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# Wireless Pressure Sensor Using Non-contact Differential Variable Reluctance Transducer

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**Abstract:** A diaphragm based wireless pressure sensor using a non-contact differential variable reluctance transducer (NC-DVRT) is developed. A NC-DVRT senses the micro displacements of a diaphragm and operates by detecting the change in reluctance of a sense coil with respect to a compensation coil, when brought in close proximity to a highly conductive material. In the present work, a stainless steel (SS) diaphragm was used as a pressure port and a commercial NC-DVRT was fixed behind it at a distance of 140 μm. Output of the NC-DVRT was digitized using PSoC microcontroller and was transmitted using a wireless RF module. The developed pressure sensor can measure the positional movement of the SS diaphragm in both the directions with an accuracy of 2 μm corresponding to a pressure of 0.1 bar and communicate to a remote PC. *Copyright © 2008 IFSA.*

**Keywords:** Wireless pressure sensor, NC-DVRT, PSoC microcontroller

## 1. Introduction

It is well known that different types of pressure sensors have been widely used in industrial, automobile and biomedical instrumentation. In most of these applications due to harsh or difficult to reach areas, it is preferable to monitor the pressure by wireless communication [1]. This allows measurements to be made safely and over a period of time. Apart from this, when measuring small pressure differences, temperature cross-sensitivity offset and long-term stability are challenging problems [2, 3]. This is due to the weak measuring signal in comparison with the signal variations produced by the mechanical changes in the diaphragm due to environmental changes like temperature, humidity, etc. or stress relaxation.

In the present work, a simple diaphragm based wireless pressure sensor using a commercial non-contact differential variable reluctance transducer (NC-DVRT) [4] is developed. It can measure both positive and negative pressure. With the present design a wide range of pressure measurement is possible with a proper selection of the diaphragm. The major advantage of the sensors based on DVRT is that the system becomes completely independent of the mechanical characteristics of the pressure port. These sensors use the displacement of the diaphragm as sensing mechanism in a non-contact way rather than strain measurement requiring contact with the diaphragm and some form of amplifying mechanism [5].

PSoC (TM) mixed-signal arrays of cypress are programmable systems-on-chips (SOCs) that integrate a microcontroller, analog and digital components in an embedded system. A single PSoC device can integrate as many as 100 peripheral functions with a microcontroller of our choice saving design time, board space and power consumption. Easy-to-use development tools enable designers to select the precise peripheral functionality they desire, including analog functions (amplifiers, ADCs, DACs, filters and comparators); digital functions (timers, counters, PWMs, SPI and UARTs) [6]. In the present work, PSoC microcontroller is used to generate an excitation ac signal to NC-DVRT, modulated synchronous measurement of output ac signal depending on target position, digitize output ac signal and transmit the same information to a remote personal computer through a wireless RF module.

Present article is organized in the following way: first the principle of NC-DVRT is explained; pressure sensor design and calibration are discussed followed by the details of PSoC microcontroller and wireless RF communication module.

## 2. Principle of NC-DVRT

NC-DVRT works on the inductance ratio principle. Two coils within the non-contact DVRT's housing form its sensing and compensation elements. When the face of the transducer is brought in close proximity to a highly conductive material, the reluctance of the sense coil is changed, while the compensation coil acts as a reference. The coils are driven by a high-frequency sine wave excitation, and their differential reluctance is measured using a sensitive demodulator, designed with a single chip PSoC. Differencing the two coils' outputs provides a sensitive measure of the position signal, while canceling out variations caused by temperature [4]. The specifications of the NC-DVRT used in the present work, as given by the manufacturer are given in Table 1.

**Table 1.** Specifications of NC-DVRT used in the present work.

| **Sensor Name: NC-DVRT-1.5** | Measurement Range : 1.5 mm |
|---|---|
| **Nonlinearity** | Exponential output |
| **Sensitivity** | 5 volts/mm typical |
| **Signal to noise** | Standard - 1000 to 1 with filter 3 dB down at 1 kHz |
| **Resolution** | 0.1 % minimum |
| **Frequency response** | 800 Hz standard, 20 kHz optional |
| **Temp. coeff. offset** | .0039 % / °C |
| **Temp. coeff. span** | .016 % /°C |
| **Repeatability** | ± 2 µm typical (at constant temperature) |
| **Operating temperature** | -55 °C to 175 °C |
| **Size** | 6.35 mm (Dia) x 19.0 mm (Length) |

## 3. Pressure Sensor Design and Calibration

Fig. 1 shows the schematic of the pressure sensor design using NC-DVRT. One side of the circular SS diaphragm (2 mm thick) is used as pressure port. On the other side a NC-DVRT has been rigidly fixed at a distance of 140 µm without any physical contact. This distance is selected to operate the NC-DVRT in its linear region, which is between 0 and 200 µm as per the calibration chart provided by the manufacturer. Teflon material was used to fix the NC-DVRT to avoid any spurious signal pickup. Output of the NC-DVRT, has been connected to a single chip embedded read-out design using PSoC, which provides an ac excitation to it and measures the modulated synchronous rectified sense coil output, which is proportional to the applied pressure.

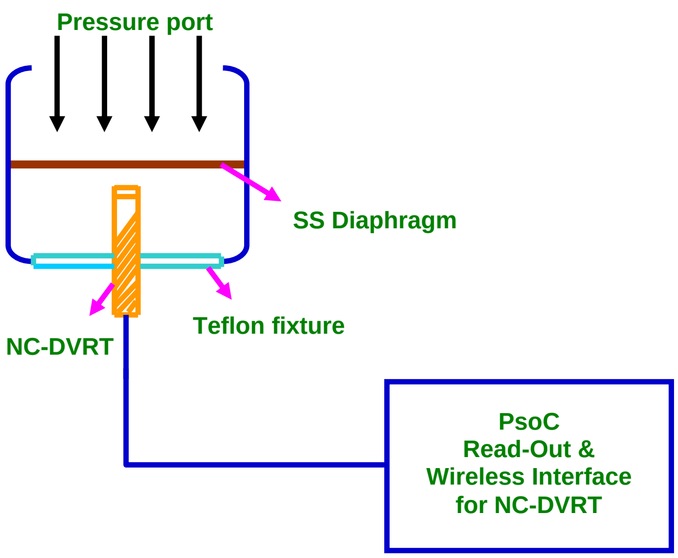


**Fig. 1.** Schematic of NC-DVRT pressure sensor.

It may be noted that the present design of the pressure sensor using NC-DVRT is different and relatively simple from that of commercially available variable reluctance based pressure sensors [7]. The main difference is that in the former case the diaphragm is placed between two sense coils and is not wireless where as in our design the sense coil (NC-DVRT) is mounted perpendicular to the one side of the diaphragm, leaving the other side exclusively for the measurand pressure. The present design also implements a compact demodulator and wireless communication using PSoC.

The sensor was calibrated using a test set-up. The pressure of organ gas was monitored simultaneously using a standard C-bourdon tube pressure gauge and the NC-DVRT pressure sensor developed. The pressure level was increased from 1 to 5 bar in 0.4 bar steps and the corresponding decrease in the output voltage of NC-DVRT was noted down. Several measurements were carried out to confirm the repeatability.

Fig. 2 shows the calibration graph of NC-DVRT output voltage as a function of the applied pressure and it is clear from this figure that the output voltage is linear. As per the manufacturer the operating temperature of the NC-DVRT is between -55 °C to 175 °C (see Table1) and hence the operating temperature of the developed pressure sensor is also the same. It may be noted that the pressure measurement range and resolution of the sensor developed is purely dependent on the physical (surface area, thickness and edge conditions) and mechanical properties of the diaphragm used and in the present case it is 0 – 5 bar and 0.1 bar respectively. For a wider range and better resolution suitable diaphragm has to be used.

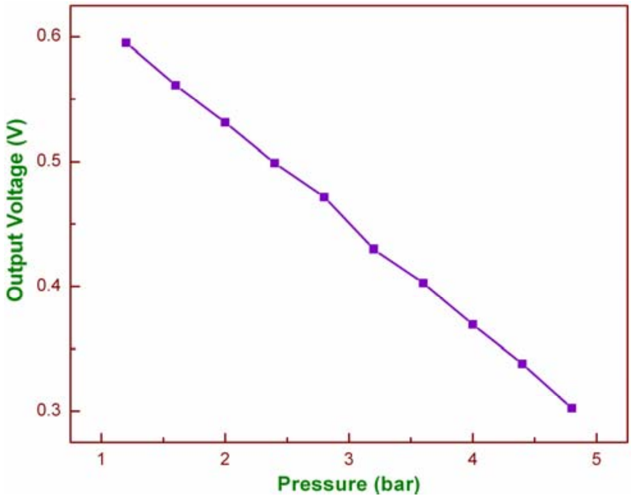


**Fig. 2.** Pressure vs. Output Voltage of the developed sensor.

## 4. Wireless Communication Using *PSoC*

Fig. 3 shows the wireless pressure measurement system using single *PSoC* microcontroller chip (CY8C29466) and 2.4 GHz wireless RF Module. Microcontroller was also programmed for a LCD port and was connected to a dot matrix LCD display. Microcontroller was powered by a rechargeable Ni-Cd battery.

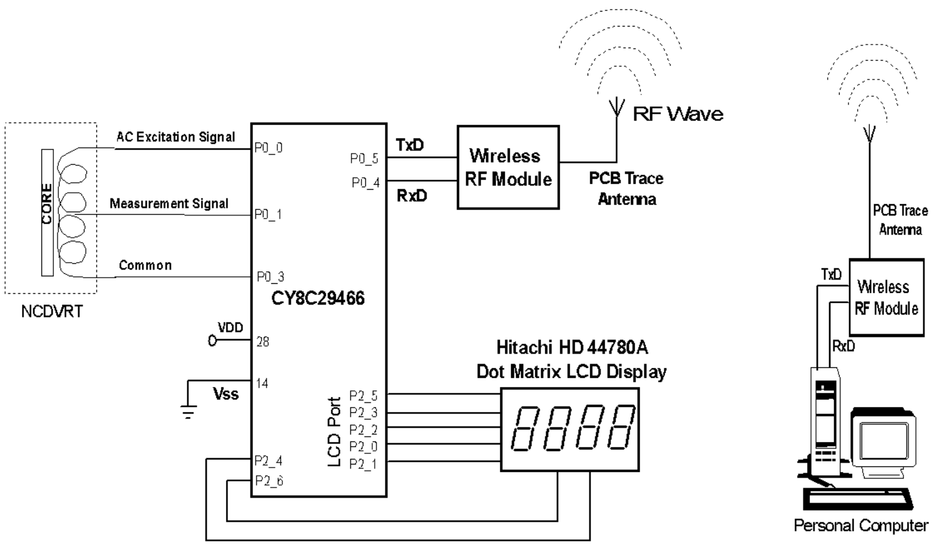


**Fig. 3.** Wireless Pressure measurement system using PSoC and NC-DVRT.

The internal blocks diagram of the *PSoC* microcontroller is shown in Fig. 4. To generate a perfect sine wave for driving the NC-DVRT, a square wave of required frequency has been generated (carrier wave generator) and passed through a narrow switched capacitor band pass filter centered on the fundamental frequency of the square wave. The resultant sine wave is smooth enough to drive the coil of NC-DVRT. The sine wave output of NC-DVRT's sense coil is an amplitude variable signal as a function of target material movement. This output was applied to a modulator rectifier followed by a programmable gain amplifier (PGA) and a low pass filter which provides a dc output voltage corresponding to the positional change of SS diaphragm, due to change in pressure in the pressure port.

This rectified dc output voltage is connected to ADC for digitizing the measured pressure change. The digitized pressure output is then fed into UART for communicating serially to the wireless RF module which can transmit the data to PC in the remote place. For convenience of the user an LCD module also attached to the PSoC designer. The communicated RF signal has been received by another RF module connected in the PCs serial port, which act as a base station at a maximum distance of 100 meters (line of sight) for the transmitting RF modules of the remote sensors.

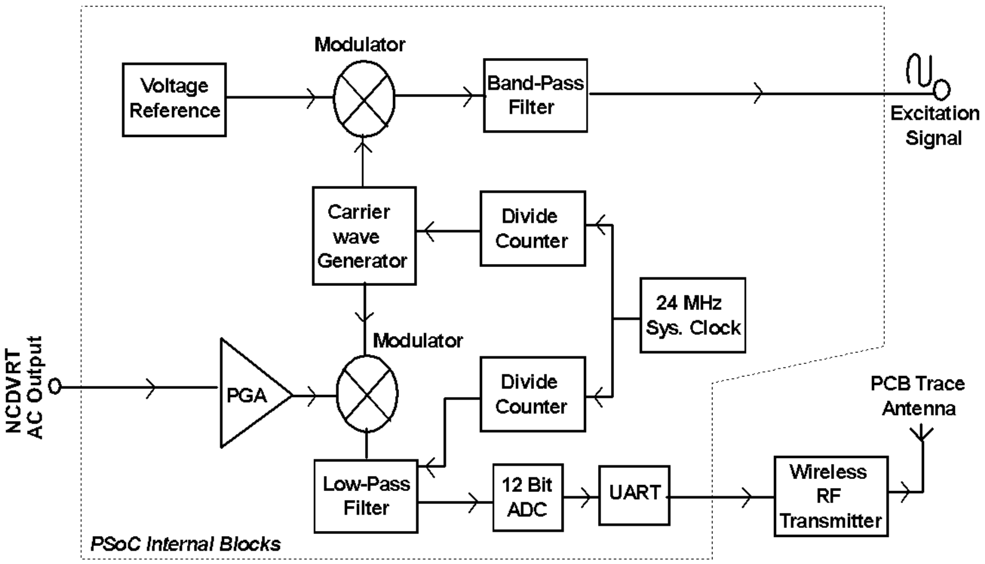


**Fig. 4.** PSoC Microcontroller's internal blocks.

Fig. 5 shows the *PSoC* designer internal blocks and pin diagram programmed with PGA, low pass filter, high pass filter, an 11-bit delta-sigma ADC, analog ground reference, LCD module and UART for serial communication.

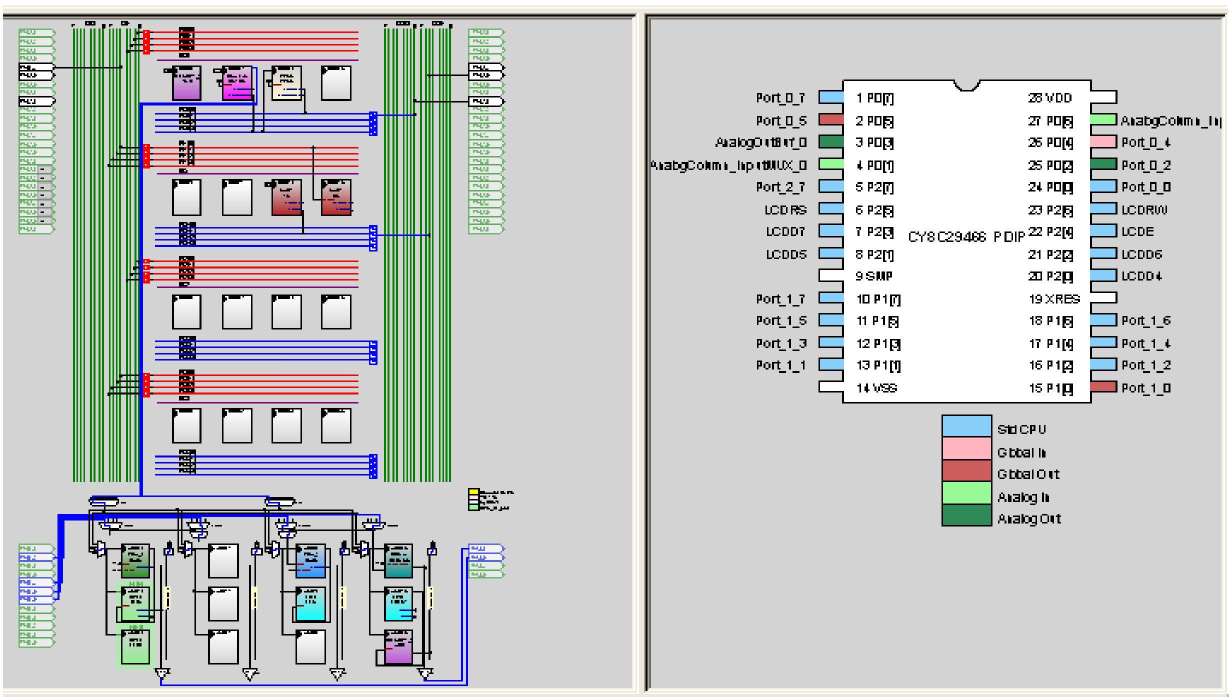

**Fig. 5.** PSoC microcontroller designer internal block diagram and pin diagram.

As already pointed out the mixed array of analog and digital blocks in a single chip is an added advantage of using *PSoC* microcontrollers. Virtual instrument (VI) based graphical language software written in LabVIEW acquires the wireless transmitted RF sensor signal, provides on-line plotting, saving data and analyzing the data as per the user requirement. The front panel diagram of virtual instrument control program for the wireless pressure sensor is shown in Fig.6, for the acquired data in incremental pressure steps of 0.5 bar up to 4 bar. VI front panel also shows the decimal display as well as the slider for visual indication.

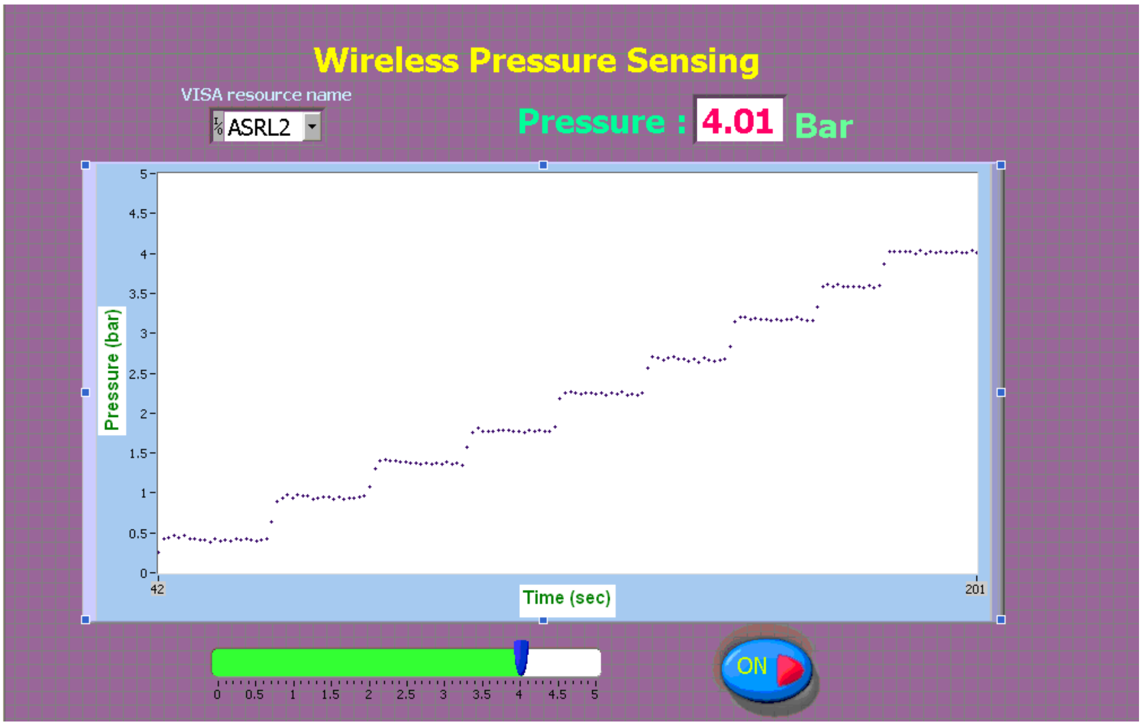


**Fig. 6.** Virtual instrument front panel diagram of wireless Pressure Sensor.

## 5. Conclusions

A simple wireless differential pressure sensor was developed using a non-contact differential variable reluctance transducer and was tested successfully with the SS diaphragm pressure port. The greatest advantage of this sensor is that it can measure both positive and negative pressure and since there are no electrical contacts between the pressure port and sensing element, it can be used for harsh environments. The prototype sensor developed can measure the pressure up to 5 bar with a resolution of 0.1 bar. By using the suitable diaphragm wide range and better resolution can be achieved. Wireless communication was established using PSoC microcontroller embedded design which enables number of such sensors to be monitored via a single communication port of the PC.

## Acknowledgements

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# Guide for Contributors

## Aims and Scope

*Sensors & Transducers Journal (ISSN 1726-5479)* provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because it is an open access, peer review international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per annual by International Frequency Association (IFSA). In additional, some special sponsored and conference issues published annually.

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- Sensor instrumentation;
- Virtual instruments;
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- Signal processing;
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- Microsystems;
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