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Intelligent Digital Pressure Sensors and Transducers Based on Universal Frequency-to-Digital Converter (UFDC-1)

Sergey Y. YURISH
Institute of Computer Sciences and Technologies, National University Lviv Polytechnic,
Bandera str., 12, 79013 Lviv, UA
Phone: +380502280003, fax: +380 32 2971641
E-mail: syurish@mail.lviv.ua

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Abstract: The application specific paper describes a design approach for digital pressure sensors and transducers. Practical realizations are based on the Universal Frequency-to-Digital Converter (UFDC-1). By eliminating the need for ADC, the frequency (duty-cycle or PWM)-to-digital conversion schemes reduce the systems complexity. The results of such design approach are high-performance single-chip pressure sensors with truly digital output (RS-232 interface) or bus output (SPI or I^2C) at significant reduction of production cost, time-to-market and simplification of the design process. Practical examples of direct interfacing of frequency, PWM and duty-cycle output pressure sensors and transducers to the UFDC-1 are given.

Keywords: pressure sensor, digital sensors, intelligent sensor, universal frequency-to-digital converter, frequency output, duty-cycle, UFDC-1

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1. Introduction

Pressure sensors and transducers are very widely spread. It can be found in numerous OEM applications, and they are used in process control, automotive industry, etc. A wide variety of pressure sensing technologies including MEMS is available today [1].

Pressure sensors convert the external pressure into the electrical output signal. In order to convert voltage signal to digital an embedded or external ADC should be used. As an alternative to the conventional ADC, it is possible to measure either a period (frequency) or a pulse width of an incoming square or rectangular wave signal [2]. In addition to eliminate the need for an ADC, a frequency output is conductive to applications requiring the sensor output to be transmitted over long distances, or where the presence of noise in the sensor environment is likely to corrupt an otherwise healthy signal… Frequency is not affected by resistive phenomena; in other words, the measured frequency will be the frequency transmitted at the output of a remote sensor [2].

The first monolithic integrated pressure sensor with the frequency output was designed and tested in 1971 at Case Western Reserve University [3]. Today many manufacturers produce frequency output pressure sensors and transducers for different applications [4]. Performances of some modern quasi-digital pressure sensors and transducers with frequency output are shown in Table 1.

Table.1. *Frequency output pressure sensors and transducers*.

Sensor	Pressure Range	Relative FS Error, %	Output Frequency
Chezara (Ukraine)			
VT2101	0.5 - 180 MPa	± 0.25 (mean square error)	15 - 22 kHz
VT 1202	0.5 - 60 MPa	± 0.15 (mean square error)	15 - 22 kHz
EFT-1-1000	1.7; 3.5; 7; 17; 35; 70; 170; 350 Bar 25; 50; 100; 250; 500; 1000; 2500; 5000 psi	2	5 - 20 kHz
Druck Incorporated			
RPT 410	17.5 to 32.5 inHg 600 to 1100 mbar (hPa)	0.05	600 - 1100 Hz
Omega			
PX106 Series	0-6 psi 0-200 psi	1	1 - 6 kHz
Omron			
D8M-R1	0 to 196.13 Pa (0 to 0.028 psi)	N/A	80 - 300 kHz
D8M-D1/D2	0 to 5.88 kPa (0 to 0.85 psi)	N/A	Pulse count, 1 pulse/9.81 Pa (1/0.0014 psi)
D8M-D82	0 to 4.9 kPa (0 to 0.71 psi)	N/A	Pulse count, 1 pulse/9.81 Pa (1/0.0014 psi)
Paroscientific, Inc.			
8DP	10 –700 m	0.01	37 – 42 kHz
8B	1400 - 7000 m	0.01	37 – 42 kHz
181KT	0 - 700 m	0.02	30 – 42 kHz
2000 Series	15 - 500 psia	0.01	30 – 42 kHz
3000 Series	1000 psia	0.01	30 – 42 kHz
4000 Series	2000- 40000 psia	0.01	30 – 42 kHz
5300 Series	0 to 3, 0 to 6, 0 to 18 psid	0.01	30 – 42 kHz
Pressure Systems			
960 Series	15 to 500 psia FS (103 to 3447 kPa)	0.01	30 - 45 kHz
Seamap			
Gun Depth and Line Pressure Transducers	0-40 m	1	6 - 10 kHz

N/A – information is not available.

If sensors can provide a frequency modulated signal that is linearly proportional to the applied pressure being measured, then an accurate system is a good solution for many challenging sensing applications. In addition to the cost saving of such system, this design concept offers additional benefits to remote sensing applications and sensing in electrically noisy environments as well as other benefits of frequency as an informative parameters like wide dynamic range, simplicity of communication and interfacing, etc.

Taking into account the high accuracy of modern frequency output pressure sensors and transducers (the FS relative error is 0.01 %) and wide frequency range (from some hundred Hz up to some hundred kHz), it is evidently that no any classical frequency-to-digital conversion methods can be used. In order to be neglected in a measuring channel, the frequency-to-code conversion relative error must be in order or at least in five times less than the sensor's error. Therefore, the frequency must be measured with 0.001 % or at least, 0.002 % relative error. Let see what will happen at the use of standard counting technique [5]. For 30 kHz measurement with quantization error 0.001 % it will be necessary 3.33 s. This conversion time is much more than sensor's response time and is redundant for all rest frequencies from output frequency range. Much better result gives any advanced frequency-to-digital conversion method but customer or manufacturer must buy a license for the use any of these methods. In addition, even the advanced method will be chosen for pressure digital sensor design, the developer must take into account many addition components of conversion error if he will use common purpose microcontroller for frequency measurement. It is the error because of the latency time between the occurrence of the interrupt request and the beginning of the interrupt machine cycle, the error due to the time delay between the beginning of interrupt machine cycle and the start or stop the built-in time/counter, etc [6]. Very often, such software related components of error are exceeded or equal to the quantization error [7-8]. It needs very careful error components analyze and different methods for its reduction.

In order to simplify a design process of digital pressure sensors and transducers and reduce time-to-market, it is expediently to use the Universal Frequency-to-Digital Converter (UFDC-1) [9].

2. Digital Readouts and Interfacing of Frequency Output Pressure Sensors

The UFDC-1 works well with all frequency ranges of modern quasi-digital pressure sensors and transducers. It has a programmable conversion error from 1 up to 0.001 % and advanced communication possibilities (RS-232 interface, SPI and I^2C bus capabilities) [9]. The UFDC-1 based systems are extremely cost-effective. The level of sensor intelligence that can be obtained for only a few percents of the total cost has made the UFDC-1 the element of choice for MEMS based pressure sensors and transducers. Very often, such MEMS based sensors contain diffused piezoresistors, the output parameters of which are temperature depended. The temperature error can be compensated due to the use of built-in temperature sensors. Many modern frequency output pressure sensors and transducers have built-in temperature sensors. For example, it is in all series of pressure sensors from *Paroscientific, Inc*. Such kind of multiparameter sensors can be used in different applications like meteorological stations, medical devices, automotive industry, etc. Temperature signal is a frequency output with a 45 ppm/°C sensitivity within the band 168 kHz to 172 kHz [10-11].

These multiparameter sensors can be directly connected to the UFDC-1 as it is shown in Figure 1 for 8000 Series of frequency output depth sensors from *Paroscientific, Inc*. The temperature frequency signal is connected to the first channel of the UFDC-1, the pressure frequency signal is connected to the second channel. Appropriate commands (RS-232 interface) for the UFDC-1 operation mode for frequency–to–digital conversion in both channels with 0.001 % relative conversion error are shown in Figure 2. The different conversion error can be chosen for each of channel.

If no any embedded sensor is built in a pressure sensor, any temperature sensors described in [12] can be used in the design of multisensor systems.

One more interesting feature of the UFDC-1 based systems is a self-adaptation. The quantization error can be changed during the conversion process depend on condition of measurement in order to have, for example, minimum possible conversion time at critical points of pressure range.

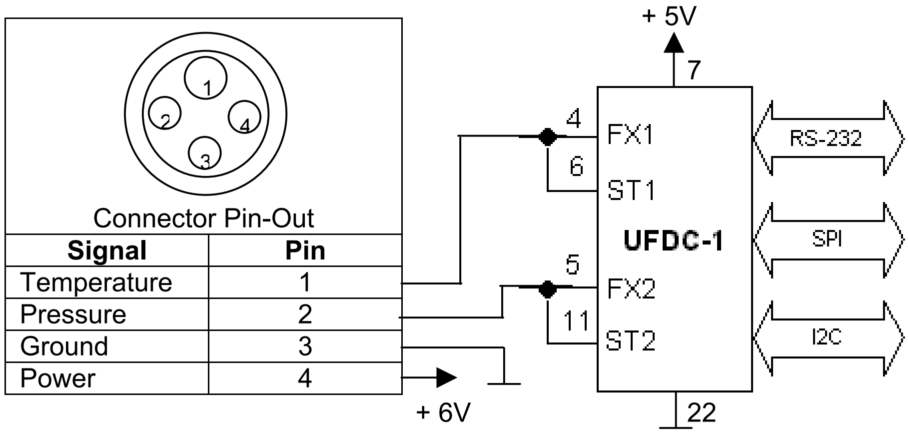

Fig. 1. *Connection diagram for 8000 Series of frequency output depth sensors from Paroscientific, Inc.*

>M0; Frequency measurement initialization in the first channel
>A0; Choose the conversion error 0.001 %
>S; Start a measurement
>R; Read a result proportional to temperature
>ME; Frequency measurement initialization in the second channel
>A0; Choose the conversion error 0.001 %
>S; Start a measurement
>R; Read a result proportional to pressure

Fig. 2. *Appropriate UFDC-1 commands (RS-232) for frequency-to-digital conversion in both cannels with 0.001 % relative error.*

The same design approach can be used for other high accurate pressure sensors and transducers shown in Table 1. For relative errors more than 0.001 % appropriate conversion error for the UFDC-1 should be chosen.

Another interesting sensors are solid-state pressure sensors D8M-D1, D8M-D2 and D8M-D82 from *Omron*. They outputs generate number of pulses proportional to the pressure. For example, 0 kPa = 30 pulses; 0.59 kPa = 60 ±32 pulses; 1.96 kPa = 200 ±24 pulses, etc. Such sensors also can be connected directly to the UFDC-1 (the first channel) because of the converter has a pulse number counting mode. Appropriate commands (RS-232 interface) for the UFDC-1 operation mode for pulse number counting are shown in Figure 3.

>MD; Pulse count initialization
>S; Start a measurement
>R; Read a result proportional to pressure

Fig. 3. *Appropriate UFDC-1 commands (RS-232) for pulse counting mode.*

Figure 4 shows an LCD pressure gauge that is made with a frequency output integrated pressure sensor and the UFDC-1.

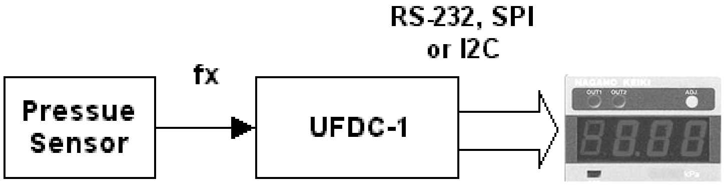

Fig. 4. *LCD pressure gauge based on UFDC-1.*

The interfacing between the UFDC-1 and LCD indicator can be made according to RS-232 interface, SPI or I2C serial buses depend on the LCD.

3. Digital Pressure Sensors with Voltage-to-Frequency Conversion

Since many pressure sensors provide a voltage output, it should be converted to a frequency proportional to the sensor output voltage (Figure 5). Assuming the sensor's analog voltage output is proportional to the applied pressure, the resulting frequency will be linearly related to the pressure being measured. Although many timing circuits can perform voltage-to-frequency conversion (VFC), most of the simple typos provide neither the accuracy nor stability needed for reliability encoding a sensor signal quantity [2]. Fortunately, there are many commercially available VFC ICs that can handle this function.

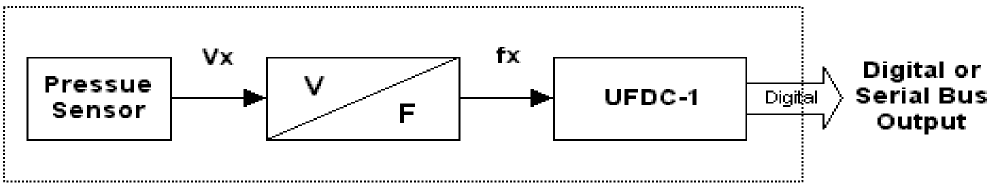

Fig. 5. *Digital pressure sensor with voltage-to-frequency conversion*.

Some interesting detailed examples, for example, using *Motorola's* pressure sensors series and *Analog Devices* VFC AD654 or any voltage output pressure sensors (0-10 V full-scale voltage range) and VFC32 from *Burr-Brown* are described in [2] and [5] accordingly. VFCs outputs can be directly connected to the UFDC-1 in order to produce digital output. Taking into account a very wide frequency range of the UFDC-1 any full scale frequency range for VFCs can be used.

4. Digital Pressure Sensors with PWM and Duty-Cycle-to-Digital Conversion

For some applications, a frequency modulated (FM) or pulse width modulated (PWM) output is more desirable than a frequency output. In comparison with a frequency output signal the duty-cycle is rather immune to interfering signals, such as spikes [13], and the ratio does not depend on the absolute value of any component [14].

Both FM and PWM outputs inherently have better noise immunity. Generally, FM outputs are more widely accepted than PWM outputs, because PWM outputs are restricted to a fixed frequency. With either an FM or PWM output, the UFDC-1 can be used to convert the frequency-time domain signal into a digital.

The stable PWM output could be obtained with simple, inexpensive circuitry, a PWM output would be a cost-effective solution for noisy environment/remote sensing applications while incorporating the advantages of frequency outputs [15]. The pulse width modulated output pressure sensor design is described in details in [15]. It was made for a *Freescale Semiconductor, Inc*. MPX5000 series pressure sensor. In order to produce digital output according to the RS-232 interface or serial buses SPI or I^2C, the UFDC-1 should be used in the design. The appropriate commands and interfacing circuits for PWM and duty-cycle-to-digital conversions were described in [12] for applicable semiconductor quasi-digital temperature sensors.

5. Conclusions

Combining silicon micromachining designs and processes with the advanced Universal Frequency-to-Digital Converter overcomes many of the early limitations of single-chip sensors. This co-integrated unit can be produced using, for example, co-integration technology or hybrid technology. By eliminating the need for ADC, the frequency (duty-cycle or PWM)-to-digital conversion schemes reduce the systems complexity. The results are high-performance single-chip pressure sensors with truly digital output (RS-232 interface) or bus output (SPI or I^2C) at significant reduction of production costs, time-to-market and simplification of the design process.

In comparison with the direct microcontroller interfacing the proposed design approach also lets to eliminate many design problems connected with the microcontroller choice, its programming and additional error components due to so-called program-dependent or software-related quantization effects.

References

[1]. Smart Sensors and MEMS, ed. by Sergey Y. Yurish and Maria Teresa S.R. Gomes, *Kluwer Academic Publishers*, 2004.
[2]. Baum J., Frequency Output Conversion for MPX2000 Series Pressure Sensors, Sensors, Vol.14, No.4, April 1997, pp.34-39.
[3]. Blaser E.M., Ko W.H.,Yon E.T., A Miniature Digital Pressure Transducer, In *Proceedings of 24 Annual Conference on Engineering in Medicine and Biology*, 1971 November; Las Vegas, Nevada, USA.
[4]. Sensors Web Portal (http://www.sensorsportal.com/HTML/SENSORS/PresSens_Manuf.htm).
[5]. Kirianaki N.V., Yurish S.Y., Shpak N.O., Deynega V.P., Data Acquisition and Signal Processing for Smart Sensors, John Wiley & Sons, 2002.
[6]. Yurish S.Y., Reverter F., Pallàs-Areny R., Measurement error analysis and uncertainty reduction for period- and time interval-to-digital converters based on microcontrollers, Measurement Science and Technology, Vol.16, No.8, 2005, pp.1660-1666.
[7]. Yurish S.Y., Program-oriented Methods and Measuring Instruments for Frequency-Time Parameters of Electric Signals, *PhD Thesis,* State University Lviv Polytechnic Lviv, 1997 (In Ukrainian).
[8]. Reverter F., Microcontroller-based Interfaces for Quasi-Digital Sensors, *PhD Thesis,* Technical University of Catalonia (UPC Barcelona, Spain), 2004.
[9]. Universal Frequency-to-Digital Converter (UFDC-1), Specification and Application Note, 2004 (http://www.sensorsportal.com/HTML/E-SHOP/PRODUCTS_4/UFDC_1.htm).
[10]. http://www.paroscientific.com/overview.htm#transducers
[11]. http://www.paroscientific.com/oceanography.htm
[12]. Yurish S.Y., Data Acquisition Systems for Quasi-Digital Temperature Sensors Based on Universal Frequency-to-Digital Converter, *Sensors & Transducers Magazine*, Vol.57, No.7, July 2005, pp.341-351.

[13]. Meijer G. C. M. , Concepts and Focus Point for Intelligent Sensor Systems, *Sensors and Actuators A,* 41-42, 1994, pp.183-191.
[14]. Middelhoek S., French P. J., Huijsing J. H., Lian W. J., Sensors with Digital or Frequency Output, *Sensors and Actuators,* Vol. 15, 1988, pp.119-133.
[15]. Jacobsen E., Baum J., Using a Pulse Width Modulated Output with Semiconductor Pressure Sensors, *Freescale Semiconductor Application Note*, AN1518, Rev 2, 05/2005.