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Design and Development of Semi Cylindrical Capacitive Type Humidity Sensor

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Abstract- An air capacitor changes its capacitance with the variation of moisture in air and can be used as a humidity sensor by measuring capacitance change. Differing from the structure of parallel plate capacitive sensor, a semi cylindrical capacitive sensor with open air as dielectric has been introduced in this present work to measure the humidity content within the air. In this work the semi cylindrical capacitive sensor consists of two thin semi cylindrical copper sheets separated by a gap distance and mounted around a PVC pipe containing air with moisture. As the humidity in the air changes, amount of moisture in the air changes and hence the capacitance of the semi cylindrical capacitor also changes. The changes of capacitance with the variation of moisture in air have been measured by using an LCR impedance meter. The variation of capacitance has been obtained in the nano farad (nF) range. The measured capacitance has been converted into voltage variation by using proper signal conditioning circuit. The characteristic curve obtained shows that the humidity and capacitance change has linear relation. The experimental results show that it has a fast response time, high reliability and high repeatability.

Keywords- Semi cylindrical capacitive sensor, copper sheets, Humidity, Open air as dielectric, Signal conditioning circuit.

I. INTRODUCTION

Humidity affects weather and climate as well as global climate change. It also affects indoor environments, so understanding of it can help to determine the best place to store books, clothing and other important items in house. It changes the electric characteristics of materials. So humidity measurement is one of the important tasks in many industrial processes [1] for manufacturing of products such as textiles, food, paper, semiconductors, medical equipment, and petrochemical.

Relative Humidity is the most commonly used measure of humidity. Usually it is expressed as a percentage, with the symbol "%RH (Relative Humidity)". At a specified temperature, there is a maximum amount of water that air can carry. Relative humidity is the percentage of the amount of water that the air can hold at a given temperature.

Relative humidity in percent:

$$\%RH = \frac{P_a}{P_s} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

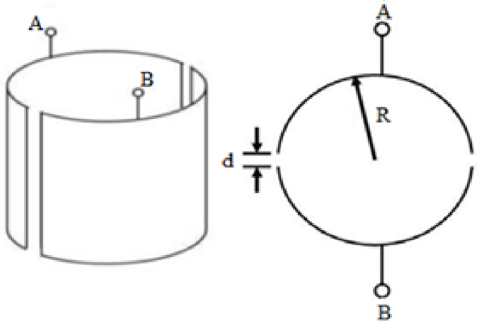
Where P_a is the actual vapour pressure of water, and P_s is the saturation vapour pressure of water. At 100%RH, the actual pressure of the water vapour is equal to the saturation pressure. The temperature where that condition exists is called the dew point [2], so dew point is a temperature at which condensation (dew) would occur if a gas were cooled.

Humidity is difficult to measure accurately. Most measurement devices absorb some moisture. There are various devices used to measure and regulate humidity. Modern electronic devices use temperature [3] of condensation, change in electric resistance, and changes in electric capacitance [4] to measure humidity changes. A Psychrometric sensor does not directly sense humidity, but rather it sense temperature indirectly to find relative humidity. The sensing elements can be thermometers, RTD's, or some other type of temperature sensor. The first sensing element, the dry bulb measures ambient temperature. The second sensing element, the wet bulb has been enclosed in a wick saturated with distilled water. Air forced across the wet bulb creates evaporation, which cools it below ambient temperature. At temperatures above the freezing point of water, evaporation of water from the wick lowers the temperature, so that the wet bulb thermometer usually shows a lower temperature than that of the dry bulb thermometer. There after many techniques are developed to measure or sense humidity and relative humidity. Smart humidity [5] sensor and monitoring of intelligent humidity [6] measurement systems have been discussed. In recent years many types of capacitive humidity sensors [7], [8] have been developed. Most recent type is air capacitor [9] with open air as dielectric where two parallel plates have been used for capacitor plates. On that air capacitor theoretical and experimental values have been compared and the dielectric constant of air at different moisture in air has been calculated. Since a capacitive sensor has very weak output signal so a proper signal conditioning is required to convert the signal into voltage signal. Various Signal conditioning circuits have been proposed to convert capacitance to voltage [10].

Differing from the structure of parallel plate capacitive sensor, a semi cylindrical capacitive [11], [12], [13] humidity sensor with open air as dielectric has been developed in the present work. According to the variation of moisture in air at room the capacitance will be changed. And from that change of value of capacitance the humidity will be measured or sensed. As the sensor has semi cylindrical structure so it is possible to pass all moisture air throughout the plate region to get better sensor capacitance variation during the change of moisture in air. Also it has been tried to show how semi cylindrical capacitive sensor capacitance is varied in accordance with the humidity. The sensor capacitance is converted into corresponding voltage signal using proper signal conditioning circuit.

II. Capacitive Sensing Technique for Semi Cylindrical Capacitive Sensor

Semi-cylindrical capacitive sensor consists of two metal semi-cylindrical plates separated by a minimum gap distance. The two metal semi cylinders have the radius *R* and a minimum gap distance *d*. In the present paper no di-electric has been used. Fig. 1(a) shows the architecture of the semi cylindrical capacitive sensor where two metal sheets is bended to form a semi cylinder and Fig. 1(b) shows the top view of the semi-cylindrical capacitive sensor.



(a) (b)

Fig. 1. (a) Architecture of semi-cylindrical capacitive sensor. (b) Top view of semi-cylindrical capacitive sensor.

Minimum gap distance of two plates is *d* and after that it is incremented by a Δd distance. The numerical analysis method is applied to approximate the capacitance of the semi-cylindrical capacitive sensor. Fig. 2(a) shows the structure of the semi cylindrical capacitive sensor for numerical analysis method. The capacitance between two semi cylindrical metallic plates can be modified as each pairs of two unit metal plates with an increment Δd distance shown in Fig. 2(b).

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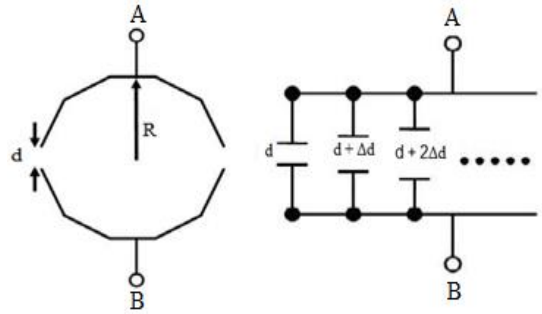

(a) (b)

Fig. 2. (a) Approximate structure of the semi-cylindrical capacitive sensor without dielectric for numerical analysis method. (b) Equivalent capacitors between A and B terminals of semi cylindrical plates.

So the capacitance of two metal semi cylinders without dielectric can be expressed as:

$$C_0 = 2\varepsilon_0\varepsilon_1 A \times [\frac{1}{d} + \frac{1}{d+\Delta d} + \frac{1}{d+2\Delta d} + ...+ \frac{1}{d+(n-1)d}] + \frac{\varepsilon_0\varepsilon_1 A}{2R}$$

$$= \sum_{i=1}^{n} 2\varepsilon_0\varepsilon_1 A \times [\frac{1}{d+(i-1)\Delta d}] + \frac{\varepsilon_0\varepsilon_1 A}{2R} \quad ....(2)$$

Where ε_0 is the permittivity of free space of magnitude 8.854 (pF/m), ε_1 is the dielectric constant of air, *n* the cutting number for numerical analysis, *A* is the unit area of metal semi-cylinders, and *R* is the radius of the semi cylinder. Equation 2 gives the general equation of capacitance of a semi cylindrical capacitor. So if ε_1, the dielectric constant of air within the cylinder varies, capacitance between the semi cylindrical plates will also vary because of the variation of moisture content in air. Thus humidity measurement in terms of the capacitance of the semi cylindrical plates can be possible.

III. Design of the Semi Cylindrical Capacitive Sensor

The semi cylindrical capacitive sensor has been designed and constructed from two Copper sheets each of thickness 0.5 mm, length 300 mm and width 164 mm. Each plate has been bent to form a semi cylindrical shape. These two semi cylindrical sheets have been mounted inside a PVC pipe using adhesives so that there has no air gap between the capacitor plates and the inside wall of the tank. Fig. 3 shows the Isometric view of constructed sensor with different parameters. Two semi cylindrical plates are separated by a gap distance of 1.0 mm. The inner diameter of the PVC tank is 105 mm.

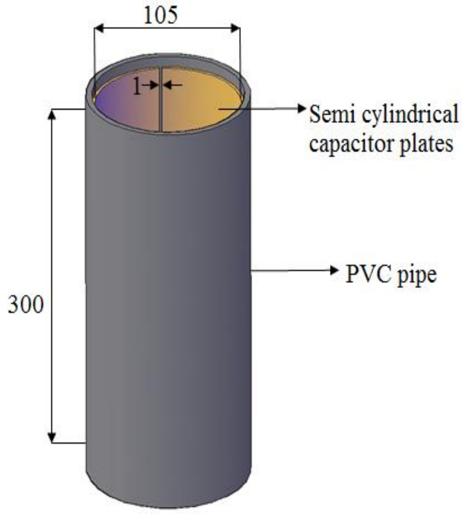

Fig. 3. Isometric view of semi cylindrical capacitive humidity sensor (All dimensions are in mm).

IV. Signal Conditioning Circuit for Semi Cylindrical Capacitive Sensor

The variation of capacitance due to change in moisture content in air has been converted into voltage variation with the help of a series RLC resonating circuit as shown in Fig. 4. At resonant condition the output voltage has been taken out from the resistive end of RLC series circuit. The sensor capacitor signal has been connected in parallel tothe fixed capacitor of RLC series resonating circuit. With the change of the sensor capacitance the output voltage has been changed.

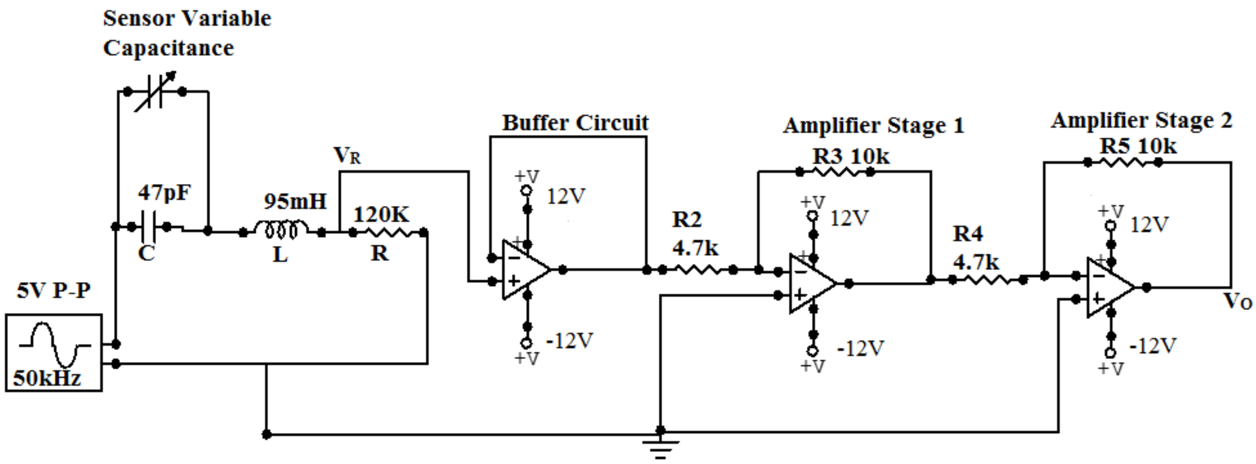

Fig. 4. Signal conditioning circuit for semi cylindrical capacitive sensor.

At resonance of RLC series circuit, the inductive reactance becomes equal to capacitive reactancei.e, $X_L = X_C$, and overall impedance, Z = R. So at series resonance the impedance of the series RLC circuit is minimum and voltage drop across resistance is maximum. The output signal voltage obtained from resistive terminal of RLC series resonating circuit is very low so it has been amplified by the amplifier circuit. Amplification has been done in two stages with minimum gain to reduce noise voltage amplification.

V. Experimental Result

After designing the semi cylindrical capacitive humidity sensor and corresponding signal conditioning circuit, the experiment has been done several times. From the experiment humidity and corresponding sensor capacitance has been taken. In this work humidity has been measured by taking a standard humidity sensor. Finally MATLAB software is performed to calculate theoretically the capacitance between the two semi cylindrical plates taking 1 atmospheric pressure dielectric constant, ε_1 of air using equation 1 and the calculated value of capacitance is also in the nano farad range i.e. same order as that of the experimental value.With the data of humidity in %RH and corresponding capacitance in nano farad, the graph has been plotted and shown in Fig. 5.

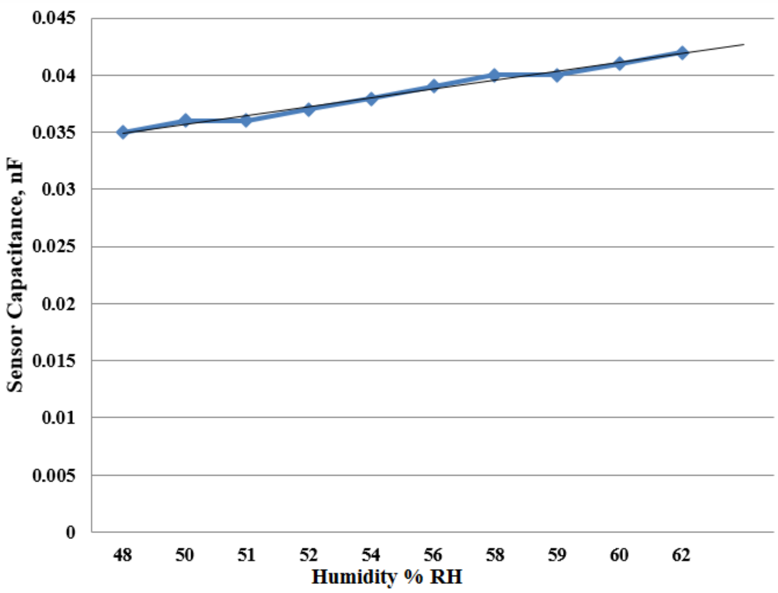

Fig. 5. Humidity Vs Capacitance Graph

From the graph of humidity Vs capacitance it has been shown clear that the graph is almost linear with some error. For error calculation a trend line has been drawn with linear equation on the graph of humidity and respective capacitance. Generated trend line equation is:

$$y = 0.0005x + 0.0109 \quad \ldots\ldots(3)$$

.
Where x has been defined as the variable of humidity and y has been defined as the variable of sensor capacitance. From that equation 3 true value and % of error has been calculated. And error graph has been drawn and shown in Fig. 6. From that error graph it has been clear that error occurs minimum in that sensor. And the error varies from -0.30% to +1.2% which is within tolerable limit.

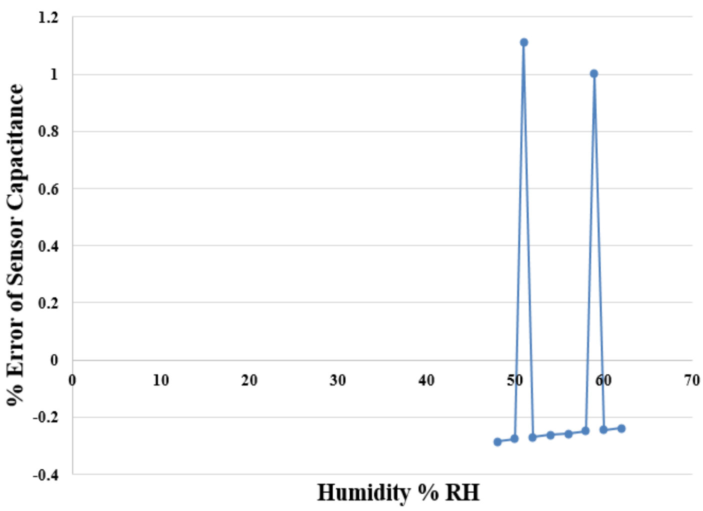

Fig. 6. Humidity Vs % of Error Graph

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Voltage output V_R (r.m.s.) after the series RLC resonating circuit and final amplified output voltage V_0 (r.m.s) after voltage amplification has been plotted against capacitance variation, which is shown in Fig. 7 and 8. Output voltage V_0 (r.m.s) has been plotted against humidity variation and have been shown in Fig.9.

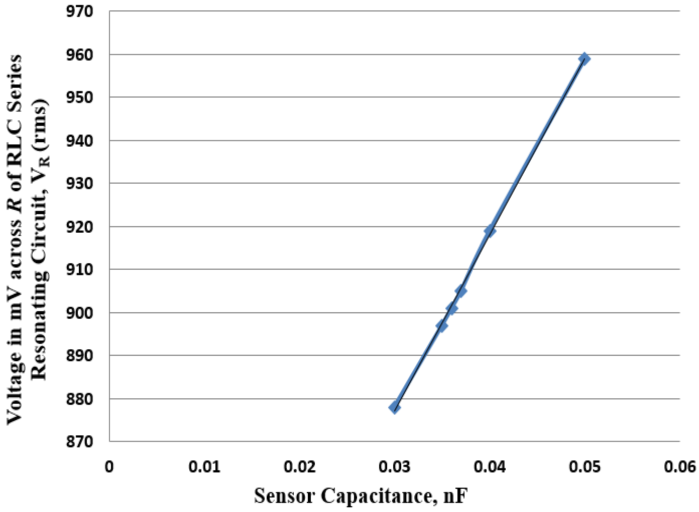

Fig. 7. Sensor Capacitance Vs Voltage across R

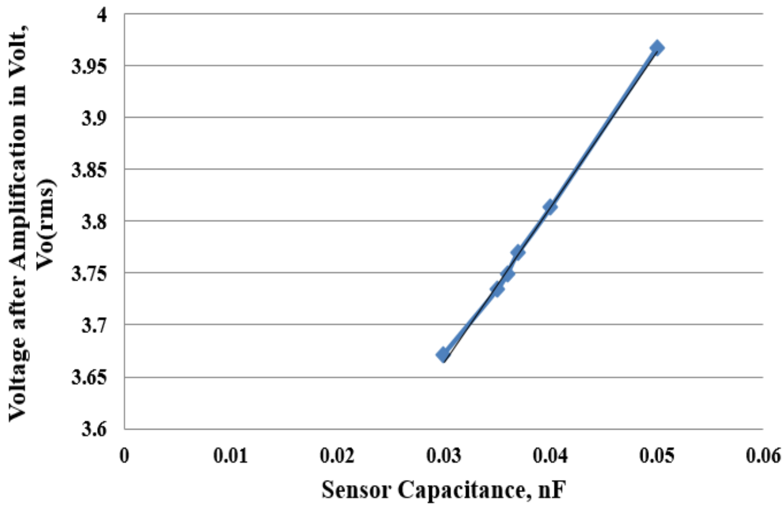

Fig. 8. Sensor Capacitance Vs Voltage after Amplification

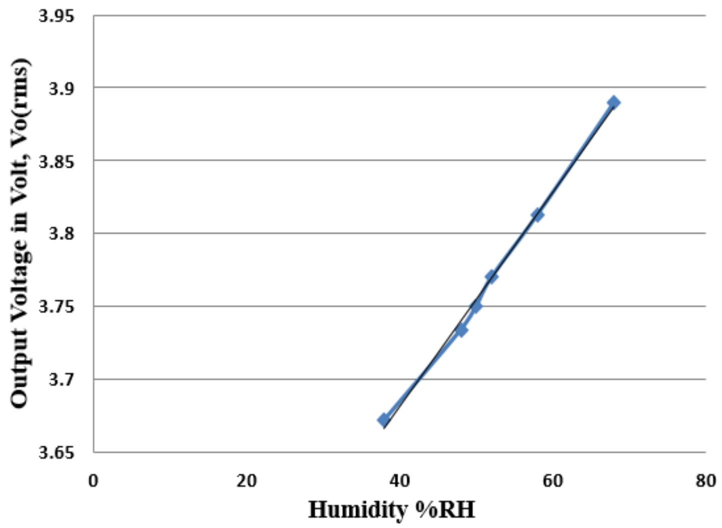

Fig. 9. Humidity Vs Voltage after Amplification

VI. CONCLUSIONS

It is to be noted that environment affects all humidity sensors in which they are measured and monitored. Psychrometer has long been a popular method for monitoring humidity due to its simplicity. Now many types of humidity sensors have been developed for better accuracy.

In this work a semi cylindrical capacitive sensor has been developed with open air containing moisture as dielectric.

This setup can measure small capacitance change with respect to moisture changes in air regardless of the environment temperature. After the complete experimental and circuit setup the various experimental data at different stages and conditions have been taken for its performance analysis and discussion. From the graph it has been observed that the characteristic is almost linear with maximum error 1.5%. As a whole, it is observed that this method provides good accuracy and repeatability within the selected range with low error. Therefore semi cylindrical capacitive sensor with open air as dielectric may be designed for commercial purpose.

The present setup has been done in laboratory on a fixed table. This can be made portable with proper setup. So far this has been developed to monitor capacitance change with respect to moisture changes in air and has been converted to the corresponding voltage signal. So this setup can be modified to measure and display humidity automatically. From the measured value, a circuit can be developed to link with automatic humidity control devices in various industrial areas.

Variation of capacitance in very low humidity (less than 10% RH) and in very high humidity (greater than 90% RH) is to be further studied.

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