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Low-Pressure Sensing with the MPX2010 Pressure Sensor

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INTRODUCTION

Until recently, low–cost semiconductor pressure sensors were designed to measure typical full–scale pressures only as low as 10 kPa (1.5 psi). Of course, "measure" is a relative term. "Measure" is used here to imply that an output of reasonable magnitude, signal–to–noise ratio, and accuracy is produced by the sensing device. Such sensor products are available in various levels of integration and package types. Depending on the level of application customization required and the budget available, a sensor user may choose from a range of low–pressure sensor products such as a 10 kPa "bare–element" (uncompensated) device, a 10 kPa calibrated and temperature compensated device, or a fully signal–conditioned (high–level output), calibrated, and temperature compensated integrated 10 kPa device. These options are typically available as well for higher pressures ranging up to 1000 kPa.

What if the sensor user must measure full–scale pressures that are two, four, or even ten times lower than what conventional sensor technology is capable of measuring? "Do such applications and customers exist?" The answer is "yes" and "yes." There are many potential customers that require such low–pressure sensing ability, the two application examples discussed here are: (1) heating ventilation and air–conditioning (HVAC) in the context of building controls and (2) water–level sensing in appliance applications such as clothes washing machines.

For the purposes of measuring low pressures, the units of inches of water (″ H_2O) or millimeters of water (mm H_2O) will be used. Typical HVAC applications have a full–scale pressure of 40 mm H_2O and washing machines have either 300 or 600 mm H_2O, depending on the region of the world (*Note:* just for reference purposes, 10 kPa ≈ 40″ H_2O ≈ 1000 mm H_2O ≈ 1.5 psi).

Of course, a sensor intended for a higher pressure range than the one of interest can be used. However, the effect is that only a small portion on the device's dynamic output range is used for the actual operating range. This low–level output may then be paired up with a larger than ideal amplifier gain. Thus, a poor signal–to–noise ratio is usually the result. Some sensor manufacturers have recently introduced pressure sensors designed for 4″ and 5″ H_2O full–scale ranges (approx. 100–125 mm H_2O). These devices typically employ silicon with very thinly micromachined diaphragms or other sensing technologies that are significantly larger in form factor without any additional functionality. Thin diaphragm devices tend to be extremely fragile and unstable. Even in cases where the device is sufficiently robust for the intended operating pressure range, the sensor has very poor overpressure capability.

Now that the pressure range of interest has been established, the stage has been set to consider the system solution that is the enabling technology for achieving such low–pressure sensing capability. Also important in presenting this low–pressure system solution are some of the other application characteristics besides the pressure range. For example, the desired pressure resolution, accuracy, available power supply voltage, and end–equipment system architecture play a major role in determining the implementation of this system solution.

DEVELOPMENT HISTORY

For simplicity's sake, let's refer to this low–pressure sensing system solution as the "smart sensing" or "smart sensor system." One of the key performance advantages of the smart sensor system is that the output of the actual sensing element is ratiometric (linearly proportional) to the excitation voltage applied to the sensing element. Since most semiconductor pressure sensors are characterized with a constant voltage power supply, current excitation will not be discussed. Although a sensor's operation is specified at a given power supply voltage, there is some maximum supply that can be applied, beyond which power dissipation and self–heating produce significant output errors or exceed the package's thermal handling capability. This means that the strategy of increasing the sensor's excitation to improve the sensor's sensitivity (increase signal output for a given applied pressure) can be done in a dc fashion only up to some maximum supply voltage. For Motorola pressure sensors, this limit allows only about a 50% to 60% increase in sensitivity, depending on the specific device family.

About five years ago, some of my colleagues were working on pulsing the sensor supply voltage with a conventional voltage and very low duty–cycle, sampling–and–holding the resulting output, and then filtering the output to produce a dc sensor output with very low–power consumption. This was the impetus to consider pulsing a sensor at a much higher than recommended voltage and a low duty–cycle (10% or less) for the purpose of increased sensitivity. It is true that some of the sensor's parasitic drawbacks, like its zero–pressure offset voltage and temperature coefficient of offset, are increased as well, but some of the sensor's negative characteristics are lessened. In addition, other sources of error and noise in the system are not subjected to the higher amplifier gain that would be required if operating the sensor at a conventional supply voltage.

The Motorola MPX2010 (see Table 1) is a calibrated and temperature compensated, 10 kPa (full–scale), pressure sensor device. The data sheet specifies a full–scale output of 25 mV at a 10 V supply voltage, for an applied pressure of 10 kPa. This same device can be pulsed at 40 V at a 10% duty–cycle and produce either 100 mV for the same 10 kPa pressure or 25 mV for only 2.5 kPa of pressure. This technique allows a four–fold increase in the signal level for the rated full–scale pressure of 10 kPa or the ability to maintain the same signal level for a pressure that is four times lower (2.5 kPa).

Although the idea is relatively simple, the key to providing a low–cost smart sensing solution is in both the hardware and software implementation of this system. In the case of the micropower application, having a “stand–alone” analog sensing solution was a key criteria. As such, this design used micropower op–amps, analog CMOS switches, gated timers (one to control pulsed sensor excitation and one to control sample–and–hold function), and capacitive sample–and–hold circuitry. The effect was a very low–current drain, micropower sensor solution. Since low–power, rather than low–pressure, was the driving design goal, errors induced by power supply variation, temperature drift, and device–to–device tolerances were not critical. Not that these issues are not important for all applications, but for low–pressure sensing, even small temperature drifts, device parameter tolerances, and power supply variations cause significant errors as a percentage of the sensor output signal.

It should be apparent that the “gated–timer pulsing/sample–and–hold” system architecture can be equally well employed to pulse at higher voltages for increased sensitivity. However, a low–cost MCU can also accomplish the functions of providing a control pulse to a switching circuit (for the pulsed sensor excitation) and affecting a synchronized sample–and–hold feature via software control of an on–chip A/D converter. In addition, the MCU has the capability to implement other “smart” features that can lend the additional required accuracy and functionality desired for many low–pressure sensing applications. The system design intended for low–pressure applications, as well as the performance–enhancing features of pulsed excitation for increased sensitivity, signal averaging, software calibration, and software power supply rejection are presented. The added functionality of intelligent communications capability and serial digital output flexibility are also discussed.

Of course, these features lead to increased performance at conventional, or even high–pressure ranges. Nonetheless, these features have been developed in the context of low–pressure sensing where the performance benefits are a requisite of the application. Also, driving acceptance of this system technology is a much easier task when coupled to providing a sensing capability and level of functionality that is otherwise not available in the industry today. Who would have suspected that a viable smart sensing technology would have resulted from the pursuit of addressing the low–pressure sensing market? Significant pieces of this system solution are protected intellectual property. Motorola holds several key patents on using pulsed excitation for semiconductor sensors and has filed several others regarding other portions and future enhancements to this technology.

Table 1. MPX2010 Operating Characteristics (Supply Voltage = 10 Vdc, TA=25°C unless otherwise noted)

Characteristic	Min	Typ	Max	Unit
Pressure Range	0	–	10	kPa
Supply Voltage	–	10	16	Vdc
Supply Current	–	6.0	–	mAdc
Full–Scale Span (FSS)	24	25	26	mV
Zero–Pressure Offset	–1.0	–	1.0	mV
Sensitivity	–	2.5	–	mV/kPa
Linearity	–1.0	–	1.0	$\%V_{FSS}$
Pressure Hysteresis (0 – 10 kPa)	–	±0.1	–	$\%V_{FSS}$
Temperature Hysteresis (–40°C to +125°C)	–	±0.5	–	$\%V_{FSS}$
Temperature Effect on Full–Scale Span	–1.0	–	1.0	$\%V_{FSS}$
Temperature Effect on Offset (0°C to 85°C)	–1.0	–	1.0	mV
Input Impedance	1300	–	2550	Ω
Output Impedance	1400	–	3000	Ω
Response Time (10% to 90%)	–	1.0	–	ms
Temperature Error Band	0	–	85	°C
Offset Stability	–	±0.5	–	$\%V_{FSS}$

SYSTEM DESIGN

As mentioned in the introduction, the lowest pressure devices in the Motorola portfolio are rated at a full–scale pressure of 10 kPa (40″ of H_2O). The calibrated and temperature compensated, 10 kPa device (MPX2010) is specified to operate at a 10 Vdc supply voltage and produce 25 mV (nominal) at the full–scale pressure of 10 kPa. This translates to a 0.25 mV/(V*kPa) pressure sensitivity. Additionally, the absolute maximum supply voltage specified is 16 Vdc. Thus, the maximum full–scale output signal that can be achieved without exceeding the maximum supply voltage rating is 40 mV, or 60% greater than the output at the 10 Vdc specification. So, a 60% increase can be achieved in the output signal of the sensor for the 0–10 kPa pressure range, or the same signal level of 25 mV can be preserved over a proportionally lower applied pressure range (i.e., 0–6.25 kPa). The point here is that increasing the dc supply excitation only produces limited improvement in the output signal level.

Much greater gains in output signal level (sensor span) can be obtained, if it is possible to operate the sensor at significantly higher voltages. Since the thermal/power dissipation limitation imposed by the maximum dc supply voltage can be avoided by using a pulsed excitation at a low duty–cycle (on–time) and reasonable period, and second order junction effects do not occur until much higher voltages, the sensor output can be greatly increased by operating at a much higher ac voltage than permitted by the dc counterpart of this same higher voltage. As an example, industrial applications like HVAC have 24 V commonly available, and we want to accurately measure pressures below 10″ H_2O. To achieve a 1–2% of full–scale accuracy (based on temperature drift errors, system noise, device tolerance, power supply variation/rejection, etc.), 9–12 mV is the typical minimum full–scale span that is the desired target for the pressure range of interest. For the MPX2010 pulsed at 24 V, we obtain 15 mV of output for an applied pressure of 10″ H_2O (2.5 kPa). This same sensor device will only produce 6.25 mV at its normally specified supply of 10 V and 2.5 kPa, thus not meeting the signal–to–noise ratio criteria for a 1–2% accuracy performance.

This smart sensing solution is intended to sense full–scale pressures below 10″ H_2O with 1% of full–scale pressure resolution and better than 2% of full–scale accuracy. The following subsystems comprise the hardware portion of this solution (see Figure 1):

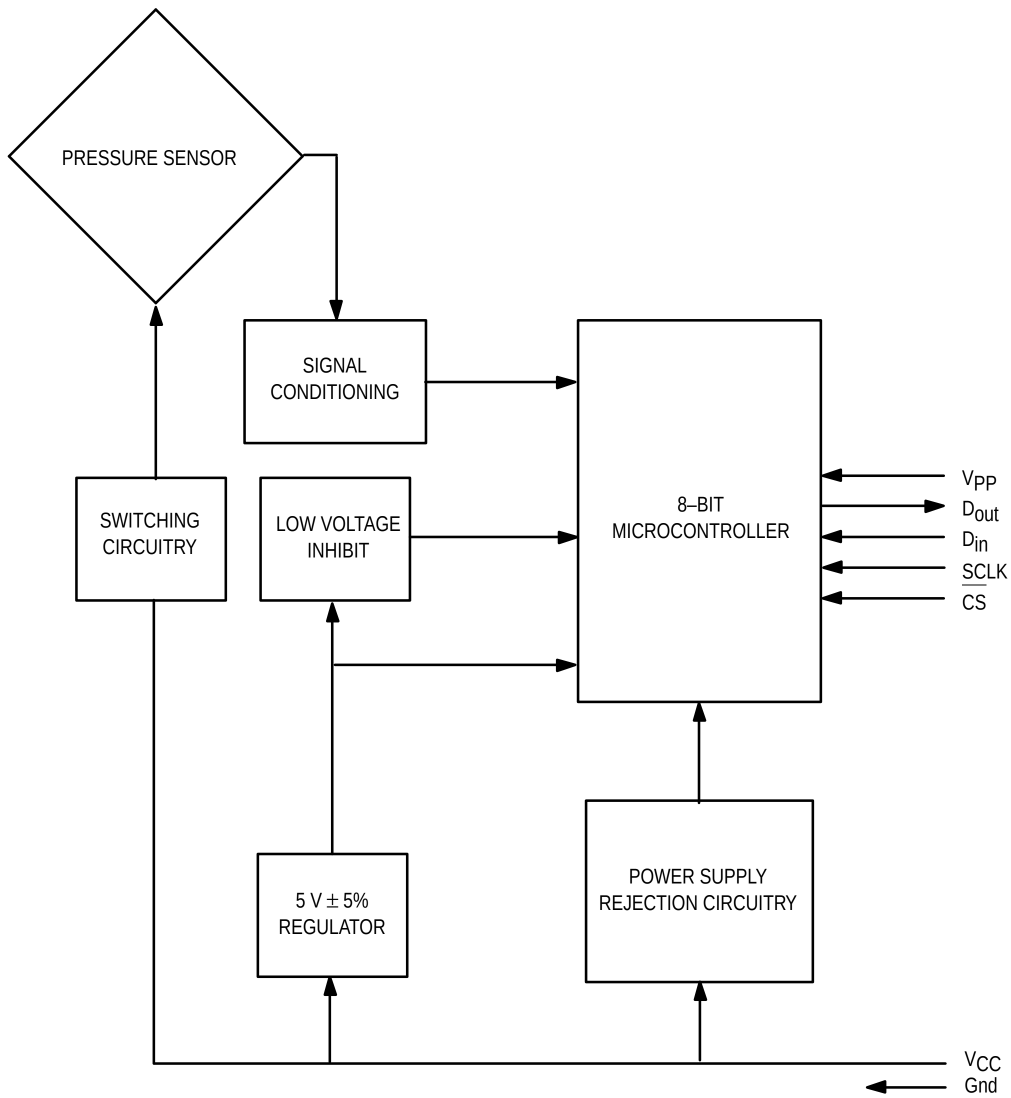

Figure 1. Smart Sensing Block Diagram

- high–side switch pulsing circuitry
- signal–conditioning amplifier interface with resistors to adjust the sensor's amplified, full–scale span and zero–pressure offset
- on–chip resources of a complete 8–bit microcontroller (MCU)
- MCU oscillator circuitry (4 MHz)
- 5 V ±5% linear voltage regulator
- low–voltage inhibit (LVI) supervisory voltage monitoring circuit
- resistor divider connected to the sensor's power supply bias to sense the excitation voltage across the sensor

These subsystems are explained as follows to provide an understanding of the system design and its intelligent features (refer to Figure 2).

Pulsing Circuitry

As previously mentioned, the sensor's output is ratiometric to the excitation voltage across the sensing element; the sensor's sensitivity increases with increasing supply voltage. Thus, to detect low pressures and minute changes in pressure, it is desirable to operate the sensor at the highest possible excitation voltage. The maximum supply voltage at which the sensor can reliably operate is determined by one or both of the following two limitations: (1) maximum allowable sensor die temperature, (2) maximum supply voltage available in the sensing application/system.

In terms of thermal/power dissipation, the maximum voltage that can be supplied to the sensor on a continuous basis is relatively low compared to that which can be pulsed on the sensor at a low duty–cycle. The average power that is dissipated in the sensor is the square of the average sensor excitation voltage divided by the input resistance of the sensor. When the sensor's supply bias is operated in a pulsed fashion, the average excitation voltage is simply the product of the dc supply voltage used and the percent duty–cycle that the dc voltage is "on."

The pulsing circuitry is a high–side switch (two small–signal switching transistors with associated bias resistors) that is controlled via the output compare (TCMP) pin of the MCU. The output compare timer function of the MCU provides a logic–level pulse waveform to the switch that has a 2–ms period and a 200–µs on–time (*Note:* this is user–programmable).

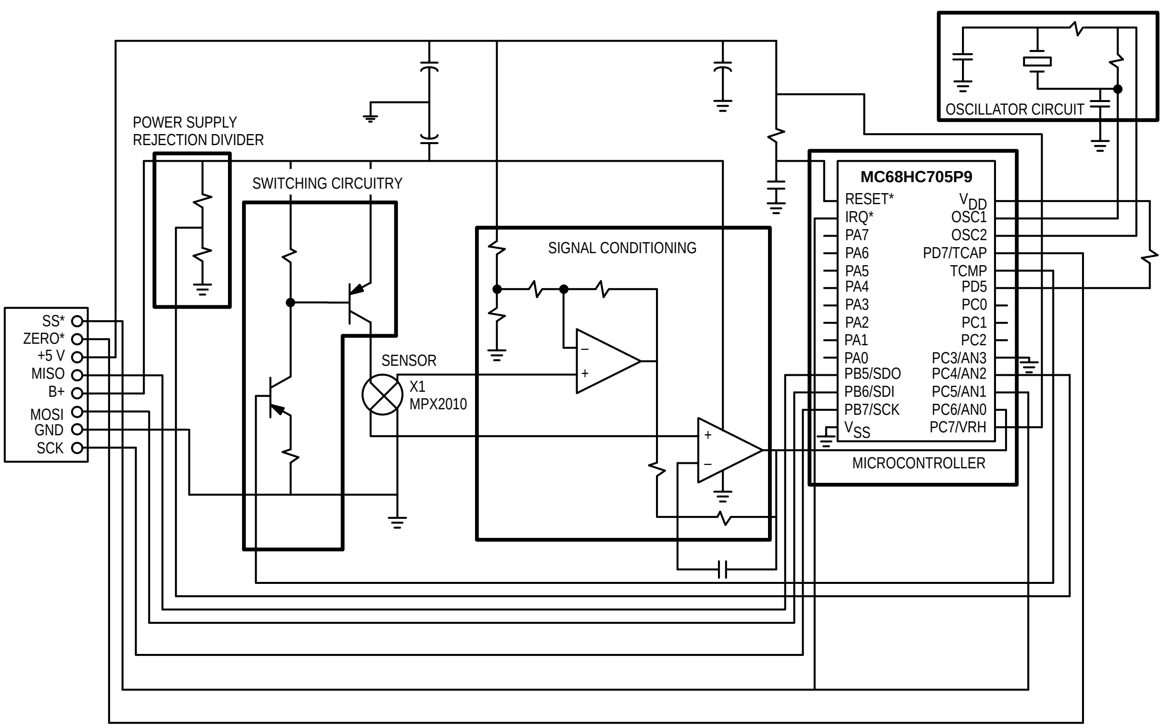

Figure 2. System Schematic

Signal Conditioning

Even with pulsing at a relatively high supply voltage, the pressure sensing element still has a full–scale output that is only on the order of tens of millivolts. To input this signal to the A/D converter of the MCU, the sensing element output must be amplified to allow adequate digital resolution. A basic two–operational amplifier signal–conditioning circuit is used to provide the following desired characteristics of an instrumentation amplifier interface:

- high input impedance
- low output impedance
- differential to single–ended conversion of the pressure sensor signal
- moderate gain capability

Both the nominal gain and offset reference pedestal of this interface circuit can be adjusted to fit a given distribution of sensor devices. Varying the gain and offset reference pedestal is desirable since pressure sensors' full–scale span and zero–pressure offset voltages will vary somewhat from lot to lot and unit to unit. During software calibration, each sensor device's specific offset and full–scale output characteristics will be stored. Nonetheless, a variable gain amplifier circuit is desirable to coarsely tune the sensor's full–scale span, and a positive or negative dc level shift (offset pedestal adjustment) of the pressure sensor signal is needed to translate the pressure sensor's signal–conditioned output span to a specific level (e.g., within the high and low reference voltages of the A/D converter).

Microcontroller

The microcontroller performs all of the necessary tasks to give the smart sensor system the specified performance and intelligent features. The following describes its responsibilities:

- Creates the control signal to pulse the sensor.
- Samples the pressure sensor's output.
- Signal averages a programmable number of samples for noise reduction.
- Samples a scaled–down version of the pressure sensor supply voltage. Monitoring the power supply voltage allows the microcontroller to reject sensor output changes resulting from power supply variations.
- Uses serial communications interface (SPI) to receive commands from and to send sensor information to a master MCU.

Resistor Divider for Rejection of Supply Voltage Variation

Since the pressure sensor's output voltage is ratiometric to its supply voltage, any variation in supply voltage will result in variation of the pressure sensor's output voltage. By attenuating the supply voltage (since the supply voltage may exceed the 5 V range of the A/D) with a resistor divider, this scaled voltage can be sampled by the microcontroller's A/D converter. By sampling the scaled supply voltage, the microcontroller can compensate for any variances in the pressure sensor's output voltage that are due to supply variations. This technique allows correct pressure determination even when the pressure sensor is powered with an unregulated supply.

5 V Regulator

A 5 V ±5% voltage regulator is required for the following functions:

- To provide a stable 5 V for the high voltage reference (V_{RH}) of the microcontroller's A/D converter. A stable voltage reference is crucial for sampling any analog voltage signals.
- To provide a stable 5 V for the resistor divider that is used to level shift the amplified zero–pressure offset voltage.

Low Voltage Inhibit (LVI) Circuitry

Low voltage inhibit circuitry is required to ensure proper power–on–reset (POR) of the microcontroller and to put the MCU in a known state when the supply voltage is decreased below the MCU supply voltage threshold.

SOFTWARE DESCRIPTION

The smart sensor system's EPROM resident code provides the control pulse for the sensor's excitation voltage and performs calibration with respect to a wide range of excitation voltages (20 ~ 28 V typically for HVAC). Pressure measurement averaging is also incorporated to reduce both signal error and noise. In addition, the availability of a serial communications interface allows a variety of software commands to be sent to the smart sensor system.

The following brief outline provides a more detailed description about the software features included in the smart sensor system.

Software Calibration and Power Supply Rejection

Only six 8–bit words of information are stored both to calibrate the smart sensor system for a given sensor device and to store the relationship between sensor output and power supply voltage. This information is used to reduce errors due to device–to–device variations and to reject variations in power supply voltage that can introduce error into the pressure measurement. The sensor's amplified output at the zero–pressure offset and full–scale pressure are stored at each of two different supply voltages. In addition, the scaled and digitized representation of the applied supply voltages is stored. Compensating for power supply variation in software allows higher performance with lower tolerance, or even unregulated, supply voltages. For HVAC applications, where a 24–Vac line voltage will be simply rectified and filtered to provide a crude 24–Vdc supply, this approach has major performance benefits. The impact on applications where a regulated supply is available is that a lower–cost regulator or dc–to–dc converter can be used without compromising system accuracy significantly.

A/D Sample Averaging

Noise inherent to the 8–bit A/D successive approximation conversion method used by the smart sensor accounts for ±1–bit resolution. Signal noise, which exhibits a measured peak–to–peak range larger in magnitude than 1 bit of A/D resolution, can be minimized by a sample averaging technique.

The current technique uses 16 A/D converted pressure samples, sums the result, and divides by 16 (the number of samples) to get the average:

$$\text{Avg} = \sum_{1}^{n} \frac{(a_n)}{n}; \text{ where } n = 16 \qquad (1)$$

Assuming a gaussian distribution of noise, this averaging technique improves the signal–to–noise ratio (SNR).

Smart Sensor Unit ID and Software Revision Level

This solution may be implemented as a single sensing system using a nondedicated MCU to provide the sensing function and smart features or as a slaved smart sensor (with dedicated sensing MCU) that communicates over a serial bus to a master controller or microprocessor (Host). Part identification and software revision level can also be read on request from the master MCU. This information is utilized by the master MCU to determine what the full–scale pressure range of a given smart sensor unit is. This allows for multiple sensor units with different pressure ranges to be controlled and sensed from a single master MCU.

Table 2. Software Command Codes

Function (Command Codes)	Command from Host	Data from Smart Sensor
Request Pressure	$01	$00~$FF
Dynamic Zero	$02	–
Undo Dynamic Zero	$03	–
Pressure Range	$04	TBD

Communication

The serial peripheral interface (SPI) is used to communicate to a master/host MCU. The master MCU initiates all I/O control and sends commands to the slave regarding data requests, calibration, etc. The command codes are parsed at the slave in a look–up table, at which time the corresponding request is serviced via subroutine. Table 2 lists the Master/Slave commands.

Request Pressure Returns the percent of full–scale pressure applied to the sensor in the form of $00 (0) through $FF (255) and is equivalent to:

Pressure Range (from 0 to 255),

where $\frac{(0 \sim 255)}{255} \times FS = \text{Measured Pressure}$ (2)

(This calculation is performed by the master MCU.)

Dynamic Zero Assigns current input pressure as the offset value, in order to use a nonzero pressure as the offset reference.

Undo Dynamic Zero Resets offset to the original stored offset (see Dynamic Zero).

Pressure Range Returns a value representing the sensor's full–scale pressure range.

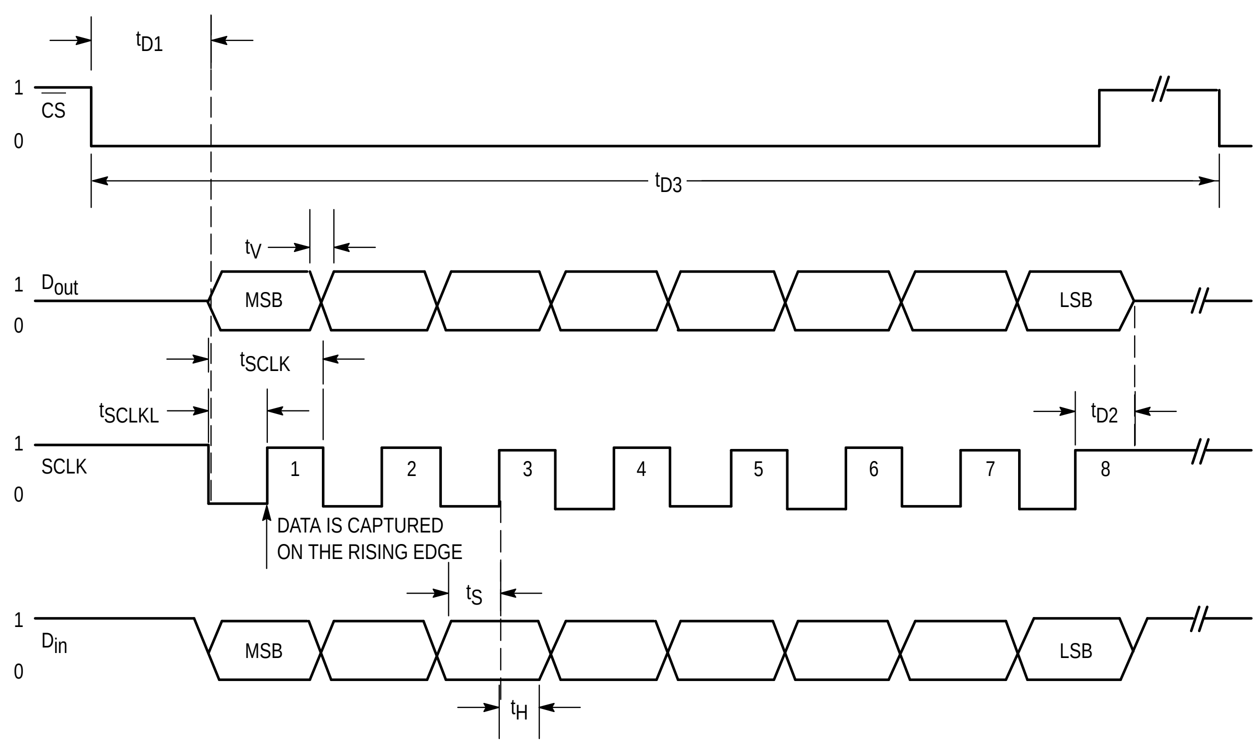

Figure 3. SPI Timing Diagram

SOFTWARE EXAMPLES

The following example listings show how a user may communicate with the smart sensor via a master MCU. The software example shown assumes that the master MCU is an MC68HC11. Any MCU with the proper I/O functionality will operate similarly with the smart sensor system.

When using parallel I/O instead of an SPI port to interface the smart sensor, the user must “bit bang” the clock and data out of the parallel I/O, so as to simulate the SPI port. As long as the timing relationships of data and clock follow those of Figure 3 (see also Table 3), the smart sensor will function properly when interfaced to a processor with a parallel type interface. In the following two code examples, the sensor unit is interfaced to the master MCU via the SPI port, and the sensor’s CS input is connected to the HC11’s Port D pin 5.

This example is coded in ‘C’ for the MC68HC11:

```
/* FIRST INITIALIZE THE I/O (INCLUDE A HEADER FILE TO INCLUDE I/O DEFINITIONS) */
void init_io(void)
{
PORTD = 0X29; /* SS* PD5 = 1, PD3 = 1, PD0 = 1 */
DDRD = 0X3B; /* SS* PD5 = 1, PD3 = 1, PD1 = 1, PD0 = 1 */
SPCR = 0X5E; /* ENABLE THE SPI, MAKE MCU THE MASTR, SCK = E CLK /4 */
/* I/O INITIALIZATION IS COMPLETE */
}

/* WE NEED A FUNCTION TO WRITE TO AND READ FROM THE SPI */
write_spi(char data)
{
SPDR = data;  /* WRITE THE DATA TO THE SPI DATA PORT */
   while( ! (SPSR & 0x80 )); /* WAIT UNTIL DATA HAS SHIFTED OUT OF AND
                                   BACK INTO THE SPI */
return(SPDR): /* RETRIEVE THE RESULTS OF THE LAST COMMAND TO
                    THE SENSOR AND RETURN */
}

/* NOW WE NEED TO CALL THE ABOVE */
void main(void)
{
char rtn_data; /* rtn_data IS THE RETURNED DATA FROM THE SENSOR */

init_io();

while(1)  /* JUST LOOP FOREVER */

rtn_data = write_spi(0x01); /* 0x01 IS THE COMMAND TO THE SENSOR
                                    THAT REQUESTS PRESSURE. THE VALUE IN
                                    rtn_data WILL BE IN THE RANGE OF
                                    0..0XFF = 0..100% FULL SCALE PRESSURE THE
                                    SECOND TIME THROUGH THE LOOP. THE INITIAL
                                    TIME THROUGH THE LOOP, THE DATA
                                    RETURNED IS INDETERMINATE  */
}
```

The next example is coded in assembly for the MC68HC11:

```
* PORT OFFSETS INTO THE I/O MAP
PORTS        EQU         $1000    ASSUME THE I/O STARTS AT $1000
PORTD        EQU         $8
DDRD         EQU         $9
SPCR         EQU         $8
SPSR         EQU         $29
SPDR         EQU         $2A

             ORG         $E000
* FIRST INITIALIZE THE I/O
INITIO       LDX         #PORTS   BASE ADDRESS OF THE I/O
             LDAA        #$29
             STAA        PORTD,X  SS* PD5 = 1, PD3 = 1, PD0 = 1
             LDAA        #$3B
             STAA        DDRD,X   SS* PD5 = 1, PD3 = 1, PD1 = 1, PD0 = 1
             LDAA        #$5E
             STAA        SPCR,X   ENABLE THE SPI, MAKE MCU THE MASTR,
*                                      SCK = E CLK /4
             RTS                       I/O INITIALIZATION IS COMPLETE
```

```
*WE NEED A SUBROUTINE TO WRITE TO AND READ FROM THE SPI
*TO CALL THIS ROUTINE LOAD ACCUMULATOR A WITH THE COMMAND DATA
*AND JSR WRITSPI. WHEN THE ROUTINE RETURNS, ACCUMULATOR A
*CONTAINS THE DATA RETURNED FROM THE SENSOR

WRITSPI      LDX         #PORTS   BASE ADDRESS OF THE I/O
             STAA        SPDR,X   SEND THE COMMAND TO THE SENSOR
WRLOOP       BRCLR       7,SPSR,WRLOOP LOOP UNTIL THE DATA HAS SHIFTED
                                       OUT OF AND BACK INTO THE SPI
             LDAA        SPDR,X        RETRIEVE THE RESULTS OF THE LAST
                                       COMMAND
*                                      TO THE SENSOR
             RTS

* NOW WE NEED TO CALL THE ABOVE */
START        JSR         INITIO   SET-UP THE I/O
LOOP         LDAA        #$1      1 IS THE COMMAND TO THE SENSOR THAT

*                                 REQUESTS PRESSURE
             JSR         WRITSPI  SEND THE COMMAND TO THE SENSOR.
*            ...                  THE VALUE RETURNED IN ACCUMULATOR A
*                                 WILL BE IN THE RANGE 0..0XFF = 0..100%
*                                 FULL SCALE PRESSURE THE SECOND TIME
*                                 THROUGH THE LOOP. THE INITIAL TIME
*                                 THROUGH THE LOOP, THE DATA RETURNED
                                  IS INDETERMINATE DATA FROM THE SENSOR
             BRA         LOOP
```

Table 3. SPI Timing Characteristics

Characteristic	Symbol	Min	Max	Unit
Frequency of Operation	f_{OP}	dc	525	kHz
Cycle Time	t_{SCLK}	–	1920	ns
Clock (SCLK) Low Time	t_{SCLKL}	932	–	ns
D_{out} Data Valid Time	t_V	–	200	ns
D_{in} Setup Time	t_S	100	–	ns
D_{in} Hold Time	t_H	100	–	ns
On–Bus Delay Time	t_{D1}	1	–	ms
Off–Bus Delay Time	t_{D2}	–	50	µs
Chip Select Period	t_{D3}	TBD	–	ms

SERIAL DATA OUTPUT FORMAT

The serial data output is an 8–bit number of value 0–255. This number represents the current applied pressure as a percentage of the full–scale pressure rating of the smart sensor. The master MCU can simply consider an output of “0” to be zero pressure and “255” to be full–scale pressure. To convert this number to engineering units, such as inches of water (″ H_2O), the master MCU must multiply the smart sensor output (0–255) by the full–scale pressure of the smart sensor in ″ H_2O and then divide (normalize) by 255. See equation 2.

The master MCU can either use an absolute number for the full–scale pressure of the smart sensor (as indicated previously) or can query each smart sensor that is connected to the serial bus for its rated pressure range. The latter technique allows multiple smart sensors of various full–scale pressure ranges to be communicating with a single master MCU, without the need for an absolute addressing scheme that contains full–scale pressure information for each sensor.

CONCLUSION

A smart sensing system that achieves high performance for low–pressure applications has been presented here. The key performance advantage of the smart sensor system is that it takes advantage of the fact that the output of the actual sensing element is ratiometric (linearly proportional) to the excitation voltage applied to the sensing element. A sensor device is pulsed at a much higher than normally specified voltage and a low duty–cycle for the purpose of increased sensitivity. Although some of the sensor’s parasitic drawbacks are increased in magnitude, some of the sensor’s negative characteristics are lessened, and other sources of error and noise in the system are reduced. The net effect is that a better signal–to–noise ratio is obtained. This, combined with several other performance–enhancing smart features, provides better pressure resolution and accuracy than inherent in the sensor device alone.

Besides the sensor excitation pulsing and output sampling functions, a low–cost MCU provides the performance–

enhancing features of signal averaging, software calibration, and software power supply rejection. The added–functionality of intelligent communications capability, serial digital output flexibility, and local control and decision–making capability are also at the user's disposal. The development history, system design, software functions, example communications routines, and serial output format have been detailed to provide the reader with an understanding of how low–pressure capability can be greatly enhanced via a smart sensor system approach.

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