1 INTRODUCTION

Sensortechnics' digital pressure sensor families offer precision absolute, gage or differential pressure measurement in various ranges. These devices are digitally calibrated and temperature compensated with an on-board ASIC, which provides a corrected pressure value with up to 15-bit resolution. The response time depends on the adjusted internal resolution. For standard parts with 12 bit resolution it is typ. 500 µs.

Sensortechnics' digital sensors can be configured to comply with SPI or I^2C bus protocol.

NOTE:
This application note only refers to SPI bus communication and therefore only applies to Sensortechnics' pressure sensors which use SPI compatible protocol (e.g. HCE, RCE).

The Serial Peripheral Interface (SPI) is a simple bus system for synchronous serial communication between one master and one or more slaves (theoretically any amount of slaves would be possible). It operates in full-duplex mode allowing communication to happen in both directions simultaneously. The master device initiates an information transfer on the bus and generates clock and control signals. Slave devices are controlled by the master through individual slave select lines and are active only when selected.

For the data transmission there needs to be two signal and two data lines. These are:

- Slave Select ($\overline{SS}$)
- Signal Clock (SCK)
- Master Out - Slave In (MOSI)
- Master In - Slave Out (MISO)

All bus lines are unidirectional.

2 BUS ARCHITECTURE

2.1 **SCK** (Signal Clock)

The clock signal is generated by the master and is connected to all slaves. It is used to synchronise all data transfer.

2.2 $\overline{\textbf{SS}}$ (**S**lave **S**elect)

Slave devices are addressed and controlled by the master through individual slave select lines. The master selects a slave by pulling the $\overline{SS}$ line to that slave to LOW. The limiting factor for the amount of slaves in a system is the possible number of $\overline{SS}$ lines to the master device.

2.3 **MOSI** (**M**aster **O**ut - **S**lave **I**n)

The MOSI line transfers data from the master to the slave.

2.4 **MISO** (**M**aster **I**n - **S**lave **O**ut)

The MISO line transfers data from the slave to the master.

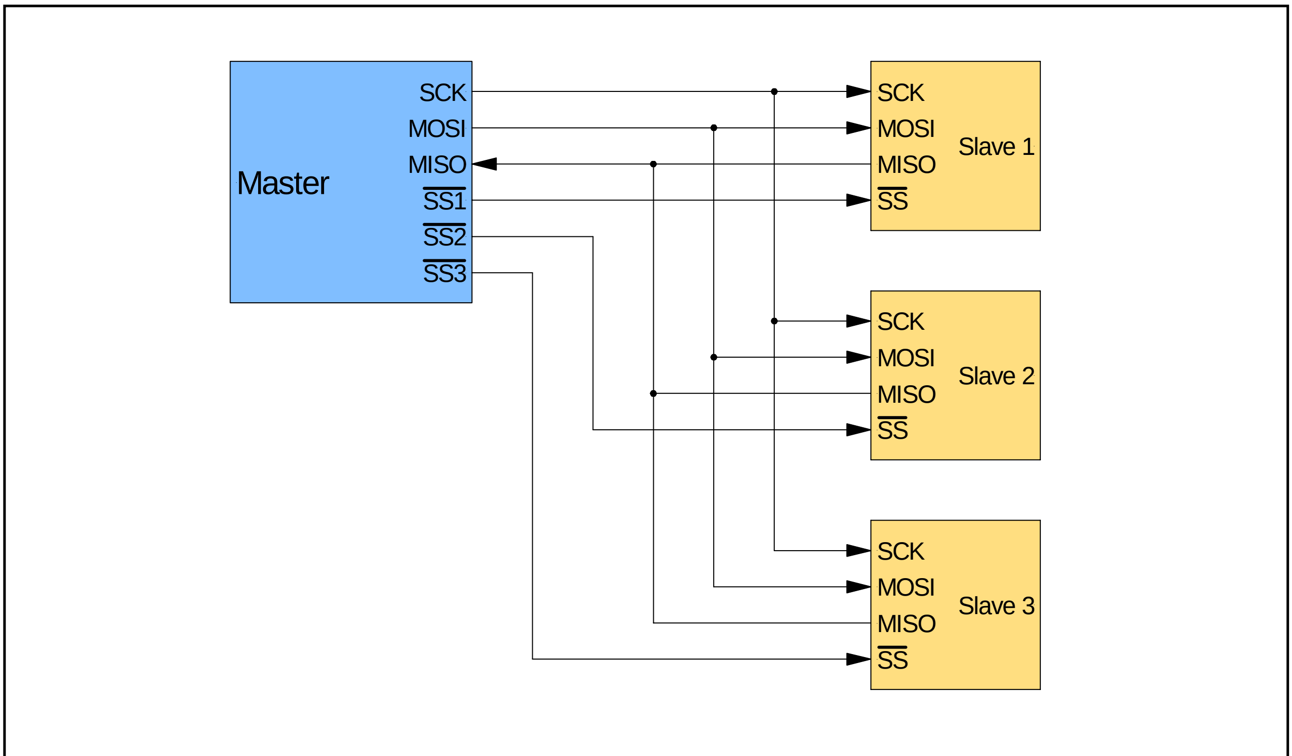

Fig. 1 Sample SPI configuration with one master and multiple slaves

3 SPI BUS PROTOCOL

3.1 Data Transmission

To start communication, the master first selects a slave by pulling the $\overline{SS}$ line to this slave down to a LOW level. The master then writes the data to be transferred into its data transmission register and, after a short delay, transmits the clock signal (see 4.5 Timing).

Data transfer is organised in full duplex mode by using shift registers in both, master and slave devices. With each clock cycle data is pushed from master to slave on the MOSI line while the slave itself pushes data to the master on the MISO line at the same time (see Fig. 2). A data transmission will be finished when the $\overline{SS}$ line is pulled up to HIGH again.

NOTE:
For Sensortechnics' digital pressure sensors with SPI bus a MOSI line is not necessary because there is no need for data transmission to the sensor (slave). Therefore, for some applications it makes sense not to connect the sensors MOSI line with the master-microcontroller but to pull up this line to HIGH level with a resistor at the sensor side. For the RCE series the MOSI is internally connected to HIGH level (see 5 Application Circuits).

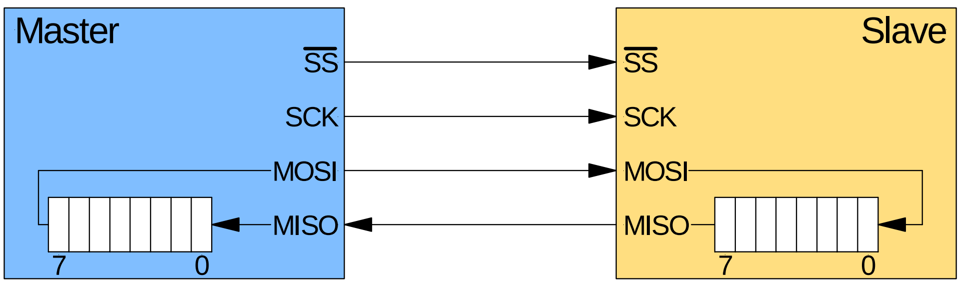

Fig. 2 Data transfer using master and slave shift registers

3.2 Communication Modes

The SPI protocol specifies the clock signal by two parameters, the clock polarity (CPOL) and the clock phase (CPHA). This results into four possible communication modes (see Table 1).

It is important to set these parameters to the same values in both, master and slave devices to ensure proper communication. CPOL and CPHA can be adjusted via two control bits in the SPI control registers.

SPI mode	CPOL	CPHA
0	0	0
1	0	1
2	1	0
3	1	1

Table 1 SPI communication modes

NOTE:
Sensortechnics' digital pressure sensors are programmed to CPHA = 0 and CPOL = 0 by default. Generally they support all four different modes. Please contact Sensortechnics for more information.

3.2.1 CPOL (Clock Polarity)

The clock polarity specifies whether the clock signal is LOW (CPOL=0) or HIGH (CPOL=1) in its idle state.

3.2.2 CPHA (Clock Phase)

The clock phase defines at which clock edge the first data is accepted as valid. CPHA=0 means that the data is valid with the first (leading) clock edge. CPHA=1 means that the data is valid with the second (trailing) clock edge.

3.3 Transfer format

3.3.1 CPHA = 0

If the clock phase is set to 0 data is valid with the first clock edge. The state of the clock polarity defines whether this first clock edge is a rising or falling edge.

For CPOL=0 the clock value is in its idle LOW state and rises to HIGH.
For CPOL=1 the clock value is in its idle HIGH state and falls to LOW.

However, the clock polarity does not influence the moment when the first data bit is valid and therefore does not influence the transfer format which is shown in Fig. 3.

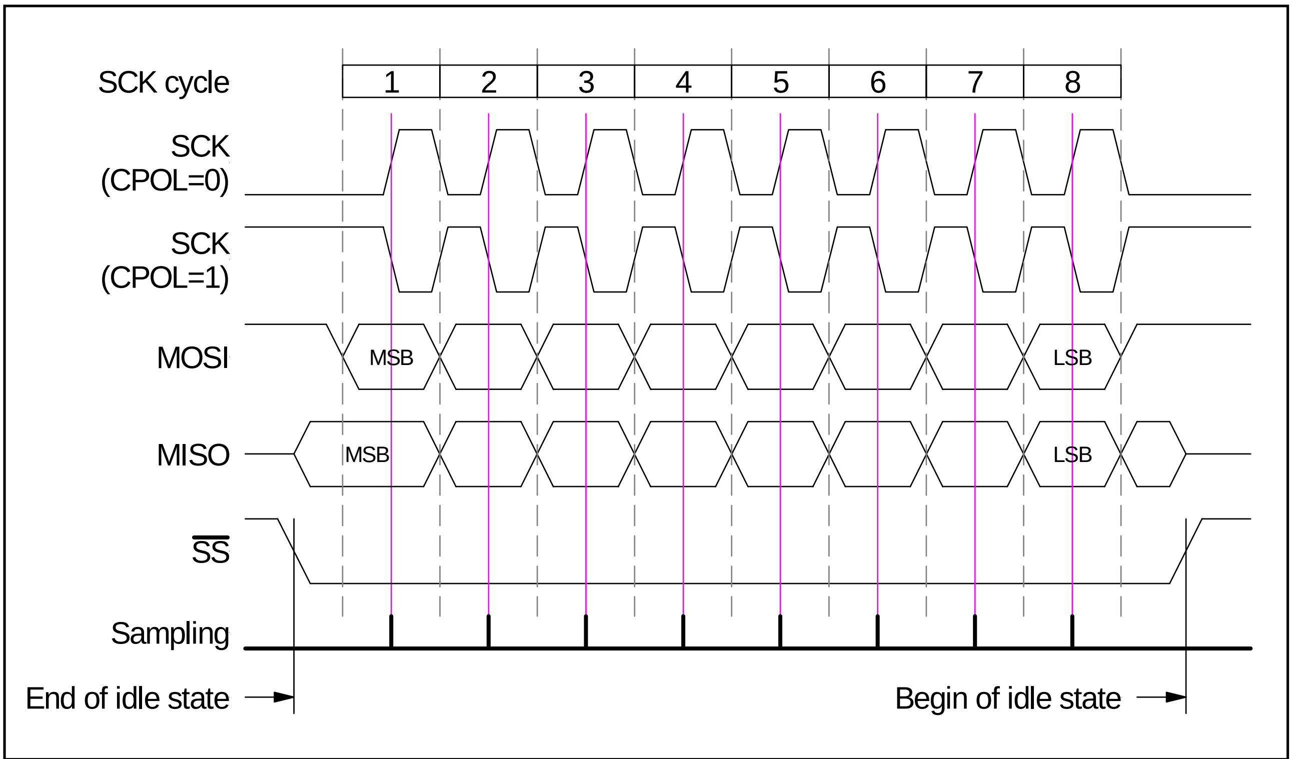

Fig. 3 Example of a 1 byte SPI data transfer for CPHA=0

3.3.2 CPHA = 1

If the clock phase is set to 1 data is valid with the second clock edge. The state of the clock polarity defines whether this second clock edge is a rising or falling edge.

For CPOL=0 the clock value is in its HIGH state after the first clock edge and is falling to LOW with the second edge.
For CPOL=1 the clock value is in its LOW state after the first clock edge and is rising to HIGH with the second edge.

The clock polarity does not influence the moment when the first data bit is valid and therefore does not influence the transfer format which is shown in Fig. 4.

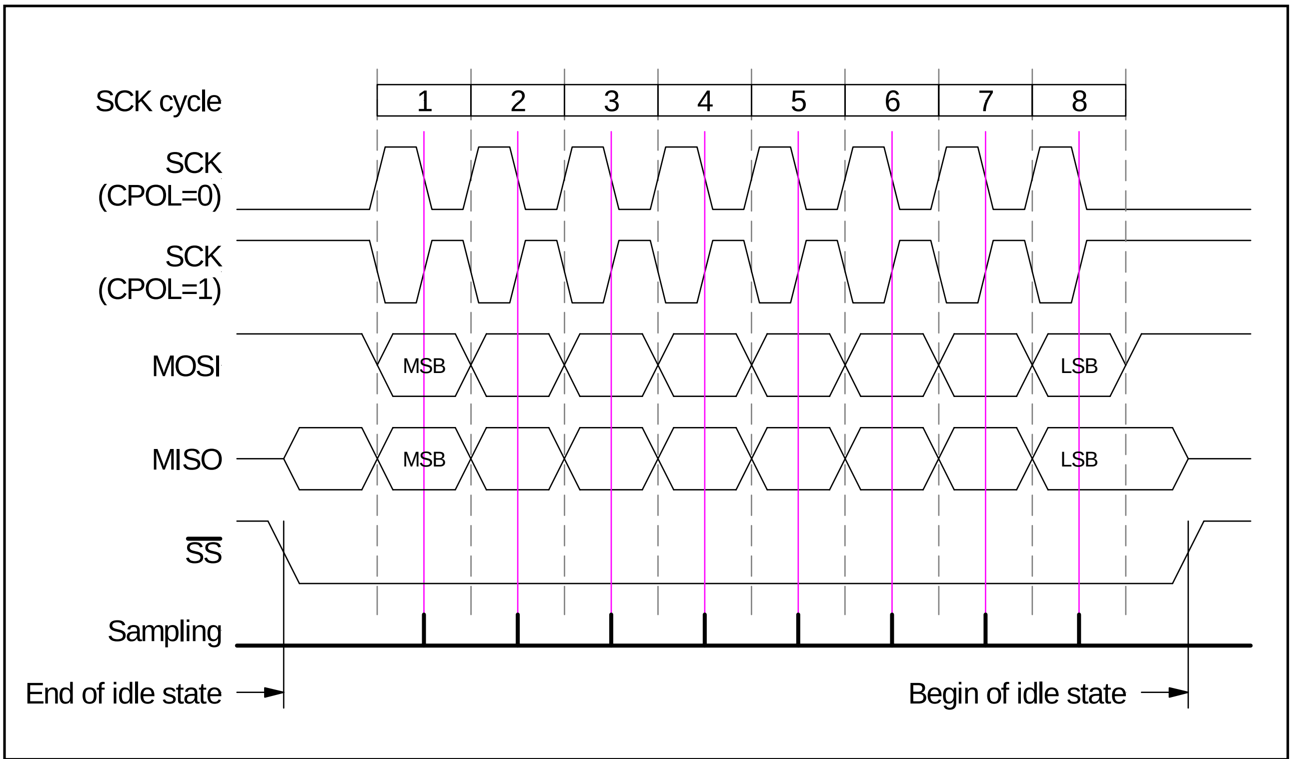

Fig. 4 Example of a 1 byte SPI data transfer for CPHA=1

4 DATA TRANSFER WITH SPI BUS PRESSURE SENSORS

Sensortechnics' digital pressure sensors are designed to work as slaves and will therefore only respond to requests from a master device. To start communication the master pulls down the $\overline{SS}$ line to a LOW level.

4.1 Pressure reading

The pressure information will be transferred as a 15 bit word within a 3 byte data stream (see Fig. 5). As the master might send some order to the slave there is a first byte without any data transmitted by the sensor. It is recommended to send only HIGH level to the sensor within this first byte not to cause any problems or undefined actions. The sensor will answer the first byte typically with 0xFFh (hexadecimal). The following 2nd and 3rd data bytes contain the current pressure information starting with the most significant bit (MSB) and ending with the least significant bit (LSB). The data transmission will be terminated when the master pulls up the $\overline{SS}$ to HIGH again.

> ***NOTE:***
> ***For Sensortechnics' SPI bus pressure sensors the $\overline{SS}$ line must not be pulled up in between the individual bytes of a data stream! The sensors are configured for a 2 or 3 byte communication. Pulling up the $\overline{SS}$ line in between would be interpreted as a start of a new communication cycle.***

The sensor is also able to send pressure values "online". That is, if the master does not pull up the $\overline{SS}$ line after the third exchanged byte the slave will go on sending the last available pressure value when it is clocked. These "online" values are then only 2 bytes long.

> ***NOTE:***
> ***With a clock frequency of 500 kHz the exchange of the first 3 data bytes takes about 50 µs. The following 2 byte of "online" pressure values take another 32 µs each. However, the internal sensor conversion cycle to obtain a new pressure value is 250 µs in standard 12 bit configuration. Therefore, if the sensor is not deactivated it will send the same digital pressure value at least 6 times before a new reading can be obtained. For further information please contact Sensortechnics.***

4.2 Optional temperature reading

As an option the sensor can be factory configured to deliver an additional 15 bit temperature reading. This will then be transmitted as a 4th and 5th byte after the pressure value. If the master does not pull up the $\overline{SS}$ Line after the 5th byte the sensor will continue sending alternating pressure and temperature values until it is deactivated by a HIGH $\overline{SS}$ line. This following combined "online" pressure and temperature information is then only 4 bytes long.

	Data Byte 1								Data Byte 2								Data Byte 3							
MOSI	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
MISO	X	X	X	X	X	X	X	X	X	P14	P13	P12	P11	P10	P9	P8	P7	P6	P5	P4	P3	P2	P1	P0

Relevant data (P14 … P0)

Fig. 5 3 byte data stream containing the pressure value as a 15 bit information

4.3 Calculation of the actual pressure value from the digital pressure word

The following formulas show how to calculate the actual pressure value from the digital sensor output:

Definitions:

S = Sensitivity [counts/mbar]
Out_{max} = Output @ max. pressure [counts]
Out_{min} = Output @ min. pressure [counts]
P_{max} = Max. value of pressure range [mbar]
P_{min} = Min. value of pressure range [mbar]
P = Pressure reading [mbar]
P_{counts} = Digital pressure reading [counts]

$$S = \frac{Out_{max} - Out_{min}}{P_{max} - P_{min}} \qquad (1)$$

$$P = \frac{P_{counts} - Out_{min}}{S} + P_{min} \qquad (2)$$

The following example shows the calculation for a RCEB001DB device (pressure range 0…±1000 mbar bidirectional). Please refer to the RCE data sheet for the specified calibration values.

Out_{min} (-1000 mbar) = 2000 counts decimal
Out_{max} (+1000 mbar) = 32000 counts decimal

With equation (1) the sensitivity of the sensor gives

$$S = \frac{32000\,\text{counts} - 2000\,\text{counts}}{1000\,\text{mbar} - (-1000\,\text{mbar})} = 15 \text{ counts/mbar}$$

For an actual digital pressure reading of

P_{counts} = 20608 counts decimal

the actual pressure in mbar can be calculated from equation (2) to be

$$P = \frac{20608\,\text{counts} - 2000\,\text{counts}}{15\,\text{counts}/\text{mbar}} + (-1000\,\text{mbar})$$

$$P = \underline{\underline{240{,}53\,\text{mbar}}}$$

This pressure reading is calculated with the typical calibration values, not taking into account that the individual sensor calibrations might differ within the tolerances specified in the RCE data sheet.

4.4 Resolution of data

Each temperature and pressure value will be transmitted as a 15 bit word. However, the actual resolution can be less than this depending upon how the internal A/D-converter is configured. Also internal calculations and signal windowing will reduce the effective resolution. The standard resolution for pressure measurement is set at 12 bits, which results in an effective resolution of 11 to 12 bits. For temperature measurement the limiting factor is the sensitivity of the sensing element. For further information please contact Sensortechnics.

Parameter	Symbol	Min.	Typ.	Max.	Unit
Input high level		90		100	
Input low level		0		10	% of Vs
Output low level				10	
Pull-up resistor		500			Ω
SPI clock frequency	f_{CLK}			640	kHz
MISO hold time after SCK sample slope	$t_{SPI\_HD\_MISO}$	200			ns
MOSI setup time before SCK sample slope	$t_{SPI\_SU\_MOSI}$	$2/f_{CLK}$			
/SS setup time before SCK sample slope	$t_{SPI\_SU\_SS}$	10			ns

Table 2 SPI bus timing and communication parameters for Sensortechnics' digital pressure sensors

4.5 Timing

To ensure correct communication the sensor must be able to detect the start condition (pull down of $\overline{SS}$ line) before the master sends the first clock signal. Therefore, a minimum delay time is required prior to the first clock edge. This timing has to be controlled by the master and is influenced by the following conditions:

- the SPI mode
- the max. communication speed
- the application circuit
  (e.g. the values of the pull-up-resistors)
- the layout of the module' s PCB
  (e.g. load capacitances of the SPI bus lines)
- the wiring to the SPI slave
  (e.g. impedances of the SPI bus lines)

… and others

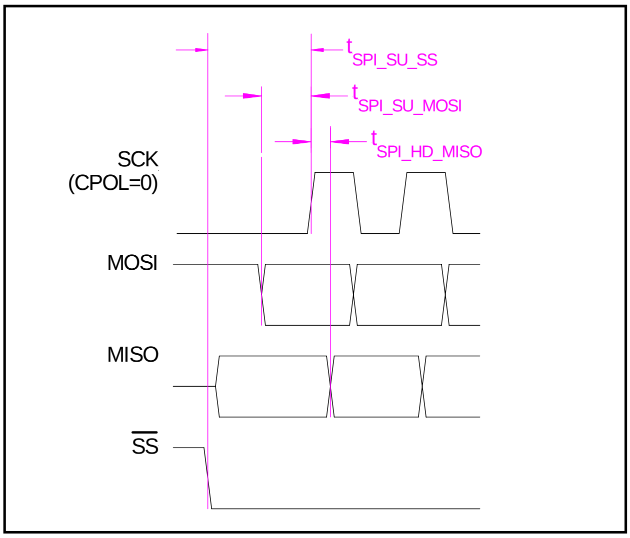

Table 3 SPI bus timing characteristics

4.6 Communication Parameters

The maximum allowed communication speed depends on the configured internal clock frequency of the pressure sensor. In the standard configuration the maximum communication speed is 640 kHz (worst case). As a special configuration this can be increased to 730 kHz.

4.7 Signal Noise due to Communication

As the pulses transmitted on the bus lines have very sharp edges, this can cause some electromagnetic interference. Especially for very low pressure values and small PCB designs these spikes can influence the analog millivolt measurement of the sensor bridge and downgrade signal quality.

NOTE:
Sensortechnics does not recommend digital readout for highly amplified ultra low pressure devices. Please contact Sensortechnics for more information.

If both digital and analog interfaces are used in parallel it is recommended to separate these lines as far as possible from each other. Further, decoupling capacitors of 220 nF between supply and ground and 15 nF between the analog output and ground are beneficial. It is important to place the capacitors as close to the pins as possible.

5 APPLICATION CIRCUITS

It is recommended to use a pull-up resistor of about 4k7 Ω and an additional 330 Ω serial resistor in each communication line as shown in Fig. 6 and 7.

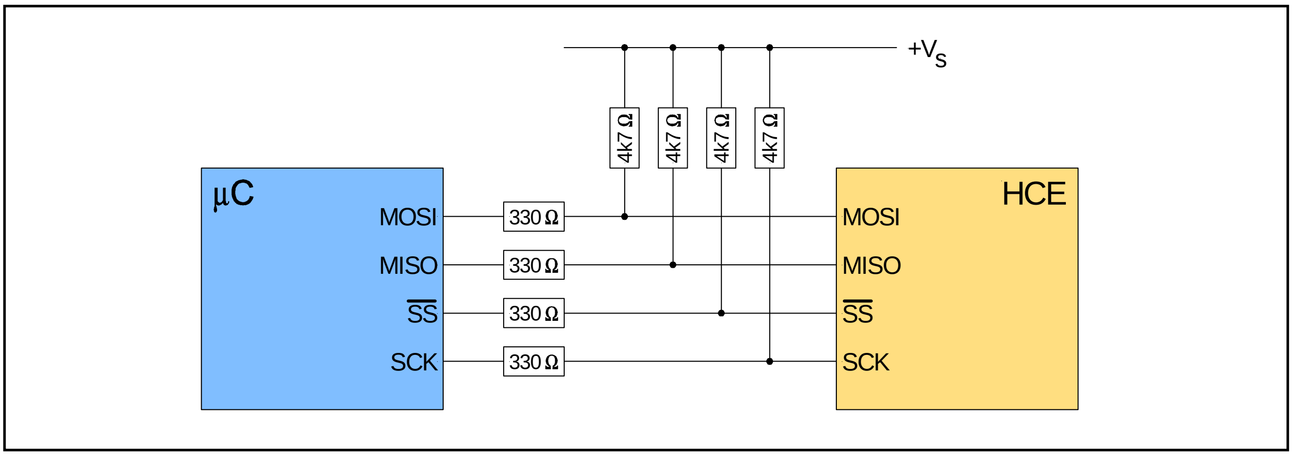

Fig. 6 SPI bus application circuit for Sensortechnics' HCE pressure sensors

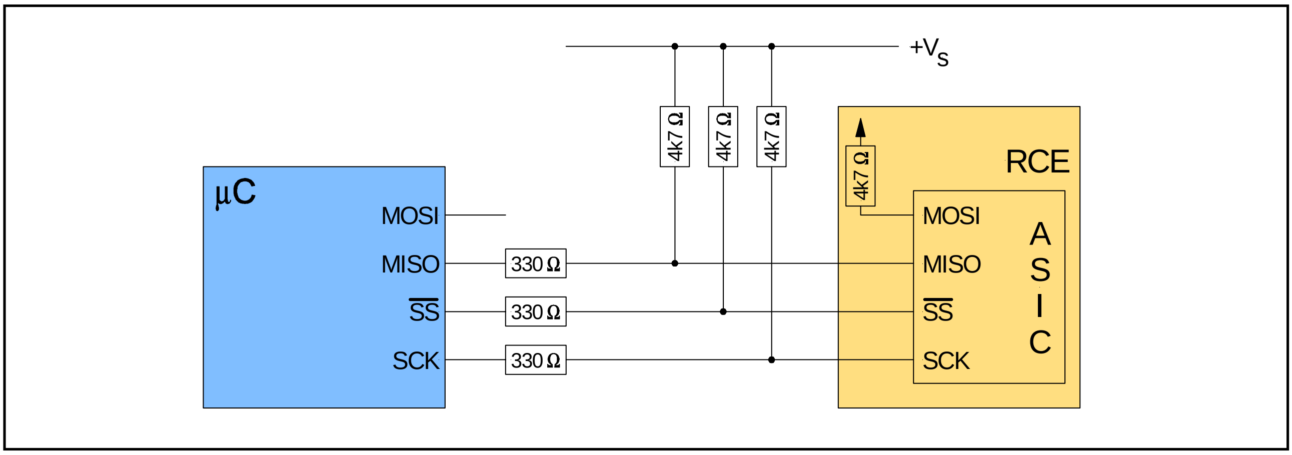

Fig. 7 SPI bus application circuit for Sensortechnics' RCE pressure sensors