This Technical Note provides implementation information for Honeywell force sensors with SPI (Serial Peripheral Interface) digital output.

1.0 INTRODUCTION

The Serial Peripheral Interface (SPI) is a simple bus system for synchronous serial communication between one “Master” and one or more “Sensors”. It can operate in either full-duplex mode (communication occurs in both directions simultaneously) or half-duplex mode (communication occurs in one direction only). The Master device initiates an information transfer on the bus and generates clock and control signals. The Master controls the Sensors through individual Sensor select lines which are active only when selected.

Honeywell force sensors with SPI output operate in half-duplex mode only, with data transfer from the Sensor to the Master (see Figure 1). Three bus lines must be used for these data transmissions:

1. **SCLK**: Signal Clock
2. **MISO**: Master In/Sensor Out
3. **SS**: Sensor Select

These three bus lines are all unidirectional. The Master controls the SCLK and SS lines while the Sensor controls the MISO line.
2.0 DATA TRANSFER

Communication begins by deasserting the SS bus line. At this point, the sensor is no longer idle and begin to send data once a clock is received.

Honeywell digital output force sensors are configured for operation such that data on the MISO bus line will transition during the falling edge of clock pulses, meaning that the Master device should sample this during the rising edge of the clock pulse.

Figure 2 shows an example of a one byte data transfer from the sensor to the Master. The data 101 (01100101 binary, or 65 hex) is the result of the read. Once the clocking begins, 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 the optional compensated temperature output.

2.1 Force Reading (see Figure 3)

The Master generates the necessary clock signal after activating the sensor with the SS bus line. The sensor 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 can terminate the communication by stopping the clock and deactivating the SS bus line.
2.2 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>
<thead>
<tr>
<th>OUTPUT</th>
<th>READING</th>
<th>LOCATION</th>
<th>RESOLUTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>8-bit</td>
<td>Optional compensated temperature value</td>
<td>third data byte</td>
<td>0.8°C</td>
</tr>
<tr>
<td>11-bit</td>
<td>Complete optional compensated temperature value</td>
<td>fourth data byte</td>
<td>0.1°C</td>
</tr>
</tbody>
</table>

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

2.3 STATUS BITS
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>
<thead>
<tr>
<th>STATUS BITS</th>
<th>DEFINITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1 S0</td>
<td></td>
</tr>
<tr>
<td>0 0</td>
<td>Normal operation, valid data</td>
</tr>
<tr>
<td>0 1</td>
<td>Device in command mode¹</td>
</tr>
<tr>
<td>1 0</td>
<td>Stale data: Indicates data that has already been fetched since the last measurement cycle, or data fetched before the first measurement has been completed</td>
</tr>
<tr>
<td>1 1</td>
<td>Diagnostic condition</td>
</tr>
</tbody>
</table>

¹Command 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.

2.3.1 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.

2.3.2 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**

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

Rearranging this equation to solve for force provides Equation 2:

**Equation 2: Force Output Function**

\[
\text{Force} = \left(\frac{\text{Output}_{\text{max}} - \text{Output}_{\text{min}}}{\text{Rated Force Range}} \times \text{Force}_{\text{applied}} + \text{Output}_{\text{min}}\right) - \text{Output}_{\text{max}}
\]

Where:

- \(\text{Output}_{\text{max}}\) = output at maximum force [counts]
- \(\text{Output}_{\text{min}}\) = output at minimum force [counts]
- \(\text{Force}_{\text{rated}}\) = maximum value of force range (N, lb, g, or kg)
- \(\text{Force}_{\text{applied}}\) = force being measured by sensor (N, lb, g, or kg)
- \(\text{Output}\) = 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:

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

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

\[
\text{Force}_{\text{rated}} = 10 \text{ N}
\]

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

\[
\text{Output} = 6880 \text{ counts}
\]

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

\[
\text{Force} = \frac{5242 \times 10}{13107}
\]

\[
\text{Force} = 4 \text{ N}
\]
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**

\[
\text{Temperature (°C)} = \frac{\text{Output (dec)} \times 200}{2047} - 50
\]

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 = 1111111b

11111111000b = 2040

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

\[
\text{Temperature (°C)} = \frac{2040 \times 200}{2047} - 50
\]

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:

\[
\text{Temperature (°C)} = \frac{1456 \times 200}{2047} - 50
\]

Temperature = 92.26°C

5.0 TIMING AND LEVEL PARAMETERS (SEE FIGURE 4 AND TABLE 3)

**TABLE 3. TIMING AND LEVEL PARAMETERS**

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SYMBOL</th>
<th>MINIMUM</th>
<th>TYPICAL</th>
<th>MAXIMUM</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCLK clock frequency</td>
<td>f_SCL</td>
<td>50</td>
<td>—</td>
<td>800</td>
<td>kHz</td>
</tr>
<tr>
<td>SS drop to first clock edge</td>
<td>t_HDSS</td>
<td>2.5</td>
<td>—</td>
<td>—</td>
<td>µs</td>
</tr>
<tr>
<td>Minimum SCLK width:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>low</td>
<td>t_LOW</td>
<td>0.6</td>
<td>—</td>
<td>—</td>
<td>µs</td>
</tr>
<tr>
<td>high</td>
<td>t_HIGH</td>
<td>0.6</td>
<td>—</td>
<td>—</td>
<td>µs</td>
</tr>
<tr>
<td>Clock edge to data transition</td>
<td>t_CLKD</td>
<td>0</td>
<td>—</td>
<td>—</td>
<td>µs</td>
</tr>
<tr>
<td>Rise of SS relative to last clock edge</td>
<td>t_SUS</td>
<td>0.1</td>
<td>—</td>
<td>—</td>
<td>µs</td>
</tr>
<tr>
<td>Bus free time between rise and fall of SS</td>
<td>t_BUS</td>
<td>2</td>
<td>—</td>
<td>—</td>
<td>µs</td>
</tr>
<tr>
<td>Output level:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>low</td>
<td>Out_LOW</td>
<td>—</td>
<td>0</td>
<td>0.2</td>
<td>VDD</td>
</tr>
<tr>
<td>high</td>
<td>Out_HIGH</td>
<td>0.8</td>
<td>1</td>
<td>—</td>
<td>VDD</td>
</tr>
</tbody>
</table>

*Combined low and high widths must equal or exceed minimum SCL period.
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Honeywell warrants goods of its manufacture as being free of defective materials and faulty workmanship during the applicable warranty period. Honeywell’s standard product warranty applies unless agreed to otherwise by Honeywell in writing; please refer to your order acknowledgement or consult your local sales office for specific warranty details. If warranted goods are returned to Honeywell during the period of coverage, Honeywell will repair or replace, at its option, without charge those items that Honeywell, in its sole discretion, finds defective. The foregoing is buyer’s sole remedy and is in lieu of all other warranties, expressed or implied, including those of merchantability and fitness for a particular purpose. In no event shall Honeywell be liable for consequential, special, or indirect damages.

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