



# DESIGN AND DEVELOPMENT OF HALL EFFECT BASED PRESSURE TRANSMITTER WITH WIRELESS READOUT

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## ABSTRACT

A simple, low cost intelligent pressure measuring technique has been proposed in this paper. In industrial applications, bellows is used as a pressure sensor with a local indication only. Hence, the deflection of bellow due to applied pressure must be converted into an efficient electrical read out for measurement and control in industry. In this study, the design of intelligent pressure transmitter with wireless read out has been described using bellow as a primary sensing element, a Hall effect sensor as sensing element and ATmega328 microcontrol unit for improving the linearity characteristics and wireless transmission. The voltage-pressure relation of the Hall effect based pressure transducer exhibits a considerable nonlinearity and limits the measurement to local operations. To estimate and compensate the nonlinearity of the pressure transmitter, we propose an artificial neural network (ANN). The intelligence of ANN modelling is included into an embedded plug-in-module (PIM). The functionality of the transmitter has been tested experimentally. The proposed intelligent transducer has exhibited considerably high sensitivity of about 1.8694 mV/psi over the pressure range of 0-40 psi. The performance of the proposed transmitter is verified with recently reported techniques.

**Keywords:** ANN, PIM, hall probe sensors, wireless read out.

## 1. INTRODUCTION

In any process plant, the important parameter needs to be monitored and controlled is pressure for smooth functioning. Mass, pressure, volume and so on are some of the important process variables to be measured in any industry. To obtain the good quality product at maximum efficiency in any process plant, accurate measurement of pressure is required. There are various fluid pressure measurement techniques which include elastic element methods, liquid column methods and electrical methods. Some of the elastic element methods, such as bourdon tubes, bellows and diaphragms which are used as primary sensors in pressure measurement techniques [1]-[4]. Transmission of bellows reading to a remote location and to the control room is very important in pressure measurement and control in any industry. A lot of works have been reported by many researchers to convert Bourdon tube movement into an electrical current signal which can be transmitted to a remote location. Among those works, an improved inductance bridge circuit with Bourdon tube as a pressure sensor is reported by Bera *et al.* [5] with a resolution of 5 psig in the range of 0-45 psig. The advantage of the circuit is large sensitivity, but it decreases with the signal-to-noise ratio of the circuit. In another work proposed by Bakhoun and Marvin[6], an ultrahigh-sensitivity pressure and vibration sensor is designed. In this paper hall probe sensor is used as secondary transducer, pressure is applied at one end of the bellows and the other end of the bellow is free to move and the total setup is fixed in a chamber. The length can be increased or decreased by using the folds.

Carbon steel can be used for manufacturing of bellows but it gets easily corroded whereas phosphorus bronze shows better hysteresis properties and Beryllium copper exhibits the better dynamic performance. Stainless

steel can be used for bellows construction but it is not having good elastic properties.

Various secondary sensors are available to convert bellows reading into an electrical signal. Bellows reading should be amplified and convert into an electrical signal in order to transmit to a remote location. The displacement of the bellow, which is non-electrical signal, is converted into an electrical signal by using the LVDT. These inductive transducers are used in sensor applications like position measurement; dynamic motion measurement touches pads etc. There are some limitations with the use of LVDT such as it requires high displacement for generating high voltages and it is heavily affected by the variations in temperature. These limitations are overcome in the proposed technique.

A parallel stream of developmental activities is focused on numerical methods for sensor linearization. A piecewise linearization method for thermistor is reported in [7]. It overcomes the limitations of the lookup table (LUT) technique. Several curve fitting methods such as spline, polynomial, progressive polynomial, improved progressive polynomial and modified progressive polynomial have been introduced for sensor linearization. ANN based linearization techniques have been proposed for various sensors [8-10]. Although these methods provide improved accuracy and simple implementation, requires a precise calibration with large number of data points to cover the complete operating range of the given sensor, which is a difficult and time-consuming task. Moreover, sensor resolution and data noise limit the efficiency in experimental process. The number of calibration points and their selection affect the performance of these methods. A high degree of polynomial function is necessary in these methods which increases the computational load.



In the conventional design of transmitters, an effective signal conditioning circuit suffers from stray effects, ambient factors, component tolerances and ageing etc. Hence the signal conditioning circuit with the integration of intelligent capabilities through soft computing techniques is a potential solution for continuous monitoring, wireless transmission and digital readout as well as on-chip interface. A parallel stream of developmental activities focused on software methods for linearization, error minimization and cross sensitivity error reduction and so on. The use of LUT requires a special read only memory for storing sensor data which is an important problem in some microprocessor and microcontroller-based systems. ANN based techniques yield better results than the classical electronic techniques. Analog and digital systems can be used to implement neural networks.

In this paper, a wireless pressure measurement technique using Bellows, Hall probe sensor is proposed. The applied pressure is converted into linearized voltage using signal conditioning circuit and ANN. The resultant voltage is transmitted in the wireless medium using GSM module.

## 2. PROPOSED PRESSURE MEASURING TECHNIQUE

### 2.1 Theory

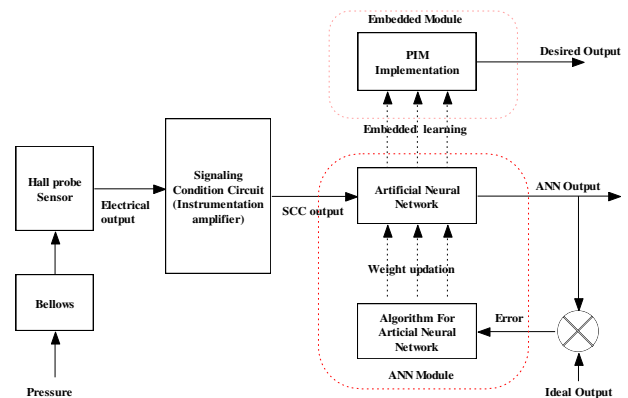
The block diagram of the complete pressure measurement technique is shown in Figure-1. Permanent magnet is placed on the top of bellows and the Hall probe sensor is kept outside the chamber. By applying pressure at one end of bellows, the distance between the Hall sensor and magnet decreases. Thus the magnetic field intensity varies by increasing the pressure. At this point the magnetic field intensity and the pressure are proportional to each other. Hence, the bellows convert the applied pressure into a linear displacement.

Consider the pressure applied to the bellows is  $p$  and the resulting displacement is  $y$ . so, the applied pressure is

$$P = K \cdot y \quad (1)$$

$K$  is the constant of proportionality.

Assume the distance between the Hall sensor at zero gauge pressure and the magnet is  $L$ . The magnet moves towards the Hall sensor with the application of pressure and consequently the distance between them decreases and the resultant Hall voltage increases.



**Figure-1.** Block diagram representation of complete pressure measurement technique.

The magnetic field  $B$  at the Hall sensor due to the change in distance between Hall sensor and magnet is written as

$$B_X = \frac{K_1}{X^2} \quad (2)$$

Where  $X = L - y$ ;  $K_1$  is constant.

The output voltage of Hall sensor is proportional to the magnetic field if the sensor current is maintained at constant and is given by

$$V_X = K_2 B_X \quad (3)$$

where  $K_2$  is constant.

From (1), (2), and (3),

$$\text{we have } V_X = \frac{K_1 K_2}{(L-y)^2} \quad (4)$$

The equation (4) can be written as

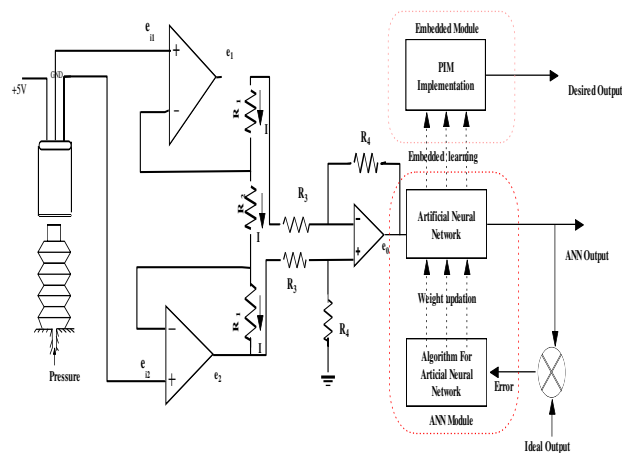
$$V_X = \frac{K_3}{(L-\frac{P}{K})^2} \quad (5)$$

The output voltage of the Hall sensor is nonlinearly related to the applied pressure. Hence, it is applied to the ANN after proper amplification using instrumentation amplifier as shown in Figure-2.

The output voltage of instrumentation amplifier is written as

$$e_0 = \frac{R_4}{R_3} \left(1 + \frac{2R_1}{R_2}\right) (V_X - 0) \quad (6)$$

The proposed linearization technique for Hall sensor based pressure transducer is shown in Fig.2. The output signal of the instrumentation amplifier is processed by the ANN linearizer. The Levenberg-Marquart (LM) algorithm is used as training algorithm in ANN linearizer to compensate the nonlinearity of Hall sensor based pressure transducer. The intelligence of the ANN is embedded in a microcontroller based PIM for practical implementation.



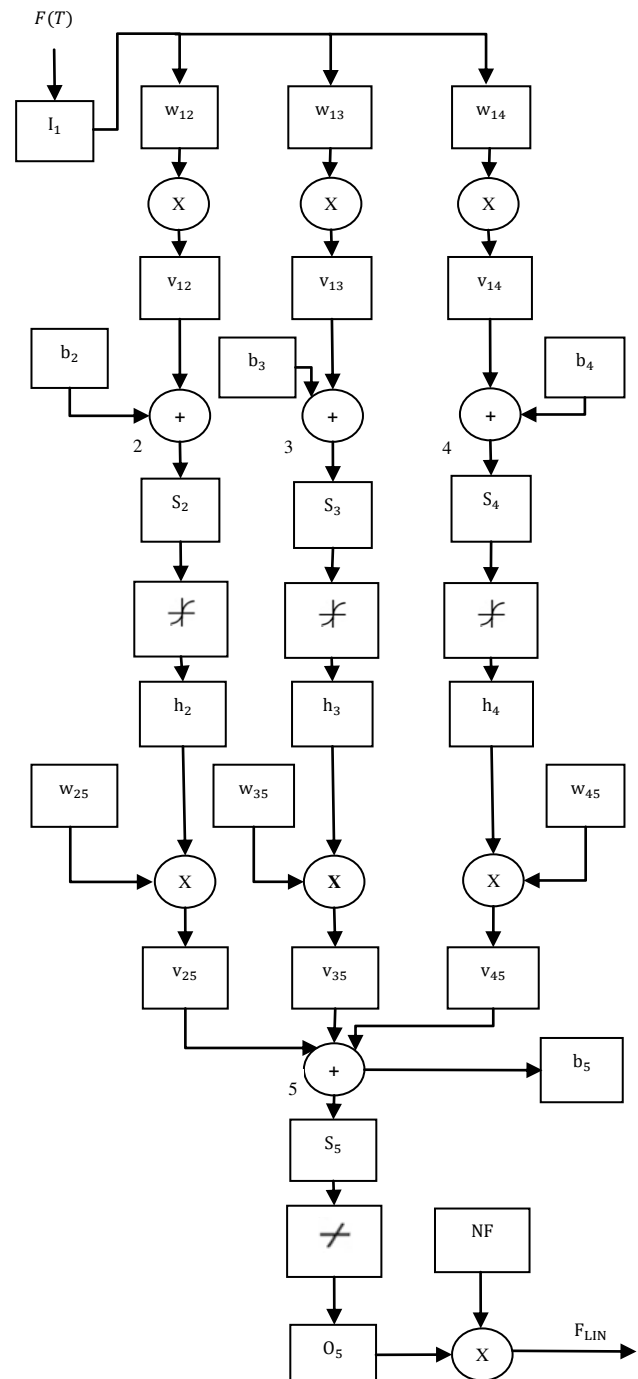
**Figure-2.** Schematic diagram representation.

## 2.2 Design

In the proposed design, a disc type permanent magnet with a thickness of 4mm and an inner diameter of 6mm, outer diameter of 16mm and weight of 3g has been used. The Hall sensor with a size of 4mm×3.5 mm, power consumption of 8mA at 5 V dc and a sensitivity of  $(4 \pm 0.25)$  mV/Gauss is used as a secondary transducer in the proposed pressure transmitter. The bellows made up of rubber is used as primary transducer in the transmitter. The bellows is placed in a chamber and pressure is applied at one end of the chamber. Hall probe sensor and the magnet are positioned at the middle of the bellows sensor. The output of the Hall sensor is in the order of mV. An instrumentation amplifier is used to amplify the sensor output voltage in the range of 1-5 V. The resultant voltage is applied to the ANN linearizer. The GSM module has been used to transmit the linearized ANN output voltage to the remote location.

## 2.3 ANN-based linearization technique

A simple MLP neural network is proposed in the ANN-based linearization technique. The network employs three neurons in the hidden layer and one neuron each in the input and output layers. The log sigmoid and linear activation functions are used in the hidden and output layers respectively. The network is trained by the LM-algorithm. The LM-algorithm is the most efficient algorithm for training the small and medium sized problems, as it has a faster convergence time and lowest mean square error. An implementation scheme of the ANN for linearization of pressure-voltage characteristic Hall sensor based pressure transducer is proposed and details of PIM are shown in Figure-3.



**Figure-3.** Schematic of the plug-in module.

The PIM embeds the intelligence of ANN by performing necessary operations on the frozen weights and biases through the registers, multipliers and adders. The registers of the PIM store the weights and the biases, weighted inputs, intermediate sum, activation functions and final output of the ANN. In the PIM,  $W_{12}, W_{13}, W_{14}, W_{25}, W_{35}$  and  $W_{45}$  represent the weights to various layers. The biases are represented as  $b_2, b_3, b_4$  and  $b_5$ . The weighted inputs are denoted as  $V_{12}, V_{13}, V_{14}, V_{25}, V_{35}$  and  $V_{45}$ . The weighted sums of the neurons are represented as  $S_2, S_3, S_4$  and  $S_5$ . The hidden layer



outputs are represented as  $O_2, O_3$  and  $O_4$  whereas  $O_5$  represents the output of the final layer. Also NF denotes normalisation factor to be multiplied with the output of the ANN to get the physical linearized voltage VPIM.

## 2.4 Error analysis

In the proposed method, errors may be introduced due to the alignment of hall probe with respect to the bellows position and also due to the effect of temperature. These can be minimized by providing proper ambient conditions. The error in the pressure measurement is calculated using

$$\% \text{ of deviation} = \frac{\text{Truevalue} - \text{Measuredvalue}}{\text{Truevalue}} \times 100$$

ANN output voltage is calculated using

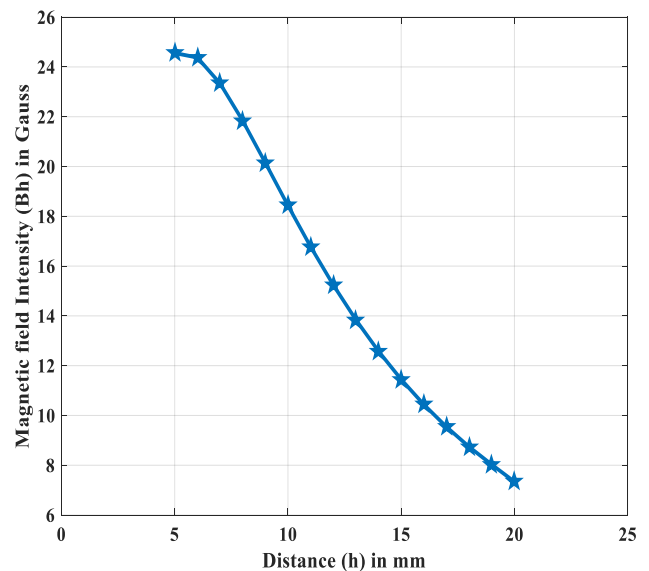
$$V_{NN} = W_4 \times \text{Tansig}(W_1 \times X_1 + B_1) + W_5 \times \text{Tansig}(W_2 \times X_1 + B_2) + W_6 \times \text{Tansig}(W_3 \times X_1 + B_3) + B_4$$

Where  $X_1 = \frac{X - 49.942}{-26.861}$ ,  $W_1, W_2, W_3, W_4, W_5$  and  $W_6$  are the weights and  $B_1, B_2, B_3, B_4$  are the biases of the MLP network.  $X$  is the hall input voltage.

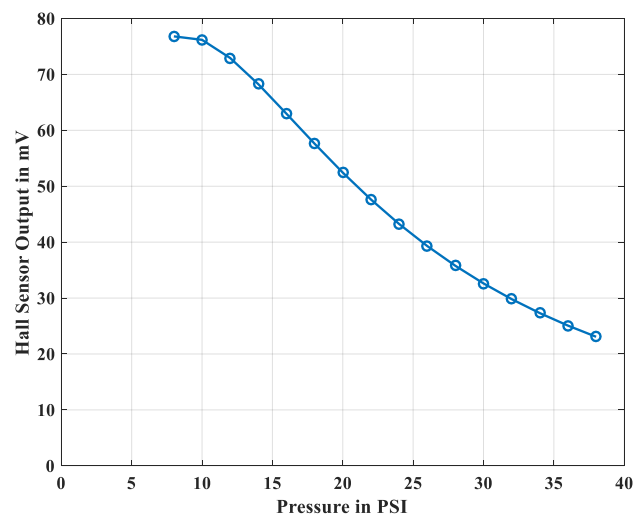
## 3. EXPERIMENTAL RESULT

The experimental setup of the proposed transmitter is shown in Fig.2. The experiment is carried out using bellows, Hall probe sensor and the signal conditioner circuit. A pressure tank fitted with a standard gauge to measure gauge pressure is used to supply for the bellow. The pressure to the bellow is varied in steps of 5 psi in the range of 0-40 psi. The displacement of the bellow with magnet near to the Hall sensor produces a voltage due to the change in magnetic field intensity. The field intensity is measured by using digital gauss meter corresponding to the displacement of range 5-20 mm. The magnetic flux density in Gauss and distance in mm is shown in the Figure-4.

The Hall sensor output voltage is measured by a 4 and 1/2 digit Multimeter. The relationship between Hall voltage and applied pressure is obtained and is plotted in Figure-5. Plotting the graph between pressure (psi) and Hall voltage (mV) is used to describe the static characteristic of Hall probe sensor.



**Figure-4.** Characteristic of hall probe used in proposed transducer.



**Figure-5.** Proposed hall probe based pressure transducer characteristic.

The Hall sensor shows nonlinear characteristics because distance and magnetic field due to magnet is nonlinear.

The Hall sensor terminals are connected to the instrumentation amplifier. The amplifier output is applied to the ANN implementation circuit based on ATmega328 microcontrol unit. The experimental data shown in the Figure-6 is almost linear and repeatable. The percentage deviation from linearity of the data is calculated from best fit linear curves. The standard deviation curve is shown in the Figure-7. The ANN training parameters and the simulation results are given in Table-1. The error analysis for the pressure transmitter is plotted in Figure-8.

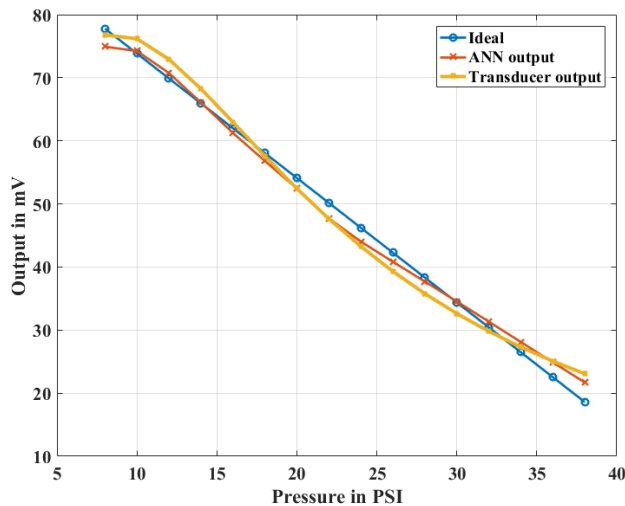


Figure-6. Characteristic of proposed pressure transducer.

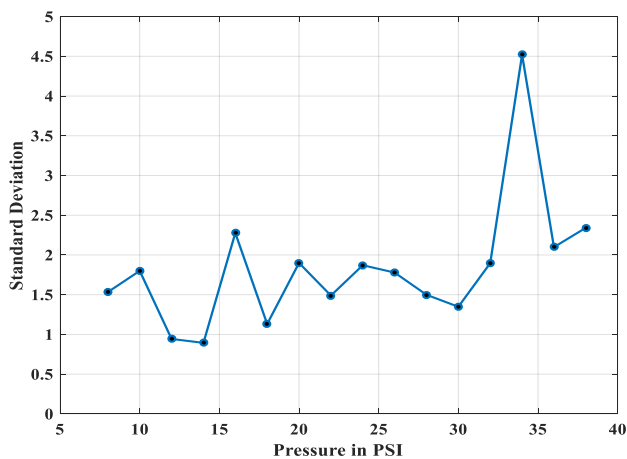


Figure-7. Standard deviation characteristics.

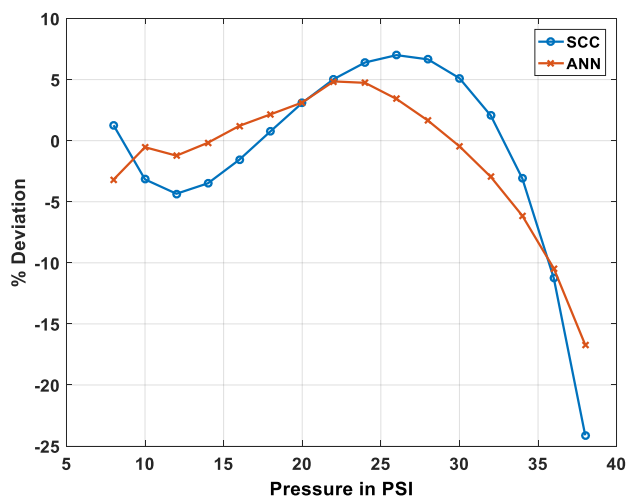


Figure-8. Error analysis of the techniques.

Table-1. ANN training parameters and simulation results.

Type of sensor	Hall probe and bellows
Neural network	Multilayer feed-forward neural network
Number of neurons	Input neurons-1, Hidden neurons-3, Output neurons-1
Activation functions	Log sigmoid for hidden layer, Linear activation function for output layer
Training algorithm	Levenberg-Marquardt
Epochs	10
weights	$W_1=1.0607$ , $W_2=6.4666$ $W_3=0.7218$ , $W_4=2.4743$ $W_5=0.0371$ , $W_6=1.3864$
Biases	$b_2=-1.9437$ , $b_3=0.0226$ , $b_4=1.0210$ , $b_5=1.3121$



Figure-9. Photograph of experimental setup.

#### 4. DISCUSSION AND CONCLUSIONS

An intelligent pressure measuring technique with bellow, Hall probe sensor and ATmega328 microcontroller unit, is presented in this paper. The proposed technique compensates the effect of nonlinearity present in the hall probe based pressure transducer characteristic. The technique proposed uses simple and low-cost components such as operational amplifiers and ATmega328 units. The performance characteristics of the proposed transmitter are shown in Figures 5-7. These characteristics indicate good repeatability and linearity since the maximum value of standard deviation is less from the characteristic graphs and percentage change in deviation from linearity lies within a tolerable limit for industrial applications.

The proposed transmitter is beneficial compared to the conventional elastic element-type pressure transducer since it makes use of a noncontact technique and is free from mechanical linkage error of the elastic element-type pressure transducer. The piezo resistance or strain gauge types of transducers have very complex





design, which requires some dummy elements to avoid the measurement error due to change in atmospheric temperature. Whereas, the proposed transmitter requires only simple mounting of a tiny circular magnet on the bellows tip by a suitable adhesives and with a same adhesive Hall sensor is mounted outside the bellows box vertically above the magnet. Hence, the proposed transducer less expensive than the conventional pressure transducers. The proposed transmitter is designed and tested over the pressure range of 0-40 psi in which the

transducer characteristic is linear. The special spring-loaded bellows element can be used to increase the range of the transducer. It is observed from Figure-5 that the proposed transducer has exhibited considerably high sensitivity of about 1.8694 mV/psi. The sensitivity of the transducer may be increased by selecting suitable Hall sensor and bellows element in the given pressure range as sensitivity depends on the sensitivity of the bellows element and Hall sensor.

**Table-2.** Comparison study of various pressure measuring techniques.

Method	Complexity	output	Maximum error	Range	Remarks
Pressure transmitter using an improved inductance bridge network and Bourdon tube as transducer[11]	Medium	Analog	$\pm 0.6$	0-45 psig	A Bourdon tube used as mechanical type pressure sensor and inductance bridge type has been developed to convert the Bourdon tube movement into electrical current signal which can be transmitted to remote location.
Reluctance type pressure transmitter[12]	Simple	Analog	.....	0-60 psig	Low cost reluctance pickup type transmitter with the displacement of the Bourdon tube is directly proportional to the applied pressure.
Reluctance type pressure transducer [13]	Medium	Analog	$\pm 0.5$	0-60 psig	Reluctance type pressure measurement technique by change of the pressure causes the displacement of the ferromagnetic core attached with the Bourdon tube.
Micro fabricated pressure sensor based on Hall effect [15]	simple	Digital	.....	0-1200 hpa	Offset voltage exists without application of a magnetic field and it changes with pressure.
Proposed method	Simple	Analog	$\pm 0.5$	0-40 psig	Design of intelligent pressure transmitter with bellows as primary sensing element and AT mega 328 microcontroller unit for improving the linearity and wireless transmission.

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