NCT72

±1°C Temperature Monitor with Series Resistance Cancellation

The NCT72 is a dual-channel digital thermometer and undertemperature/overtemperature alarm, intended for use in PCs and thermal management systems. It is pin and register compatible with the NCT1008 but the NCT72 allows the user to pull the $\overline{\text{ALERT}}$ pin to 1.8 V without increasing the device Idd. A feature of the NCT72 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 NCT72 has a configurable $\overline{\text{ALERT}}$ output and an extended, switchable temperature measurement range.

The NCT72 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, but it can be switched to a wider measurement range of −64°C to +191°C.

The NCT72 communicates over a 2-wire serial interface, compatible with system management bus (SMBus/I^2C) standards. The default SMBus/I^2C address of the NCT72 is 0x4C. An NCT72D is available with an SMBus/I^2C address of 0x4D. This is useful if more than one NCT72 is used on the same SMBus/I^2C.

An $\overline{\text{ALERT}}$ output signals when the on-chip or remote temperature is out of range. The $\overline{\text{THERM}}$ output is a comparator output that allows on/off control of a cooling fan. The $\overline{\text{ALERT}}$ output can be reconfigured as a second $\overline{\text{THERM}}$ output, if required.

Features

- On-chip and Remote Temperature Sensor
- 0.25°C Resolution/1°C Accuracy on Remote Channel
- 1°C Resolution/1°C Accuracy on Local Channel
- Series Resistance Cancellation Up to 1.5 kΩ
- Extended, Switchable Temperature Measurement Range 0°C to +127°C (Default) or –64°C to +191°C
- Pin and Register Compatible with NCT1008
- Remote $\overline{\text{THERM}}$ Limit of 108°C
- 2-wire SMBus/I^2C Serial Interface with SMBus Alert Support
- Programmable Over/Undertemperature Limits
- Offset Registers for System Calibration
- Up to Two Overtemperature Fail-safe $\overline{\text{THERM}}$ Outputs
- Small 8-lead DFN
- 240 μA Operating Current, 5 μA Standby Current
- Compatible with 1.8 V Logic
- These Devices are Pb-Free, Halogen Free/BFR Free and are RoHS Compliant

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Applications

- Smart Phones

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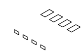

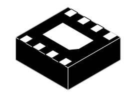

V_{DD}	1	8	SCLK
D+	2	7	SDATA
D−	3	6	$\overline{\text{ALERT}}$/$\overline{\text{THERM2}}$
$\overline{\text{THERM}}$	4	5	GND

WDFN8

7x = Device Code (Where x = C or D)
M = Date Code
▪ = Pb-Free Package

(Note: Microdot may be in either location)

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DFN8

x = C or D
A = Assembly Location
L = Wafer Lot
Y = Year
W = Work Week
▪ = Pb-Free Package

(Note: Microdot may be in either location)

* Automotive
* Embedded Systems

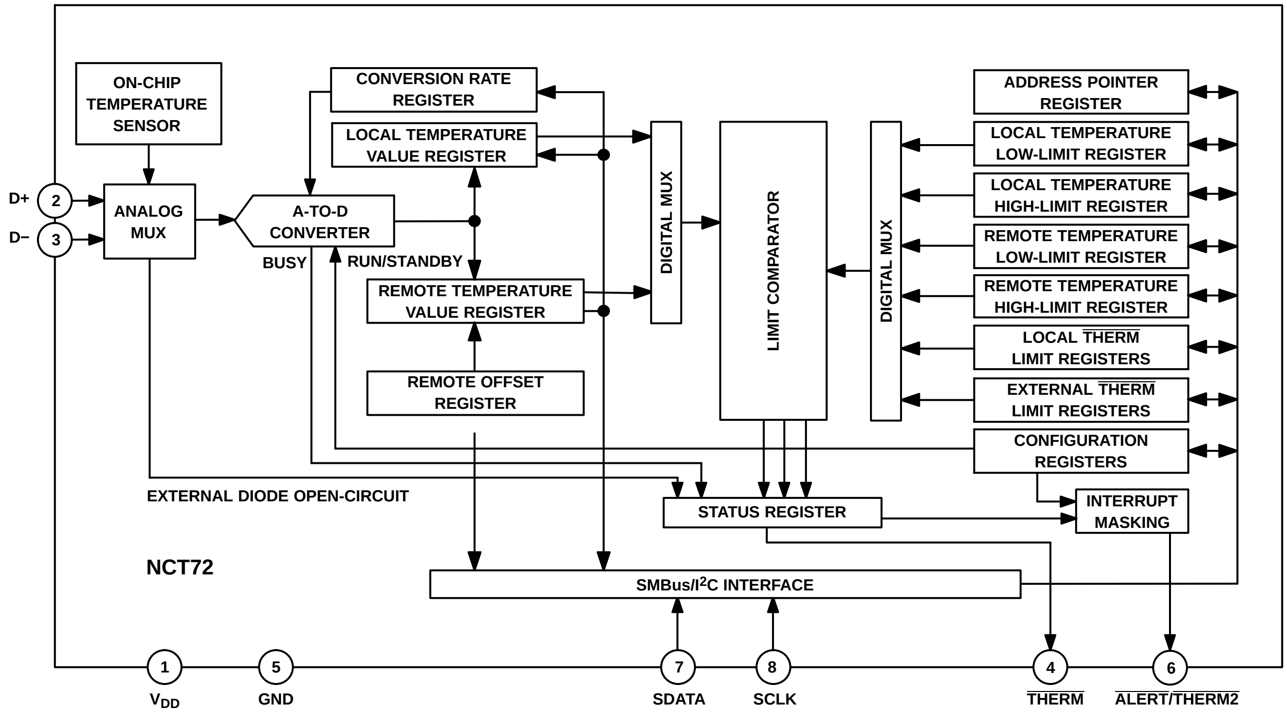

Figure 1. Functional Block Diagram

Table 2. ABSOLUTE MAXIMUM RATINGS

Parameter	Rating	Unit
Positive Supply Voltage (V_{DD}) to GND	−0.3, +3.6	V
D+	−0.3 to V_{DD} + 0.3	V
D− to GND	−0.3 to +0.6	V
SCLK, SDATA, $\overline{ALERT}$, $\overline{THERM}$	−0.3 to +3.6	V
Input Current, SDATA, $\overline{THERM}$	−1, +50	mA
Input Current, D−	±1	mA
ESD Rating, All Pins (Human Body Model)	1,500	V
Maximum Junction Temperature ($T_{J\ MAX}$)	150	°C
Storage Temperature Range	−65 to +150	°C

Stresses exceeding those listed in the Maximum Ratings table may damage the device. If any of these limits are exceeded, device functionality should not be assumed, damage may occur and reliability may be affected.

NOTE: This device is ESD sensitive. Use standard ESD precautions when handling.

Table 3. THERMAL CHARACTERISTICS (Note 1)

Package Type	θ_{JA}	θ_{JC}	Unit
8-lead DFN	142	43.74	°C/W

1. θ_{JA} is specified for the worst-case conditions, that is, a device soldered in a circuit board for surface-mount packages.

Table 4. 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
$t_{HD;\ STA}$ (Note 2)	600	ns min	Start Condition Hold Time
$t_{SU;\ DAT}$ (Note 3)	100	ns min	Data Setup Time
$t_{SU;\ STO}$ (Note 4)	600	ns min	Stop Condition Setup Time
t_{BUF}	1.3	μs min	Bus Free Time between Stop and Start Conditions

1. Guaranteed by design, but not production tested.
2. Time from 10% of SDATA to 90% of SCLK.
3. Time for 10% or 90% of SDATA to 10% of SCLK.
4. Time for 90% of SCLK to 10% of SDATA.

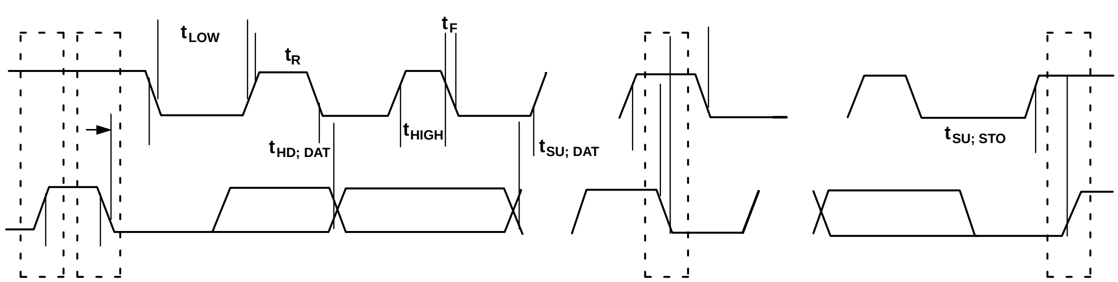

Figure 2. Serial Bus Timing

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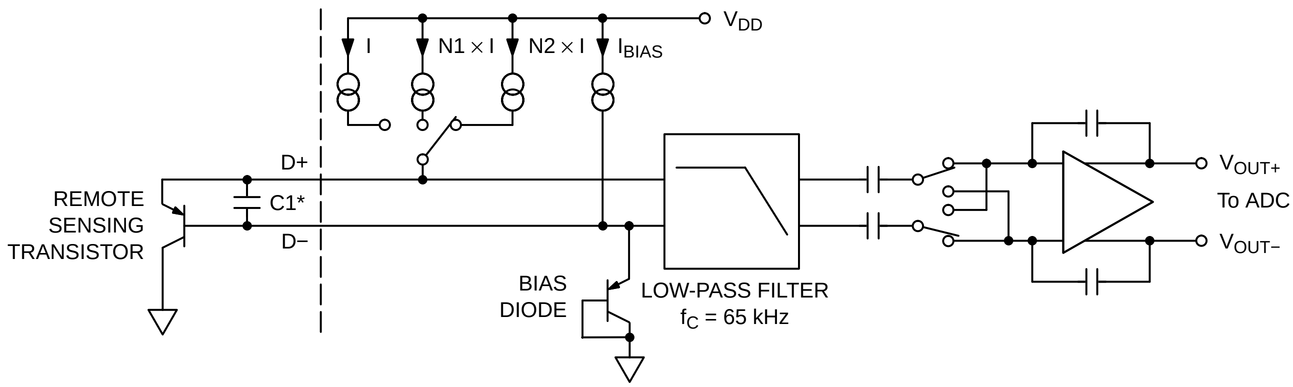
Remote Diode Sensor Accuracy 2.8 V to 3.6 V	0°C ≤ T_A ≤ +70°C, −20°C ≤ T_D ≤ +110°C −20°C ≤ T_A ≤ +110°C, T_D = +40°C	− −	− −	±1.5 ±2.25	°C
Resolution		−	0.25	−	°C
Remote Sensor Source Current	High Level (Note 3) Middle Level (Note 3) Low Level (Note 3)				

TYPICAL PERFORMANCE CHARACTERISTICS (Cont'd)

Theory of Operation

The NCT72 is a local and remote temperature sensor and over/under temperature alarm, with the added ability to automatically cancel the effect of 1.5 kΩ (typical) of resistance in series with the temperature monitoring diode. When the NCT72 is operating normally, the on-board ADC operates in a free running mode. The analog input multiplexer alternately selects either the on-chip temperature sensor to measure its local temperature or the remote temperature sensor. The ADC digitizes these signals and the results are stored in the local and remote temperature value registers.

The local and remote measurement results are compared with the corresponding high, low, and $\overline{\text{THERM}}$ temperature



*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 6 lists the data format for the external temperature low byte.

Table 6. 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 NCT72 can be operated using an extended temperature range. The extended measurement range is −64°C to +191°C. Therefore, the NCT72 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 NCT72 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 NCT72 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 NCT72 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 7.

set, the $\overline{\text{THERM2}}$ output goes low to indicate that the temperature measurements are outside the programmed limits. Flag 5 and Flag 3 have no effect on $\overline{\text{THERM2}}$. The behavior of $\overline{\text{THERM2}}$ is otherwise the same as $\overline{\text{THERM}}$.

Table 10. STATUS REGISTER BIT ASSIGNMENTS

Bit	Name	Function
7		

Table 13. LIST OF REGISTERS

Read Address (Hex)	Write Address (Hex)	Name	Power-on Default
Not Applicable	Not Applicable	Address Pointer	Undefined

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 NCT72, 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.

SCLK

A6

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

When reading data from a register there are two possibilities.

- If the address pointer register value of the NCT72 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 NCT72 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.
-

fault is detected. If the ALERT pin is enabled, setting this flag causes ALERT to assert low.

If the user does not wish to use an external sensor with the NCT72, tie the D+ and D− inputs together to prevent continuous setting of the open flag.

The NCT72 Interrupt System

The NCT72 has two interrupt outputs, ALERT and THERM. Both have different functions and behavior. ALERT is maskable and responds to violations of software programmed temperature limits or an open-circuit fault on the external diode. 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 ALERT output is asserted low. An open-circuit fault on the external diode also causes ALERT

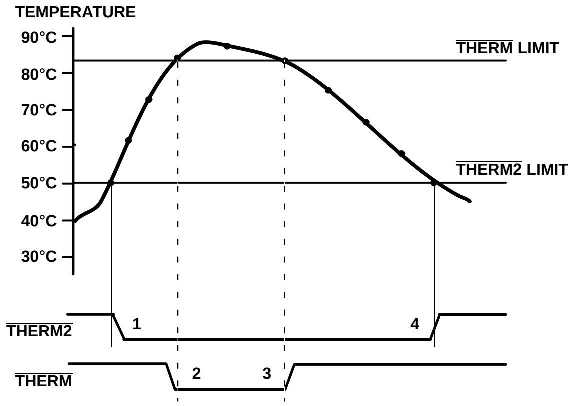


Figure 20. Operation of the $\overline{\text{THERM}}$ and $\overline{\text{THERM2}}$ Interrupts

- 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 NCT72 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 NCT72 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.

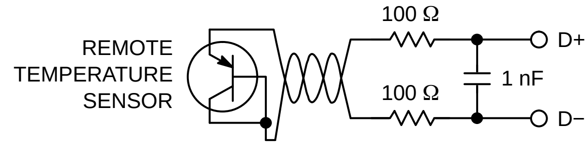


Figure 21. Filter between Remote Sensor and NCT72

Factors Affecting Diode Accuracy

Remote Sensing Diode

The NCT72 is designed to work with substrate transistors built into processors or 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 both substrate and discrete transistors, consider several factors:

- The ideality factor, nF, of the transistor is a measure of the deviation of the thermal diode from ideal behavior. The NCT72 is trimmed for an nF value of 1.008. The following equation may be used to calculate the error introduced at a temperature, T (°C), when using a transistor whose nF does not equal 1.008. Consult the processor data sheet for the nF values.

  $$\Delta T = (nF - 1.008)/1.008 \times (273.15 \text{ Kelvin} + T)$$

  To factor this in, the user writes the ΔT value to the offset register. It is then automatically added to, or subtracted from, the temperature measurement.
- Some CPU manufacturers specify the high and low current levels of the substrate transistors. The high current level of the NCT72, I_{HIGH}, is 220 μA and the low level current, I_{LOW}, is 13.5 μA. If the NCT72 current levels do not match the current levels specified by the CPU manufacturer, it may become necessary to remove an offset. The CPU data sheet should advise whether this offset needs to be removed and how to calculate it. This offset is programmed to the offset register. It is important to note that if more than one offset must be considered, the algebraic sum of these offsets must be programmed to the offset register.

If a discrete transistor is used with the NCT72, the best accuracy is obtained by choosing devices according to the following criteria:

- Base-emitter voltage greater than 0.25 V at 6 μA, at the highest operating temperature
- Base-emitter voltage less than 0.95 V at 100 μA, at the lowest operating temperature

- Base resistance less than 100 Ω
- Small variation in h_{FE} (50 to 150) that indicates tight control of V_{BE} characteristics

Transistors, such as the 2N3904, 2N3906, or equivalents in SOT−23 packages are suitable devices to use.

Thermal Inertia and Self-heating

Accuracy depends on the temperature of the remote sensing diode and/or the internal temperature sensor being at the same temperature as that being measured. Many factors can affect this. Ideally, place the sensor in good thermal contact with the part of the system being measured. If it is not, the thermal inertia caused by the sensor's mass causes a lag in the response of the sensor to a temperature change. In the case of the remote sensor, this should not be a problem since it is either a substrate transistor in the processor or a small package device, such as the SOT−23, placed in close proximity to it.

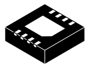
The on-chip sensor, however, is often remote from the processor and only monitors the general ambient temperature around the package. How accurately the temperature of the board and/or the forced airflow reflects the temperature to be measured dictates the accuracy of the measurement. Self-heating due to the power dissipated in the NCT72 or the remote sensor causes the chip temperature of the device or remote sensor to rise above ambient. However, the current forced through the remote sensor is so small that self-heating is negligible. In the case of the NCT72, the worst-case condition occurs when the device is converting at 64 conversions per second while sinking the maximum current of 1 mA at the $\overline{\text{ALERT}}$ and $\overline{\text{THERM}}$ output. In this case, the total power dissipation in the device is about 4.5 mW. The thermal resistance, θ_{JA}, of the 8-lead DFN is approximately 142°C/W.

Layout Considerations

Digital boards can be electrically noisy environments, and the NCT72 is measuring very small voltages from the remote sensor, so care must be taken to minimize noise induced at the sensor inputs. Take the following precautions:

- Place the NCT72 as close as possible to the remote sensing diode. Provided that the worst noise sources, that is, clock generators, data/address buses, and CRTs are avoided, this distance can be 4 inches to 8 inches.
- Route the D+ and D– tracks close together, in parallel, with grounded guard tracks on each side. To minimize inductance and reduce noise pickup, a 5 mil track width and spacing is recommended. Provide a ground plane under the tracks, if possible.

Figure 22. Typical Arrangement of Signal Tracks



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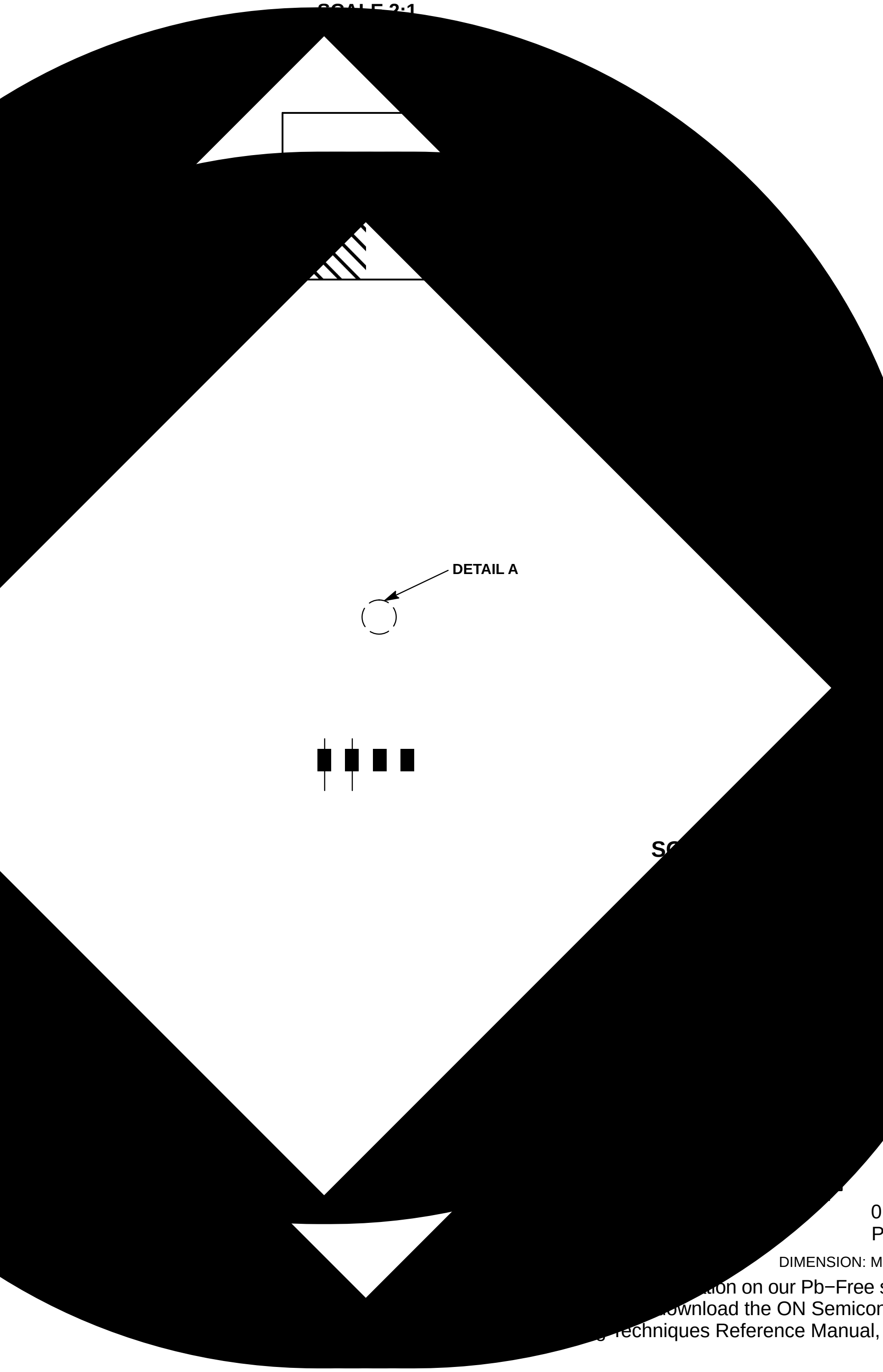

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GENERIC
MARKING DIAGRAM*

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XXX = Specific Device Code
= Assembly Location
= Wafer Lot
= Year
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DIMENSION: MILLIMETERS

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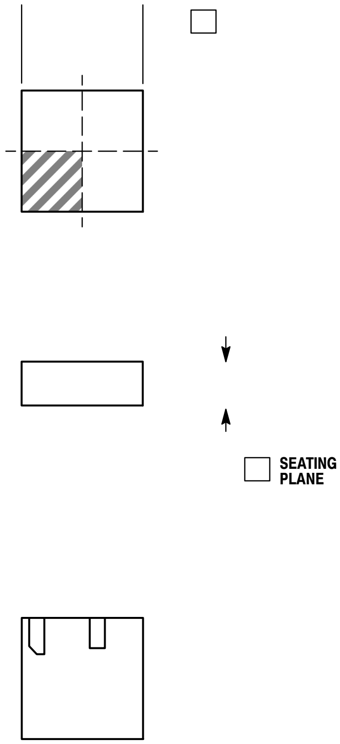
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