DIGITAL OUTPUT FORCE SENSORS
I²C COMMUNICATIONS

Technical Note

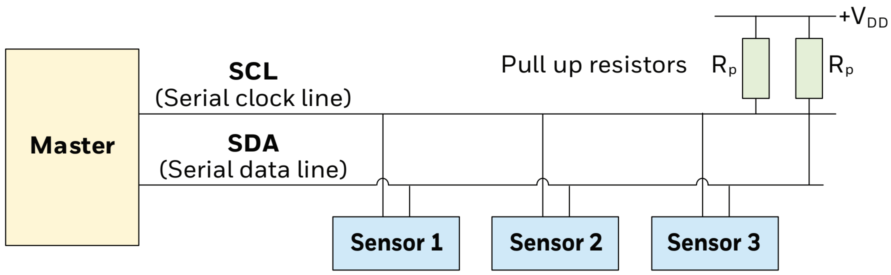
This Technical Note provides implementation information for Honeywell force sensors with I²C (Inter-IC) digital output.

1.0 INTRODUCTION

The I²C (Inter-IC) bus is a simple, serial 8-bit oriented computer bus for efficient I²C (Inter-IC) control. It provides good support for communication between different ICs across short circuit-board distances, such as interfacing microcontrollers with various low speed peripheral devices.

Each device connected to the bus is software addressable by a unique address and a simple “Master”/”Sensor” relationship that exists at all times. The output stages of devices connected to the bus are designed around an open collector architecture. Because of this, pull-up resistors to $+V_{DD}$ must be provided on the bus. Both SDA (Serial Data Line) and SCL (Serial Clock Line) are bidirectional lines, and it is important for system performance to match the capacitive loads on both lines. In addition, in accordance with the I²C specification, the maximum allowable capacitance on either line is 400 pF to ensure reliable edge transitions at 400 kHz clock speeds (see Figure 1). When the bus is free, both lines are pulled up to $+V_{DD}$. Data on the I²C-bus can be transferred at a rate up to 100 kbit/s in the standard mode, or up to 400 kbit/s in the fast mode.

FIGURE 1. I²C BUS CONFIGURATION



NOTICE

For detailed specifications of the I²C protocol, see Version 2.1 (January 2000) of the I²C Bus Specification (source: NXP Semiconductor at (http://www.nxp.com/acrobat_download/literature/9398/39340011.pdf).

2.0 DATA TRANSFER

Honeywell’s digital output force sensors are designed to respond to requests from a Master device. Following the address and read bit from the Master, these Sensors are designed to output up to four bytes of data, depending on the sensor options and application needs. In all cases, the first two data bytes are the compensated force output, along with sensor status bits. The third and fourth bytes are for optional compensated temperature output.

2.1 SENSOR ADDRESS

Each sensor is referenced on the bus by a 7-bit Sensor address. The default address for Honeywell force sensors is 40 (28 hex). Other available standard addresses are: 56 (38 hex), 72 (48 hex), 88 (58 hex), 104 (68 hex), 120 (78 hex). (Other custom values are available. Please contact Honeywell Customer Service.)

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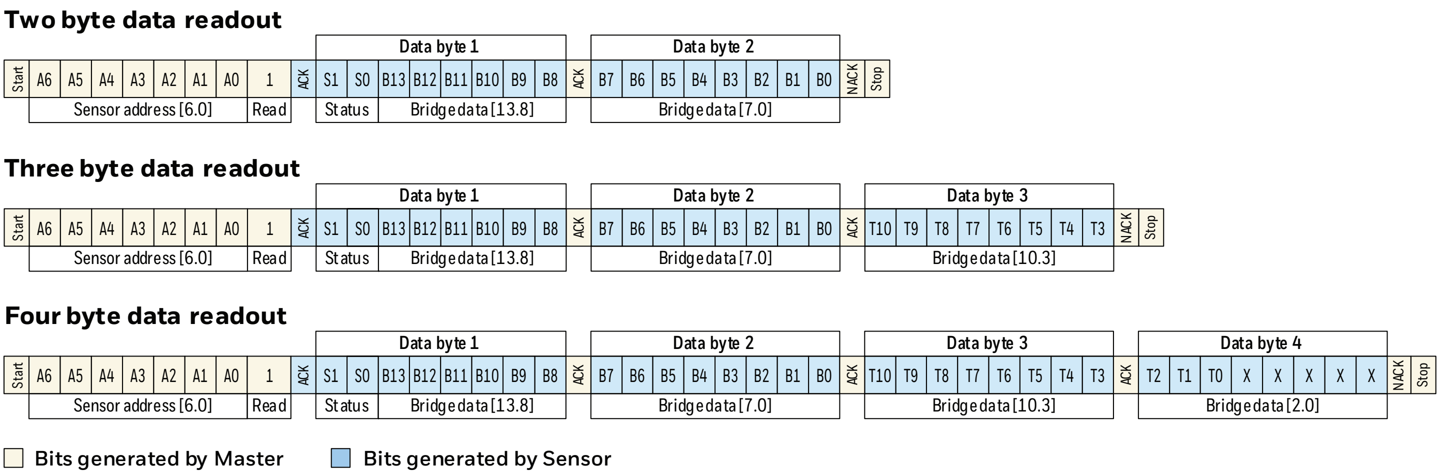
2.2 FORCE READING (SEE FIGURE 2)

The Master generates a "Start" condition and sends the Sensor address followed by a "Read" bit. After the Sensor generates an "Acknowledge" (ACK), it will transmit up to four bytes of data: the first two bytes contain the compensated force output, and the second two bytes contain the optional compensated temperature output. The Master must acknowledge the receipt of each byte, and can terminate the communication by sending a "Not Acknowledge" (NACK) bit followed by a "Stop" bit after receiving both bytes of data.

FIGURE 2. I²C FORCE AND TEMPERATURE MEASUREMENT PACKETS READOUT[1]



2.3 TEMPERATURE READING

The optional corrected temperature data may be read out with either 8-bit or 11-bit output. See Table 1 for specifics.

TABLE 1. OPTIONAL COMPENSATED TEMPERATURE

OUTPUT	READING	LOCATION	RESOLUTION
8-bit	Optional compensated temperature value	third data byte	0.8°C
11-bit	Complete optional compensated temperature value	fourth data byte[1]	0.1°C

[1] The five least significant bits of the fourth data byte are "Do Not Care" and should be ignored.

2.4 DIAGNOSTIC STATES

Honeywell digital output force sensors offer both standard and optional diagnostics to ensure robust system operation in critical applications. The diagnostic state is indicated by the first two Most Significant Bits of data byte 1 as shown in Table 2.

TABLE 2. DIAGNOSTIC STATES

STATUS BITS		DEFINITION
S1	S0	
0	0	Normal operation, valid data
0	1	Device in command mode[1]
1	0	Stale data: Indicates data that has already been fetched since the last measurement cycle, or data fetched before the first measurement has been completed
1	1	Diagnostic condition

[1] Command mode is used for programming the sensor. This mode should not be seen during normal operation.

A status bit reading of "10" indicates "stale" data. This state may occur when the Master polls the data quicker than the sensor can update the output buffer.

2.41 Standard Diagnostic Function

The standard diagnostic function is an EEPROM (Electrically Erasable Programmable Read-Only Memory) signature used to validate the EEPROM content during startup. Any EEPROM content change after calibration flags a diagnostic condition.

2.42 Optional Diagnostic Functions

The two optional diagnostic functions, either of which may be indicated by a status bit reading of "11", are:

- Loss of sense element connection
- Short circuit of sense element

(Please contact Honeywell Customer Service with questions regarding the availability of optional digital output force diagnostics.)

3.0 CALCULATING FORCE FROM THE DIGITAL OUTPUT

The output of the sensor may be expressed by its transfer function as shown in Equation 1.

Equation 1: Force Sensor Transfer Function

$$\text{Output} = \frac{(\text{Output}_{max.} - \text{Output}_{min.})}{\text{Rated Force Range}} \times (\text{Force}_{applied}) + \text{Output}_{min.}$$

Rearranging this equation to solve for force provides Equation 2:

Equation 2: Force Output Function

$$\text{Force} = \frac{(\text{Output} - \text{Output}_{min.})}{(\text{Output}_{max.} - \text{Output}_{min.})} \times \text{Rated Force Range}$$

Where:

$\text{Output}_{max.}$ = output at maximum force [counts]

$\text{Output}_{min.}$ = output at minimum force [counts]

Force_{rated} = maximum value of force range (N, lb, g, or kg)

$\text{Force}_{applied}$ = Force being measured by the sensor (N, lb, g, or kg)

Output = digital force reading [counts]

Example: Calculate the force for a 10 N force sensor with a 10% to 90% calibration and a force output of 6880 (decimal) counts:

$\text{Output}_{max.}$ = 14745 counts (90% of 2^{14} counts or 0x3999)

$\text{Output}_{min.}$ = 1638 counts (10% of 2^{14} counts or 0x0666)

Force_{rated} = 10 N

Force = force in N

Output = 6880 counts

$$\text{Force} = \frac{[(6880 - 1638) \times 10]}{(14745 - 1638)}$$

$$\text{Force} = \frac{(5242 \times 10)}{13107}$$

Force = 4 N

4.0 CALCULATING OPTIONAL TEMPERATURE FROM THE DIGITAL OUTPUT

For those sensors so equipped, the optional compensated temperature output may be converted to °C using Equation 3:

Equation 3: Temperature Conversion Function

$$\text{Temperature (°C)} = \left(\frac{\text{Output (dec)}}{2047} \times 200\right) - 50$$

If the 8-bit temperature output is used, shift the data to the left by three bits and set the three Least Significant Bits (LSB) to zeros.

Example: Calculate the optional compensated temperature output for a sensor with an 8-bit temperature output of 255:

Step 1: Left shift the above 8-bit value by three places and append the three LSBs with zeros:

Digital Temperature Output (8-bit) = 255 = 11111111b

11111111000b = 2040

Step 2: Use the adjusted value and insert into Equation 3:

$$\text{Temperature (°C)} = \left(\frac{2040}{2047} \times 200\right) - 50$$

Temperature = 149.31°C

Example: Calculate the optional compensated temperature for a sensor with an 11-bit temperature output of 1456:

Step 1: Insert the digital temperature output value into Equation 3:

$$\text{Temperature (°C)} = \left(\frac{1456}{2047} \times 200\right) - 50$$

Temperature = 92.26°C

5.0 TIMING AND LEVEL PARAMETERS (SEE FIGURE 3 AND TABLE 3)

FIGURE 3. TIMING AND LEVEL PARAMETERS

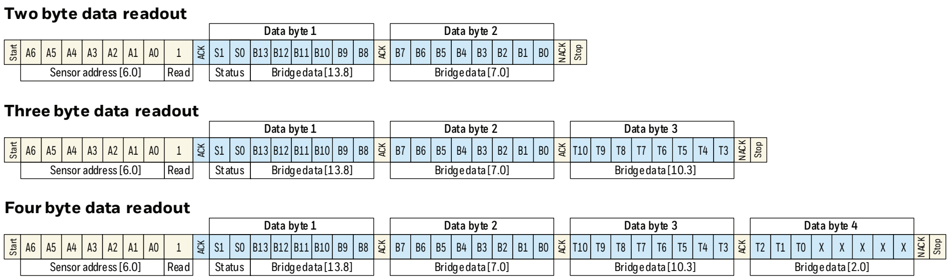


TABLE 3. TIMING AND LEVEL PARAMETERS

PARAMETER	SYMBOL	MINIMUM	TYPICAL	MAXIMUM	UNIT
SCL clock frequency	f_{SCL}	100	–	400	kHz
Start condition hold time relative to SCL edge	t_{HDSTA}	0.1	–	–	µs
Minimum SCL clock width[1]: low high	 t_{LOW} t_{HIGH}	 0.6 0.6	 – –	 – –	 µs µs
Start condition setup time relative to SCL edge	t_{SUSTA}	0.1	–	–	µs
Data hold time on SDA relative to SCL edge	t_{HDDAT}	0	–	–	µs
Data set-up time on SDA relative to SCL edge	t_{SUDAT}	0.1	–	–	µs
Stop condition setup time on SCL	t_{SUSTO}	0.1	–	–	µs
Bus free time between stop condition and start condition	t_{BUS}	2	–	–	µs
Output level: low high	 Out_{LOW} Out_{HIGH}	 – 0.8	 0 1	 0.2 –	 V_{DD} V_{DD}
Pull-up resistance on SDA and SCL	R_P	1	–	50	kOhm

[1]Combined low and high widths must equal or exceed minimum SCL period.

FOR MORE INFORMATION

Honeywell Advanced Sensing Technologies services its customers through a worldwide network of sales offices and distributors. For application assistance, current specifications, pricing or the nearest Authorized Distributor, visit our website or call:

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