IMPLEMENTATION OF A LOW POWER SENSOR USING THE 1N4148 SIGNAL DIODE

F.E. IDACHABA AND V.E. EKONG

Department of Electrical and Information Engineering Covenant University Ota

+Department of Computer and Information Engineering Covenant University Ota

{ idachabafe@yahoo.com, victor_eshiet_ekong@yahoo.co.uk}

ABSTRACT

Wireless sensor networks are designed to be added to an existing infrastructure and to function remotely of it. They are characterized by limited radio and sensing range, the nodes are installed at a sufficient density to make it probable both that multidrop communication will be possible between any pair of nodes and that a significant phenomenon of the environment can be sensed. The networks have sensors for temperature, sound and light and they run on batteries and as such low power sensors are often desired for sensor networks. We propose a low temperature and low power wireless temperature sensor using 1N4148 signal diode that can ensure long term usage of at a significant power consumption and low cost.

Keywords: Wireless sensor network, transducers, diode

1.0 INTRODUCTION

A Wireless sensor network (WSN) consists of a number of small, low cost devices or nodes, each with facilities for sensing, computing and wireless communication ([1]. It is a special case of ad hoc networks where the nodes are physically arranged more or less randomly, but they can communicate over multiple wireless hops between their peers.

Wireless sensor network are designed to be added to an existing natural or built environment, and to function independently of it, without reliance on infrastructure. They provide distributed network and internet access to sensors, controls and processors that are embedded in equipment, facilities and the environment. These systems can provide monitoring and control capabilities for applications in transportation, manufacturing, environmental monitoring, safety and security. It combines micro sensor technology, low power and low cost wireless networking in a compact system. The lossless sensor networks led to the concept of smart environment. The smart environment relies on sensory data from the real world. Sensory data is collected from multiple sensors of different modulators in distributed locations [2].

2.0 WIRELESS SENSOR NETWORKS

Wireless sensors utilize small low cost embedded device and they do not need to communicate directly with the nearest base station. Peer to peer networking protocols are used to provide a mesh like inter connect that shuttle data between the embedded devices in a multi hop fashion. Figure 1 and 2 show the composition of wireless sensor networks.

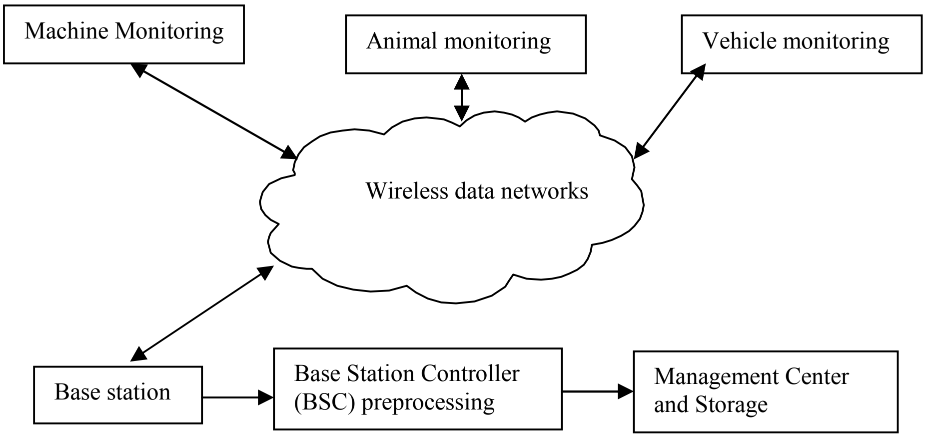


Figure 1: Data acquisition network

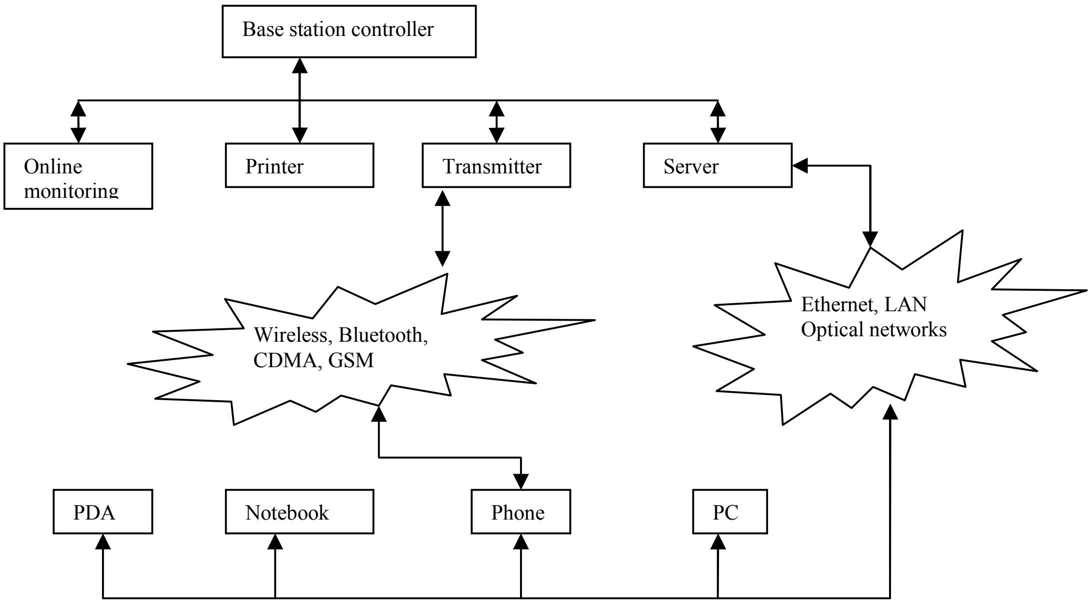


Figure 2: Data Distribution Network

The communication networks used with sensors is composed of nodes each with a computing power and transceiver capability over wired or wireless links.

Desirable functions for sensors include; ease of installation, self identification, self diagnosis, reliability. The IEEE approved in 1997 a smart sensor network standard known as IEEE 1451 to cope with compatibility of devices [3]

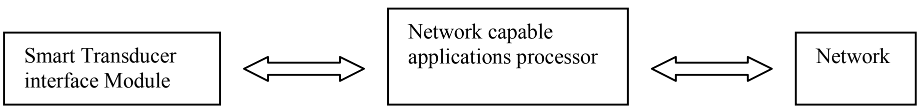


Figure 3: IEEE 1451 standard for smart sensors

This standard utilizes the principles of smart sensing. A smart sensor is a sensor which provides extra functions like signal controlling, processing and decision making/alarm functions. A general model of a smart sensor is shown in figure 4.

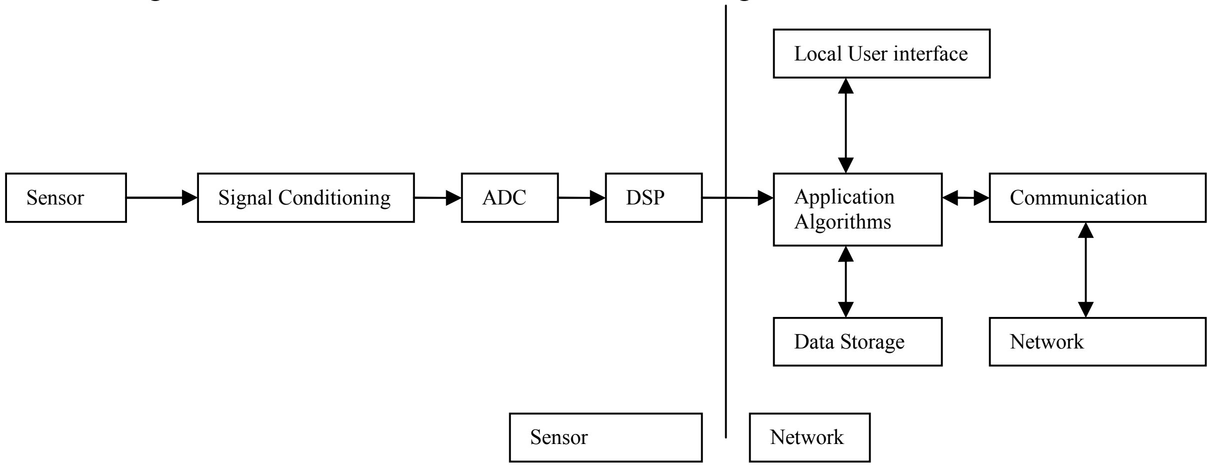


Figure 4 General model of a Smart sensor

We propose a model using an IEEE 4148 signal diode and transducers to design a low power wireless sensor network. A transducer is a device that converts energy from one form to another. The node (sensor) scattered on the environment, establishes a routing path and transmits data back in a collection point. If one node fails, a new topology will be selected and the overall network would continue to deliver data [4].

3.0 THE DESIGN ISSUES

Transmission Range

The wireless network will utilize omni-directional antennas as these antennas will allow nodes communicate effectively in all direction. Typical receivers are 85dBm and -110dBm. The transmission range for these device increases as the sensitivity and transmission power increases.

Topologies

There are three classic network topologies for sensors;

1. Point –to-point
2. Multi-drop and
3. Web network.

Point to point is the most reliable because there is only one point of topology and that is the host. (see figure 5). Each sensor node requires a separate twisted shielded pair connection. The cost of implementation is high and configuration management is difficult and almost all the information processing is done by the host [5].

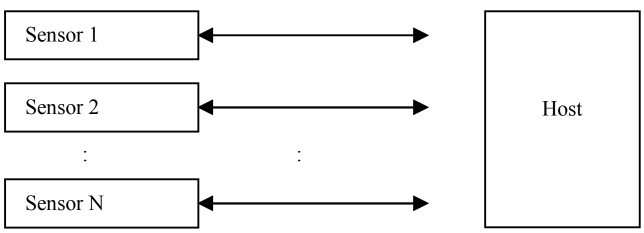


Figure 5: Point to point sensor network topology

In Multi-drop networks each sensor puts its information onto a common medium. Its use of a common medium introduced a potential single point of failure. Redundant connections are introduced to take care of this problem. The development of the Ethernet, Carrier Sense Multiple Access Schemes (CSMA) has enhanced the advancement of the multi-drop network.

The web network utilizes a small star network. The advantage of web connectivity for sensor network becomes clear as the level of intelligence in each sensor increases. Cooperating Sensors can form a temporary configuration to replace the host. Self- hosting network become self-configuring and then self aware. In a wireless web network, individual nodes have the potential of being connected (physically) with other nodes on the network. The configuration of the network is determined by the software running it. Routing is a major concern in web circulations. Repeaters are introduced in the network since all nodes cannot reach each other in a single hop [6], [7].

The Sensor

We use 1N4148 as a temperature sensor for the wireless network. The block diagram of this sensor is shown in Figure 6.

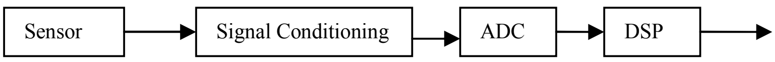


Figure 6: Block Diagram of the sensor

The IN4148 is considered for the wireless sensor application for a temperature ranges of 25^{o}C to 100^{o}C. The diode has the following advantages: -

1. Low cost
2. It is readily available
3. Rugged
4. Allows for simplicity of design

The diode current I_D is given as:

$$I_D = I_S(e^{\left(\frac{V_D}{nV_T}\right)} - 1) \qquad (1)$$

Where, I_s is the saturation current in the range of 10^{-15} to 10^{-13}A, V_T is the thermal voltage of approximately 0.026V and n is the ideality factor and ranges between 1 and 2.

When a constant current of about 1mA is passed through the diode, a forward voltage of approximately 600mV is developed in the junction. The precise value of the junction exhibits a negative coefficient of temperature of approximately -2mV/ ^{o}C.

The Sensor circuit [9]

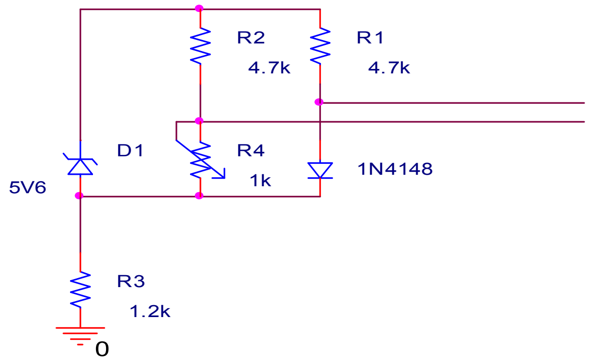


Figure 7: The sensor circuit

The current through the sensor diode (IN 4148) is given by

$$V = iR \tag{2}$$

Where V = Zener voltage 5.6V

$$i = \frac{5.6}{4.7k} = 1.19mA$$

The Zener diode is used to maintain a fixed and stabilized voltage across the ¼ bridge containing the sensor. The Zener diode ensures the development of a temperature dependent voltage across the diode.

Difference Amplifier

The sensor's output is amplified using an operational amplifier LM 741 configured as a differential amplifier. This circuit amplifies the difference between two input signals and rejects any signal common to both inputs.

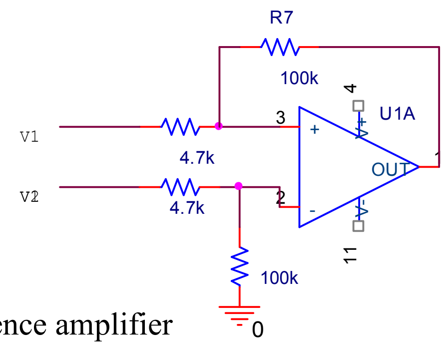


Figure 8: Difference amplifier

Applying the superposition theorem and the virtual earth concept;

R1 = R3 = 4.7k, R2 = R4= 100k

$$V_{01} = \frac{-R_2}{R_1} V_1 \tag{3}$$

$$V_{02} = \left[1 + \frac{R_2}{R_1}\right]\left[\frac{R_4/R_3}{1 + R_4/R_3}\right] V_2 - \left[\frac{R_2}{R_1}\right] V_1 \tag{4}$$

An important property of the differential amplifier is that its output voltage is zero when both inputs are the same (common mode rejection).

This forms the equation above, with $V_1 = -V_2$

$$\frac{R_4}{R_3} = \frac{R_2}{R_1} \tag{5}$$

$$V_0 = \frac{R_2}{R_1}(V_2 - V_1) \tag{6}$$

The differential gain is then given as:

$$\frac{R_2}{R_1} = Ad \tag{7}$$

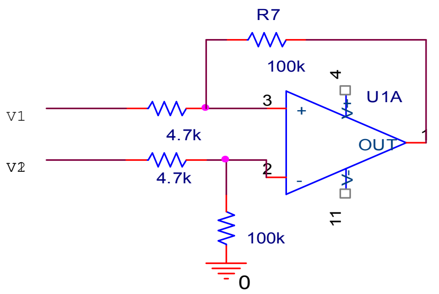
The common mode gain is defined by A (cm) = $\frac{V_o}{V_{cm}}$

The common mode rejection ratio is used as a quality factor for differential amplifier. Good differential amplifiers have a CMRR in the range of 80dB to 100dB.

$$CMRR = \frac{Ad}{A_{CM}} \tag{8}$$

$$CMRR(dB) = 20\log\frac{Ad}{A_{CM}} \tag{9}$$

The differential amplifier circuit is shown below;



$$Ad = \frac{100k}{4.7k} = 21 \tag{10}$$

The sensor circuit combines with the differential amplifier circuit to yield the transducer circuit as shown in figure 9.

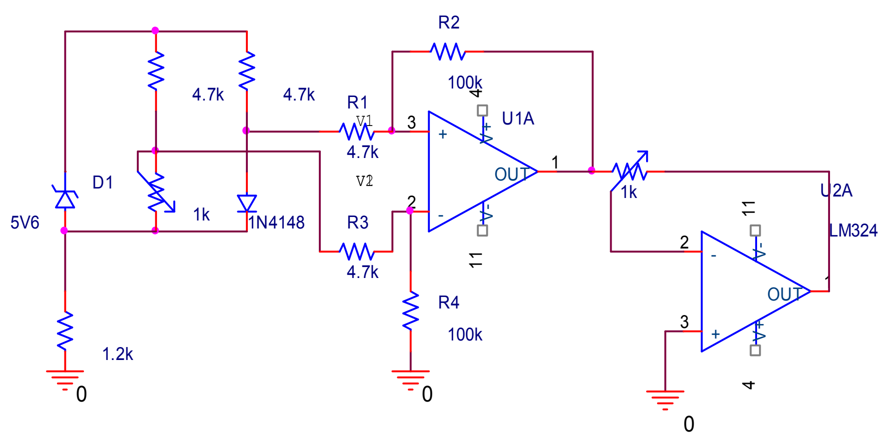


Figure 9: Transducer circuit

From equation (4);

$$V_0 = \left[1+\frac{R_2}{R_1}\right]\left[\frac{R_4/R_3}{1+R_4/R_3}\right]V_2 - \left[\frac{R_2}{R_1}\right]V_1 \quad (11)$$

$$With\frac{R_4}{R_3} = \frac{R_2}{R_1} = \frac{100k}{4.7k} = 21$$

$$V_0 = (1+21)(\frac{21}{1+21})V_2 - 21V_1$$

$$= 22(0.95)V_2 - 21V_1 = 21V_2 - 21V_2$$

$$= 21(V_2) - 21(V_1) = (V_2 - V_1)(21-21).$$

$$V_0 = 0$$

Differential input voltage is given by;

$$Vd = V_2 - V_1 \quad (12)$$

$$V_{CM} = \frac{V_1 + V_2}{2} \quad (13)$$

$$V_1 = V_{CM} - \frac{Vd}{2} \quad (14)$$

$$V_2 = V_{CM} + \frac{Vd}{2} \quad (15)$$

Substituting equation (14) and (15) into (11);

$$V_0 = 21(V_{CM} + Vd/2) - 21(V_{CM} + Vd/2) \quad (16)$$

$$V_0 = 21(Vd) + 0V_{CM}$$

This output voltage is given to be of the form

$$V_0 = AdVd + A_{CM}V_{CM} \quad (17)$$

From equation (16) and (17)

$A_d = 21$ and $A_{cm} = 0$

From the above it is observed that the CMRR is very high.

4.0 EXPERIMENTAL TEST-BED

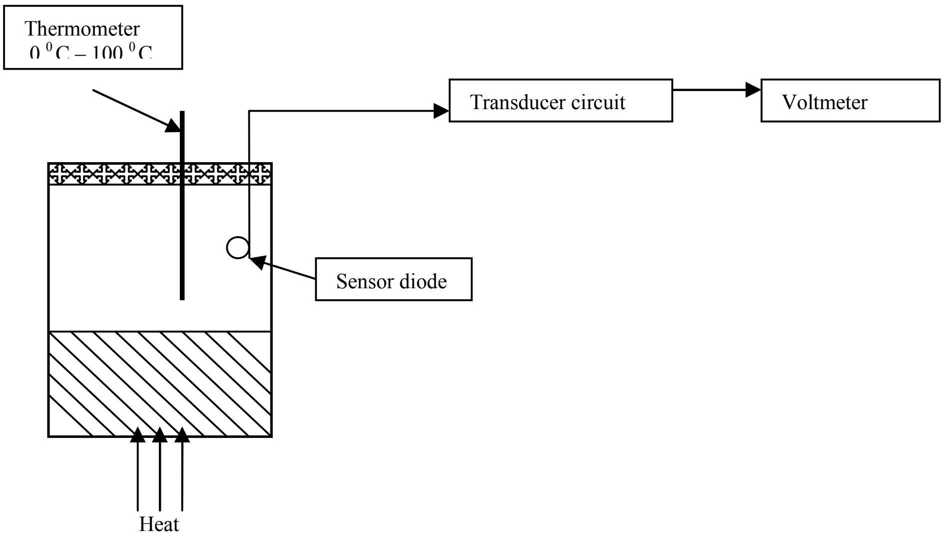


Figure 10: Experimental test set up [8].

The proposed set-up above is used to determine the temperature characteristics of the sensor. The water in the container was heated from room temp.(27°C) to boiling point (100°C) with a transducer voltage reading taken for every 5°C rise in temperature. The water is allowed to cool down and the cycle repeated. Ten different readings were taken and the average of the readings is presented in the table below.

Table 1 Temperature reading of the sensor diode

Temperature(°C)	Transducer output voltage(V)
27	3.96
30	3.92
35	3.83
40	3.69
45	3.55
50	3.40
55	3.24
60	3.05
65	2.86
70	2.67

75	2.47
80	2.27
85	2.05
90	1.76
95	1.49
100	1.33

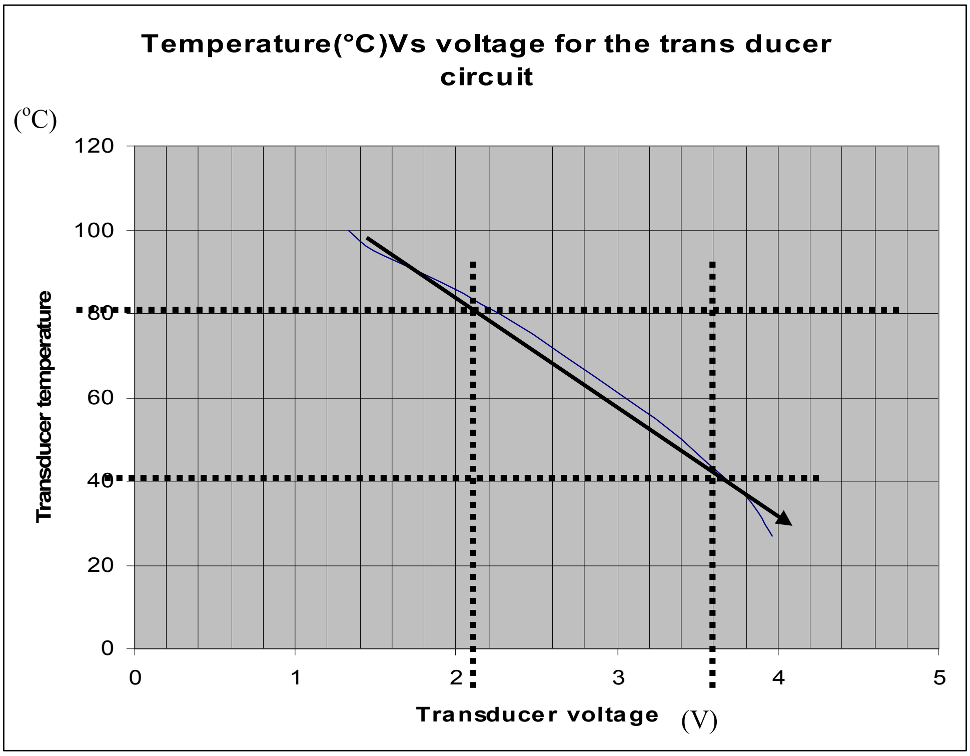


Figure 11: Graph of results for temperature and voltage readings taken

The slope of the transducer circuit is given to be:

$$\text{Slope} = \frac{2.67 - 2.27}{70 - 80} = \frac{0.4}{-10} = -0.04\ \text{V}/^{0}\text{C} = -40\text{mV}/^{0}\text{C}$$

The readings show the negative temperature coefficient of the diode sensor and the influence of the differential amplifier. An inverter circuit can be added to give the transducer output a positive temperature coefficient and bring the voltage readings to a range suitable for ADC chips. The resultant transducer circuit and the readings are shown below:

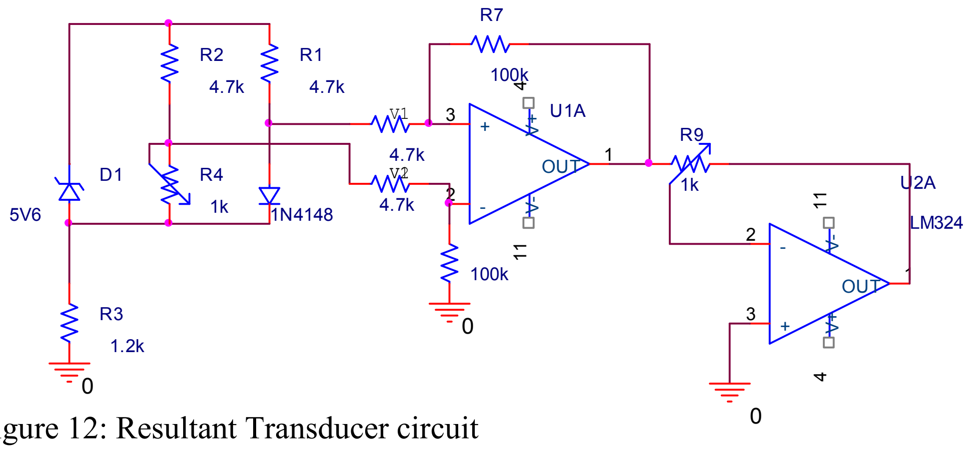


Figure 12: Resultant Transducer circuit

Table 2: Resultant system output results

Temperature °C	**Transducer output**	**Inverter output voltage**
27	3.96	1.31
30	3.92	1.32
35	3.83	1.33
40	3.69	1.35
45	3.55	1.39
50	3.40	1.43
55	3.24	1.48
60	3.05	1.53
65	2.86	1.59
70	2.67	1.64
75	2.47	1.70
80	2.27	1.76
85	2.05	1.82
90	1.76	1.90
95	1.49	1.99
100	1.33	2.04

5.0 CONCLUSION

From our design and the test bed readings obtained, it is observed that the silicon diode can be used a as sensor within the range of 27°C to 100°C conveniently. The overall sensitivity and temperature coefficient can be altered by the use of a suitable circuit. The resultant circuit can be realized using minimal discrete component or completely fabricated in integrated circuit (IC) chips. The final sensitivity of the overall circuit using the readings taken from the inverter output shows the sensitivity as given below.

$$\text{Sensitivity} = \frac{1.53 - 1.43}{60 - 50} = 0.01 = 10\text{mV}/^{o}\text{C}$$

This shows an increase from the -2mV/^{o}C of the diode and a conversion of the temperature coefficient from negative to positive which simplifies further signal processing.

REFERENCES

[1] George C., Jean D. and Tim, D (2005) *Distributed systems: Concepts and design*, 4th ed., Addison Wesley, England.

[2] Lewis, F. L. (2004) *Wireless Sensor Networks: Smart Environments Technologies, Protocol and Application*. D. J. Cook and S. K. Das (*Ed*) John Wiley New York.

[3]. Culler, D., Estrin D. and Srivastava M. (2004) Overview of sensor network, *IEEE Computer*, Vol. 37, no. 8, August, pp. 41-49.

[4] Romer, K. Oliver K., and Friedmann M. (2003) Middleware challenges for wireless sensor networks, *Mobile Computing and Communications Review*, Vol. 6 No. 2.

[5] Hill, J. L (2003) System Architecture for Wireless Sensor Networks, Ph.D Thesis University of California, Berkeley Spring.

[6] Ekong, V. E (2002) Wireless communication network design issues, M.Sc Thesis, University of Benin, Benin city, Nigeria.

[7] Culler, D., Hill, J., Buonadonna, P. *et al* (2001) A network-centric approach to embedded software for tiny devices, *Proc. of the first International workshop on embedded software*, Tahoe city, CA USA, pp. 114- 130.

[8] Idachaba, F. E (2002) Design of a microcontroller based process monitoring and control unit using the 8751 microcontroller, M.Eng Thesis University of Benin, Benin City, Nigeria.

[9] Donald A. Neaman (1996) Electronic circuit analysis and design, McGraw-Hill, USA.