Digital Output Description for SPI Pressure Sensors

This Application Note applies to the following Smate pressure sensors:
> CCD 54D
> CCD 53D
> STX 13D
> MCD 70D

Abstract:
This application note describes in detail the digital output format of smart digital pressure sensors with SPI output.

Design considerations as well as hints for writing interface firmware with an MCU are given

After reading this application note the user should be able to:

- Be able to issue commands to initiate a pressure measurement and read out the result
- Calculate the transfer function for his/her respective sensor

Foreword
The smart pressure transducers represent the next generation in digital pressure sensing. Designed to be Microcontroller friendly and optimized for battery powered operation. Among the key features:
- SPI interface with master MCU
- Sleep mode with 2µA standby current
- Peak operating current of 2mA
- Low voltage operation from 2.7V to 5.5V and as low as 2.4V with de-rated accuracy.
### SPI Parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCLK Clock Frequency (4 MHz clock)</td>
<td>50</td>
<td>800</td>
<td>kHz</td>
<td></td>
<td>f_{SCL}</td>
</tr>
<tr>
<td>SCLK Clock Frequency (1 MHz clock)</td>
<td>50</td>
<td>200</td>
<td>kHz</td>
<td></td>
<td>f_{SCL}</td>
</tr>
<tr>
<td>SS drop to first clock edge</td>
<td>2.5</td>
<td></td>
<td>µs</td>
<td></td>
<td>t_{HDSS}</td>
</tr>
<tr>
<td>Minimum SCLK clock Low width (^1)</td>
<td>0.6</td>
<td></td>
<td>µs</td>
<td></td>
<td>t_{LOW}</td>
</tr>
<tr>
<td>Minimum SCLK clock High width (^1)</td>
<td>0.6</td>
<td></td>
<td>µs</td>
<td></td>
<td>t_{HIGH}</td>
</tr>
<tr>
<td>Clock edge to data transition</td>
<td>0</td>
<td>0.1</td>
<td>µs</td>
<td></td>
<td>t_{CLKD}</td>
</tr>
<tr>
<td>Rise of SS relative to last clock edge</td>
<td>0.1</td>
<td></td>
<td>µs</td>
<td></td>
<td>t_{SUSS}</td>
</tr>
<tr>
<td>Bus free time between rise and fall of SS</td>
<td>0.1</td>
<td></td>
<td>µs</td>
<td></td>
<td>t_{SUDAT}</td>
</tr>
</tbody>
</table>

**Notes**

1. Combine low and high widths must equal or exceed minimum SCLK period

### SPI Bus Data Output Timing

![SPI Bus Data Output Timing Diagram](image-url)
SPI Read_DF (Data Fetch)

For simplifying explanations and illustrations, only the falling edge SPI polarity will be discussed in the following sections. The SPI interface will have data change after the falling edge of SCLK. The master should sample MISO on the rise of SCLK. The entire output packet is 4 bytes (32 bits). The high of pressure data byte comes first, followed by the low of pressure data byte.

For option of pressure+ temperature, then 11 bits of corrected temperature (T[10:0]) are sent: first the T[10:3] byte and then the {T[2:0],xxxx} byte. The last 5 bits of the final byte are undetermined and should be masked off in the application. For defaulted option only requires the corrected pressure value, the read will be terminated after the 2nd byte.

SPI Output Packet with Falling Edge SPI_Polarity

Packet = [{S(1:0)}, {B(13:8)}, {B(7:0)}, {T(10:3): T(2:0), xxxx}] Where
S(1:0) = Status bits of packet (normal, command, busy, diagnostic)
B(13:8) = Upper 6 bits of 14-bit bridge data
B(7:0) = Lower 8 bits of 14-bit bridge data
T(10:3) = Corrected temperature data (if application does not require corrected temperature, terminate read early)
T(2:0), xxxx = Remaining bits of corrected temperature data for full 11-bit resolution
HiZ = High impedance
Working Mode

Sleep

Power On

Reset Functions

6.5ms / 1.5ms

Power Down (Wait for Command)

Command Received

SPI Read_MR

Yes

Perform Measurement

25 ms

Power Down (Wait for Command)

Command Received

SPI Read DF

Yes

Fetch Data

No

Yes

How to Interpret the Pressure/Temperature Value

All Smate digital pressure sensors have been calibrated to a straight line transfer function. Temperature and non-linearity compensation are already included and are transparent to the user. The pressure value can be easily obtained by inserting the output into the transfer function. The process is explained below.

The pressure value is read out as a 14 bit word. The word corresponds to 0x0000 to 0xFF in Hex or 0 to 16383 in Decimal.

The first step is to convert the Hex value to Decimal. The calculator supplied with Microsoft Windows will easily do this.

The next step is to port the decimal value into the straight line function shown in the chart below.

The following example is for a -5 to +5 psi transfer function:

The output word is 0x1ABC.

The output word is translated into decimal which is 6844

The decimal word is then inserted into the equation which gives:

\[
6844 = 1310.6x + 8191.5 \text{ where } x \text{ is the pressure in psi}
\]

We then compute \( x = -1.028 \) psi

Note: The transfer function varies for each pressure range. Make sure you use the correct function. The transfer functions for standard ranges are found on the next page.
Transfer Function

To obtain the transfer function we start with the two parameters found in the sensor datasheet shown again below for convenience.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zero Output</td>
<td>0666</td>
<td>Typ</td>
<td>Max</td>
<td>Hex</td>
</tr>
<tr>
<td>Full Scale Output</td>
<td>3996</td>
<td></td>
<td></td>
<td>Hex</td>
</tr>
</tbody>
</table>

Zero output = 0x0666 and Full Scale output = 0x3996.

The total output resolution is 14 bits or 0x3FFF.

We convert these into decimal for convenience:
Zero output = 1638, Full Scale output = 14742 and Total output resolution = 16383

Note that 1638 is 10% of total resolution and 14742 is 90% of total resolution so only 80% of the total 14 bit resolution is used to represent the required FS.

Now we correlate the outputs to the pressure range (see ordering guide in datasheet on how to specify pressure range). The example below refers to the output function on the previous page.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Corresponding Pressure</th>
<th>Hex</th>
<th>Decimal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zero Output</td>
<td>-5 psi</td>
<td>0x0666</td>
<td>1638</td>
</tr>
<tr>
<td>Full Scale Output</td>
<td>+ 5 psi</td>
<td>0x3996</td>
<td>14742</td>
</tr>
</tbody>
</table>

So taking the coordinates (-5 psi, 1638 counts) and (+5 psi, 14742 counts) we can calculate the corresponding straight line transfer function by calculating the gradient and Y-axis intercept.

In this case it is \( Y = 1310.6X + 8191.5 \) where \( Y = \) Digital output in Decimal and \( X = \) pressure in psi

Temperature Transfer Function:

<table>
<thead>
<tr>
<th>Temperature Range</th>
<th>Transfer Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>-50 to 150 °C</td>
<td>( y = 1.275x + 63.75 ) (8 bit (MSB version))</td>
</tr>
<tr>
<td>-50 to 150 °C</td>
<td>( y = 10.24x + 512 ) (11 bit version)</td>
</tr>
</tbody>
</table>

Note: The temperature transfer function is the same regardless of the pressure range chosen. The temperature output is not intended for high accuracy measurements but instead an additional function provided at no extra cost.
Effective Resolution

While the resolution is stated as 14 bits in the datasheet it is impossible to attain this resolution in practice.

14 bits is merely the resolution of the internal Analog to Digital converter (ADC) of the ASIC used to achieve the digital compensation and output.

In practice its resolution will be lower than 14 bits with quantization noise and amplification errors that result in a non-perfect match of the input range of the ADC to the sensor being compensated.

Therefore the guaranteed resolution of Sensormate sensors is 0.05% FS or 11 bits.

In most cases the software designed to read the pressure word should (where possible) allow for an averaging of 2-8 readings. The exact resolution versus sampling speed should be determined by the customer as it is very much dependent on the application.
Working Mode Update

- Power On
- Reset Function
- Perform Measurement
- Power Down

Update rate period over or command received

Command = SPI Read_DF?

Command Received

- Yes: Fetch Data
- No: Back to Update rate period over or command received
We are here for you. Addresses and Contacts.

### Sales Germany & Austria

<table>
<thead>
<tr>
<th>Postcode</th>
<th>Contact Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>00000 – 31999</td>
<td>Kurt Stritzelberger &lt;br&gt;Phone: +49 89 260 52 80 &lt;br&gt;Mobile: +49 171 803 41 35</td>
</tr>
<tr>
<td>38000 – 39999</td>
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</tr>
<tr>
<td>80000 – 99999</td>
<td>Kurt Stritzelberger &lt;br&gt;Phone: +49 89 260 52 80 &lt;br&gt;Mobile: +49 171 803 41 35</td>
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### Sales Switzerland & Liechtenstein

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<tr>
<th>Postcode</th>
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</tr>
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<tbody>
<tr>
<td>3000 – 9999</td>
<td>Basil Frei &lt;br&gt;Phone: +41 44 877 35 18 &lt;br&gt;Mobile: +41 76 279 37 26</td>
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<thead>
<tr>
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<tbody>
<tr>
<td>Peter Felder &lt;br&gt;Phone: +41 44 877 35 05 &lt;br&gt;Mobile: +41 79 406 49 83</td>
</tr>
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### Sales Other Countries / Product Management

<table>
<thead>
<tr>
<th>Product</th>
<th>Contact Details</th>
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<tbody>
<tr>
<td>Pressure Sensors</td>
<td>Philipp Kistler &lt;br&gt;Phone: +41 44 877 35 02</td>
</tr>
<tr>
<td>Gas sensors / Gas sensor modules Load cells</td>
<td>Dr. Thomas Clausen &lt;br&gt;Phone: +41 44 877 35 13</td>
</tr>
<tr>
<td>Acclerometers / Level Flow sensor elements</td>
<td>Sebastiano Leggio &lt;br&gt;Phone: +41 44 877 35 06</td>
</tr>
<tr>
<td>Drive technology CH Postcode 5000 – 9999 / DE</td>
<td>Christian Mohrenstecher &lt;br&gt;Mobile: +41 76 444 00 86</td>
</tr>
<tr>
<td>Flow / Level / Medical products</td>
<td>Dr. Adriano Pittarelli &lt;br&gt;Phone: +49 8245 774 95 44</td>
</tr>
<tr>
<td>Linear position sensors Angle sensors</td>
<td>Eric Letsch &lt;br&gt;Phone: +41 44 877 35 14</td>
</tr>
<tr>
<td>Current sensors Power solutions</td>
<td>Osman Coban &lt;br&gt;Phone: +49 71 635 363 898</td>
</tr>
</tbody>
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