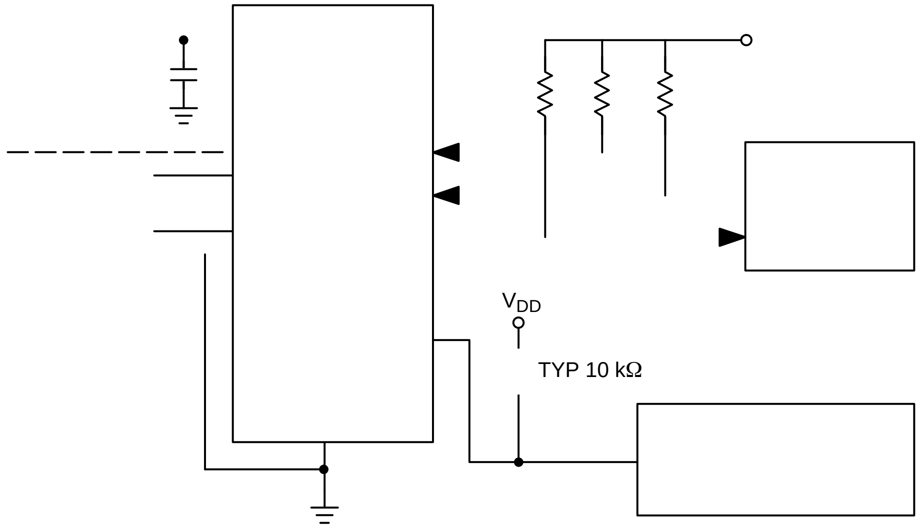
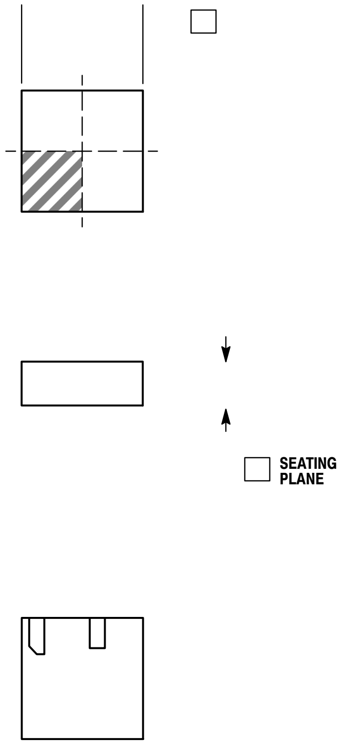


Figure 23. Typical Application Circuit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