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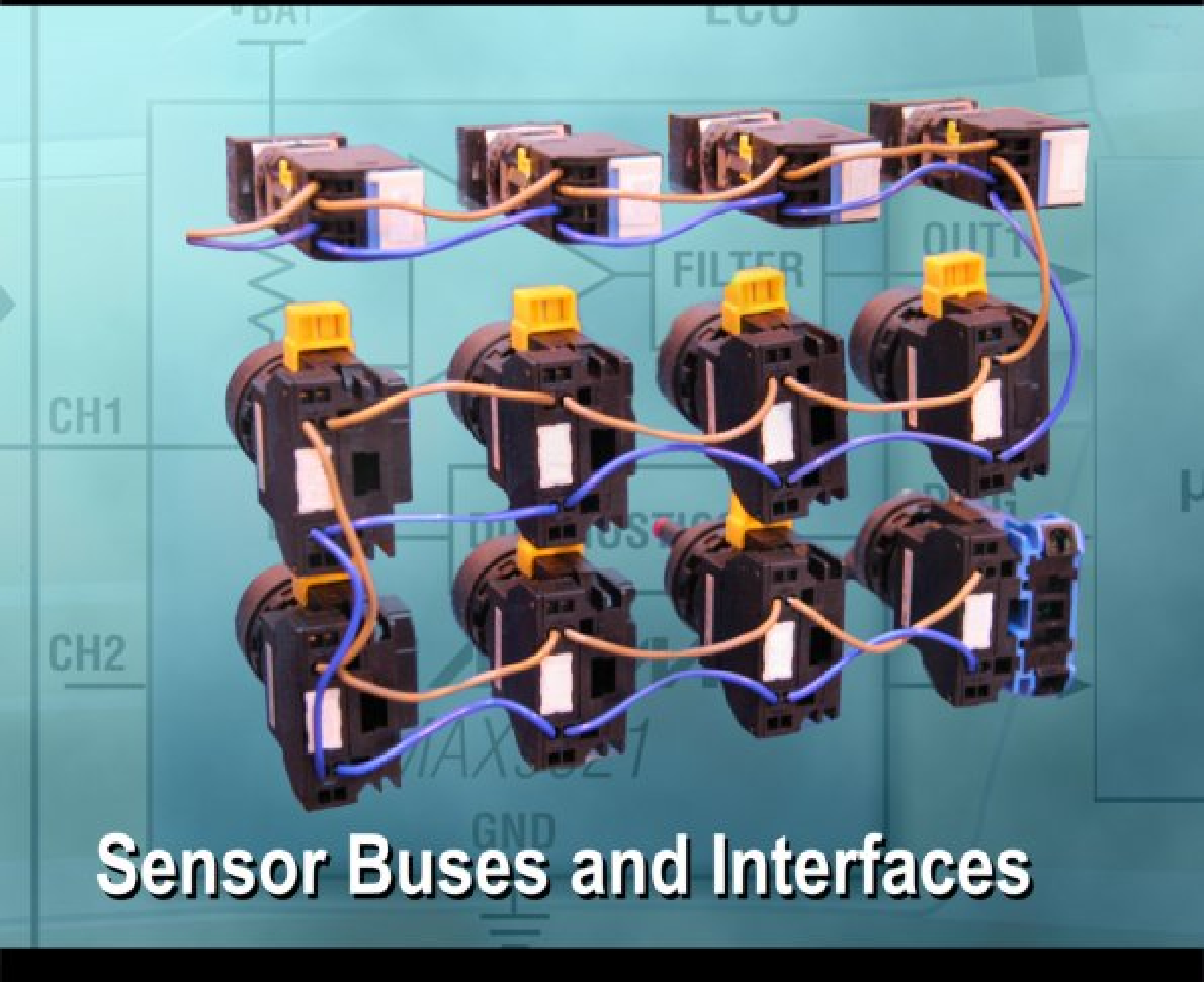

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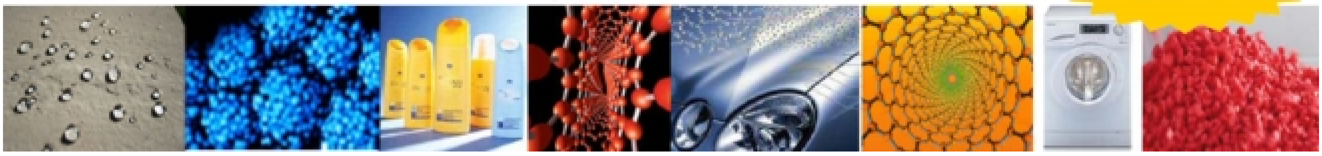

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Design, Development and Testing of a Semi Cylindrical Capacitive Sensor for Liquid Level Measurement

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Abstract: In the present paper a low cost noncontact semi cylindrical capacitive type liquid level sensor has been designed, developed and tested. The semi cylindrical capacitive sensor consisting of two thin semi cylindrical metal plates separated by a gap distance and mounted around a non conducting storage tank, has been used to measure the liquid level in the tank. The measured capacitance variation with variation of liquid level is linear and obtained in the nano farad range which again has been converted into voltage variation by using proper signal conditioning circuit. Since the sensor is noncontact type it can be used for both conducting and non conducting type of liquid contained within a non conducting tank. For converting the capacitance variation in to voltage variation a series R-L-C resonating circuit has been used instead of conventional bridge circuit. Experimental results confirm the satisfactory performance of the sensor for liquid level measurement. *Copyright © 2010 IFSA.*

Keywords: Liquid level sensor, Semi cylindrical capacitive sensor, Series R-L-C resonating circuit, Non-contact sensor, Signal conditioning circuit

---

1. Introduction

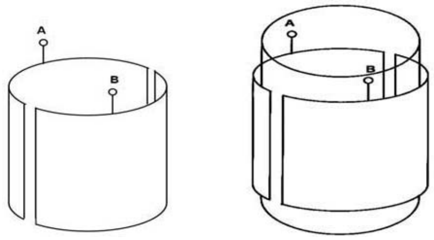
Liquid Level in a storage vessel is one of the important variables that are required to be measured and controlled in any process industry. Capacitive type of liquid level sensing techniques has been widely accepted due to its low cost, low power consumption, high linearity and simple to use. Various researchers [1, 2] and [3], have introduced various techniques for sensing liquid level using capacitive technique. Baxter [4] established that liquid level in reservoir or container can be monitored by measuring the electrical capacitance between two electrodes immersed in a liquid. The contact type level sensing probes like capacitance probe have the disadvantage that their characteristic properties with liquid level may change due to physical or chemical reaction between the liquid and probe material. Behzadi & Golnabi [5] studied the temperature effect of reactance capacitance for tap water and distilled water using a cylindrical cell probe. They observed that capacitance of liquid increases for increasing temperature and vice versa due to variation in conductance.

The non-contact type level sensing probes have been designed by Suresh Babu et. al. [6], which employs self-compensation technique to avoid the influence of environmental factor. Bera et. al. [7] designed a novel non-contact capacitance type drum level sensing technique for conducting liquid. Chiang and Huang [8] and [9] used semi cylindrical capacitive sensor for flow rate and fluidic measurement. They used numerical analysis method to calculate the capacitance of the semi cylindrical capacitive sensor and the variation of capacitance has been converted to voltage by interface circuit. Jaworek and Krupa [10] proposed a radiofrequency resonance sensor with variable capacitance in the form of two semi cylindrical electrodes for gas/liquid volume measurements. Since a capacitive sensor has very weak output signal, proper signal conditioning is needed to convert the signal in usable form. Various Signal conditioning circuits have been proposed by various researchers [11], and [12] for converting change in capacitance in to an electrical signal.

In the present paper, differing from the structures of conventional cylindrical capacitive sensor, a novel semi cylindrical capacitive sensor has been investigated for liquid level measurement. The semi cylindrical capacitive sensor consists of two semi cylindrical metal plates which are separated by a gap distance. These two semi cylindrical metal plates are mounted vertically around a polyvinyl chloride (PVC) type liquid container. Water has been used as dielectric medium of the capacitor. The variation in capacitance due to variation in water level has been converted into voltage variation using series resonating R-L-C circuit. The experimental results are found to have good repeatability, linearity, and resolution.

2. Capacitive Sensing Technique for Semi Cylindrical Capacitive Sensor

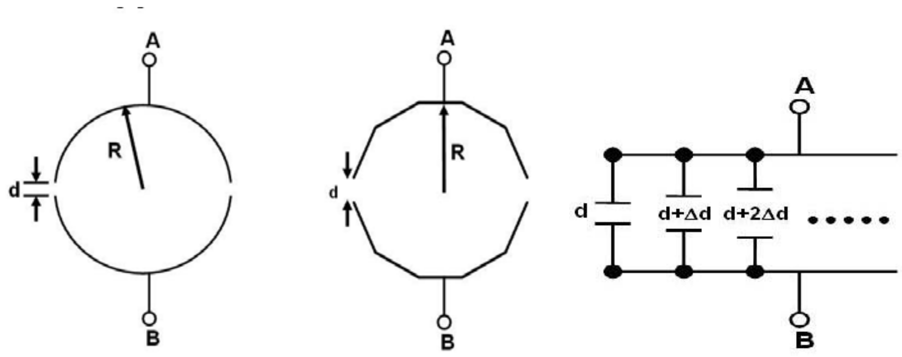
The semi-cylindrical capacitive sensor consists of two metal semi-cylindrical plates, which are separated by a gap distance. Fig. 1 (a) and (b) shows the architecture of the semi cylindrical capacitive sensor without and with dielectric fluid.



(a) (b)

Fig. 1. The architecture of the semi-cylindrical capacitive sensor:
(a) without dielectric fluid; (b) with dielectric fluid.

In Fig. 1 (a) the dielectric material is air, thus the dielectric constant ε_1 is equal to 1. Fig. 2 (a) displays the top view of the semi-cylindrical capacitive sensor without dielectric fluid. The two metal semi-cylinders have the radius R and a minimum gap distance d.



(a) (b) (c)

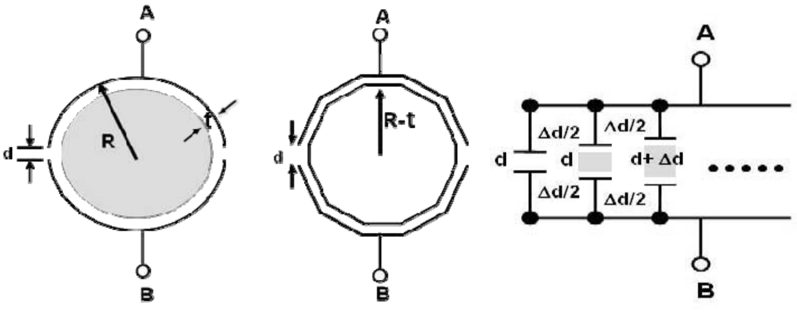
Fig. 2. (a) The top view of the semi-cylindrical capacitive sensor without dielectric fluid; (b) The approximate structure of the semi-cylindrical capacitive sensor without dielectric for numerical analysis method; (c) Equivalent capacitors between A and B terminals.

The numerical analysis method is applied to approximate the capacitance of the semi-cylindrical capacitive sensor. Fig. 2 (b) 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 as shown in Fig. 2 (c). So capacitance of two metal semi cylinders without dielectric fluid can be expressed as

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

where ε_0 is the permittivity of free space of magnitude 8.85 (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.

In the present paper two thin semi cylindrical aluminum plates have been fixed with adhesives on the wall of a thin PVC tank where liquid level measurement have been performed. The PVC tank has wall thickness t. The schematic diagram is shown in Fig. 3.



(a) (b) (c)

Fig. 3. (a) The top view of the semi-cylindrical capacitive sensor with dielectric fluid; (b) The approximate structure of the semi-cylindrical capacitive sensor with dielectric for numerical analysis method; (c) Equivalent capacitors between A and B terminals

So approximate capacitance between the semi cylindrical plates embracing the PVC tank fully filled with liquid can be given by equation 2.

$$C_1 = \varepsilon_0 2A\left[\frac{1}{\frac{d}{\varepsilon_2}} + \frac{1}{\frac{\Delta d}{\varepsilon_2}+\frac{d}{\varepsilon_3}} + \frac{1}{\frac{\Delta d}{\varepsilon_2}+\frac{d+\Delta d}{\varepsilon_3}} + \ldots.. + \frac{1}{\frac{\Delta d}{\varepsilon_2}+\frac{d+\Delta d\,(n-1)}{\varepsilon_3}}\right] + \frac{\varepsilon_0 A}{\frac{2t}{\varepsilon_2}+\frac{2R-2t}{\varepsilon_3}} \tag{2}$$

where ε $_2$ is the dielectric constant of the PVC tank material, ε_3 is the dielectric constant of the specified liquid, t is the wall thickness of the PVC tank.

If the semi cylindrical capacitive plates have height h, equation 2 can be modified as expressed in equation 3.

$$C_1 = \varepsilon_0 2(\pi Rh)\left[\frac{1}{\frac{d}{\varepsilon_2}} + \frac{1}{\frac{\Delta d}{\varepsilon_2}+\frac{d}{\varepsilon_3}} + \frac{1}{\frac{\Delta d}{\varepsilon_2}+\frac{d+\Delta d}{\varepsilon_3}} + \ldots.. + \frac{1}{\frac{\Delta d}{\varepsilon_2}+\frac{d+\Delta d\,(n-1)}{\varepsilon_3}}\right] + \frac{\varepsilon_0(\pi Rh)}{\frac{2t}{\varepsilon_2}+\frac{2R-2t}{\varepsilon_3}} \tag{3}$$

In the present level measurement system, maximum liquid level that can be measured must be equal to the semi cylindrical capacitive plate height h. If at any instant the PVC tank is partially filled with liquid height h_1 (of dielectric constant of ε_3), and the remaining height $h_2 = (h-h_1)$ is filled with air (of dielectric constant ε_1), the overall capacitance C will be given by equation 4.

$$C = C_1 + C_2\,, \tag{4}$$

where

$$C_1 = \varepsilon_0 2(\pi R h_1)\left[\frac{1}{\frac{d}{\varepsilon_2}} + \frac{1}{\frac{\Delta d}{\varepsilon_2}+\frac{d}{\varepsilon_3}} + \frac{1}{\frac{\Delta d}{\varepsilon_2}+\frac{d+\Delta d}{\varepsilon_3}} + \ldots.. + \frac{1}{\frac{\Delta d}{\varepsilon_2}+\frac{d+\Delta d\,(n-1)}{\varepsilon_3}}\right] + \frac{\varepsilon_0(\pi R h_1)}{\frac{2t}{\varepsilon_2}+\frac{2R-2t}{\varepsilon_3}}$$

$$C_2 = \varepsilon_0 2(\pi R h_2)\left[\frac{1}{\frac{d}{\varepsilon_2}} + \frac{1}{\frac{\Delta d}{\varepsilon_2}+\frac{d}{\varepsilon_1}} + \frac{1}{\frac{\Delta d}{\varepsilon_2}+\frac{d+\Delta d}{\varepsilon_1}} + \ldots.. + \frac{1}{\frac{\Delta d}{\varepsilon_2}+\frac{d+\Delta d\,(n-1)}{\varepsilon_1}}\right] + \frac{\varepsilon_0(\pi R h_2)}{\frac{2t}{\varepsilon_2}+\frac{2R-2t}{\varepsilon_1}}$$

So if the liquid level h_1 within the cylinder varies, capacitance between the semi cylindrical plates will also vary because of the variation in height of the dielectric medium. Thus liquid level measurement in terms of the capacitance of the semi cylindrical plates can be possible.

3. Design of the Semi-cylindrical Capacitive Sensor

The semi cylindrical capacitive sensor has been designed and constructed from two Aluminum plates of thickness 0.2 mm, length 330 mm and width 11 mm. Each plate has been bent to form a semi cylindrical shape. These two semi cylindrical plates are mounted vertically around a PVC type liquid container using adhesives so that there is no air gap between the capacitor plates and the outer wall of the tank as shown in the Fig. 4. Two semi cylindrical plates are separated by a gap distance of 2.0 mm. The outer and inner diameters of the PVC tank are 73 mm and 70 mm respectively. Thickness of the tank wall is 3 mm.

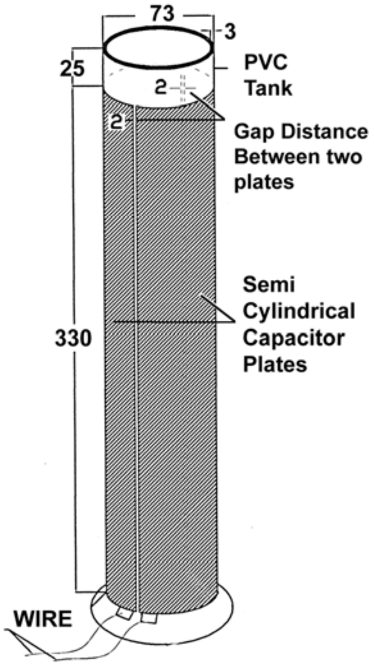


Fig. 4. Isometric view of the semi cylindrical capacitive level sensor (All dimensions are in mm).

4. Signal Conditioning Circuit for Semi-cylindrical Capacitive Sensor

The variation of capacitance due to changes in liquid level in the tank has been converted into voltage variation with the help of a series RLC resonating circuit as shown in Fig. 5, where the semi cylindrical capacitance C1 has been connected in parallel with the capacitance C.

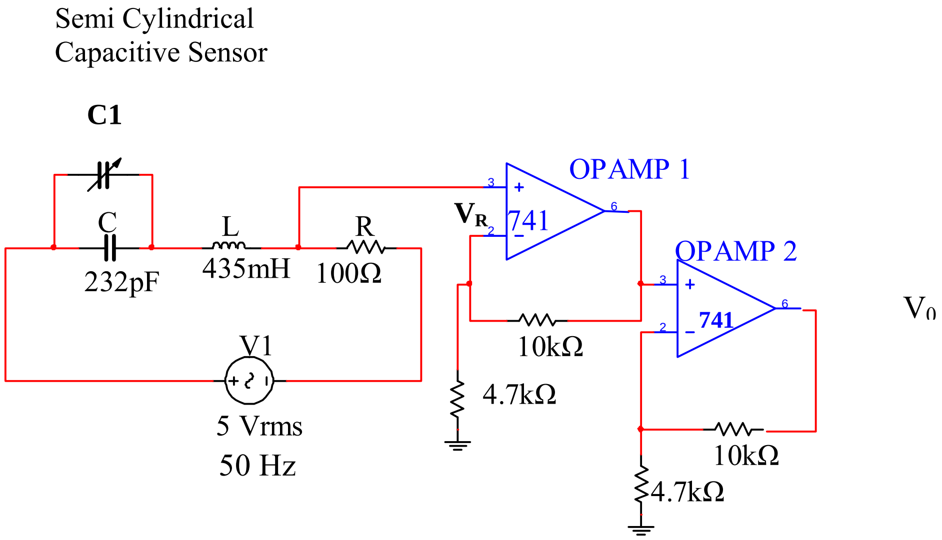


Fig. 5. Signal conditioning circuit for semi cylindrical capacitive sensor.

During series resonance, the inductive reactance becomes equal to capacitive reactance. i.e. $X_L = X_C$, and overall impedance Z = R. So at series resonance the impedance of the circuit is minimum and voltage drop across resistance is maximum. The measured resonating frequency with the R, L, C and C_1 as shown in the Fig. 5 is in the range of KHz. During achieving the resonating condition, there is no liquid in the tank and in that condition the voltage across R i.e. V_R has been noted. Then water level in the tank has been gradually increased. As the water level changes the semi cylindrical capacitance C_1 changes and accordingly V_R (r.m.s.) also changes. V_R is further amplified by two stage amplifier and final output V_0 (r.m.s) has been recorded with the liquid level in the tank.

5. Experimental Result

In the proposed scheme water has been used as the dielectric medium within the PVC tank and between the two plates of the semi cylindrical capacitor. The capacitance of the semi-cylindrical capacitive sensor has been measured by varying water level in the PVC tank ranging from 0 mm to 330 mm. The variation of the capacitance with dielectric water has been observed in the nano farad range.

Finally MATLAB software is performed to calculate theoretically the capacitance between the two semi cylindrical plates using equation 4 and the calculated value of capacitance is also in the nano farad range i.e. same as that of the experimental value.

The experimental capacitance variation with the variation of liquid level in the tank is linear and is shown in Fig. 6.

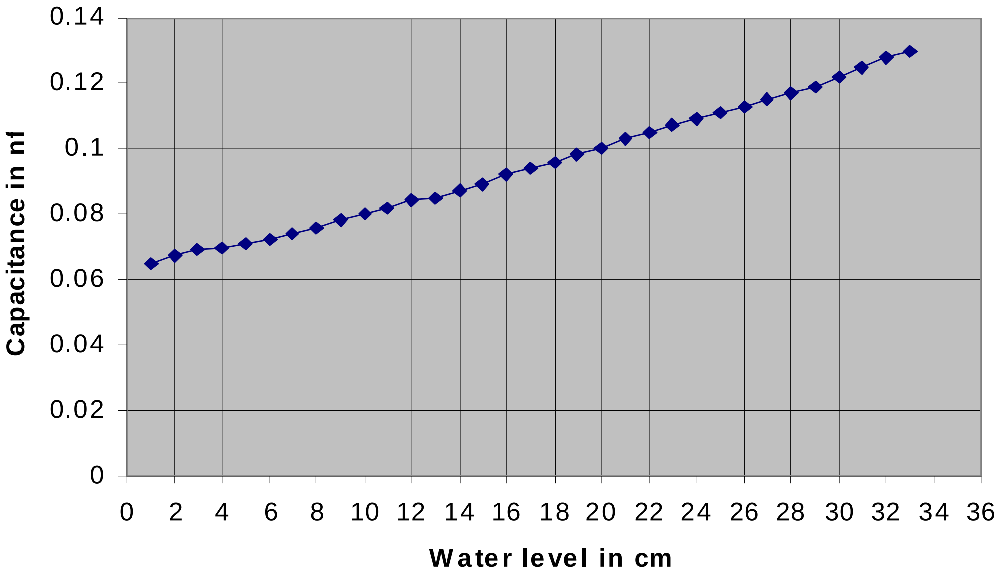
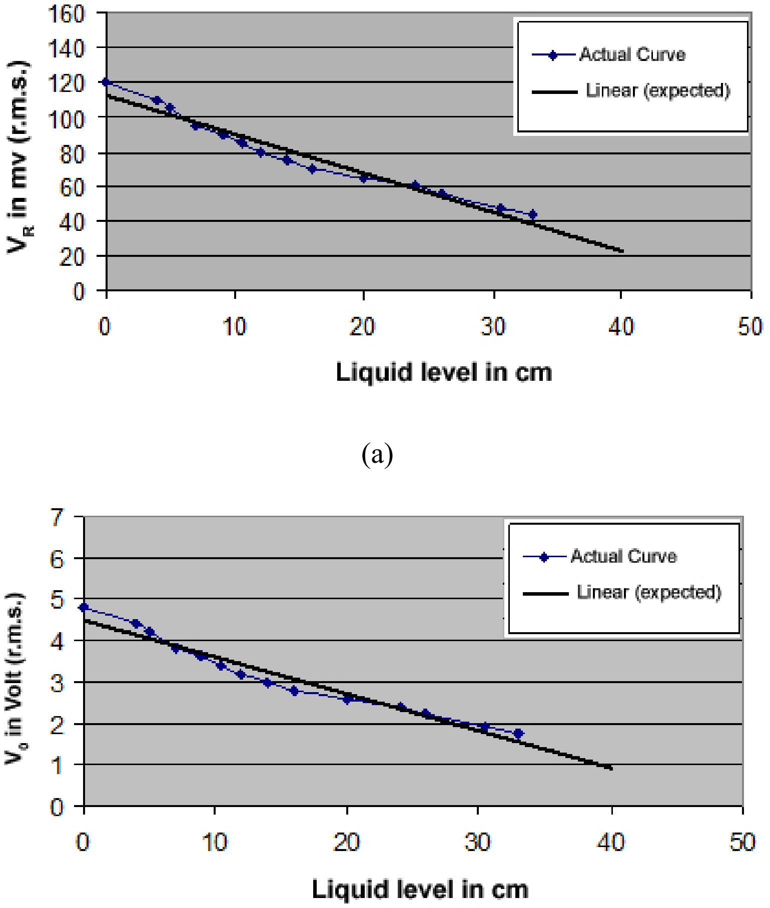


Fig. 6. Semi cylindrical Capacitance variation with liquid level in the tank.

By using the signal conditioning circuit shown in Fig. 5, the capacitance variation of the sensor has been converted in to voltage variation. Voltage output V_R (r.m.s.) after the series RLC circuit and final amplified output V_0 (r.m.s) has been plotted against the liquid level variation in the tank, which is shown in Fig. 7.



(a)

(b)

Fig. 7. Voltage variation with liquid level: (a) after the RLC network; (b) after amplification.

6. Conclusions

In the experiment, liquid level in the tank has been changed from 0-330 mm and the semi cylindrical capacitance has been observed to vary from 0.065 – 0.130 nano farad.

From the Fig. 6. the variation of capacitance with the variation of liquid level is linear and theoretically computed value of the capacitance from equation 4 matches with the experimental value.

It has been observed that the semi cylindrical capacitance type level sensor has good linearity and repeatability in the measured range.

Since it is a noncontact type of liquid level measurement, it can be used for both conducting and non conducting type of liquid contained within a non conducting tank.

In the present scheme the capacitance variation has been converted in to voltage variation by using the series resonating RLC circuit instead of conventional bridge circuit for simplicity.

From Fig. 7. the voltage variation with the liquid level variation has been observed linear but with negative slope. Rectification of the final output voltage along with zero and span adjustment is the future scope of work.

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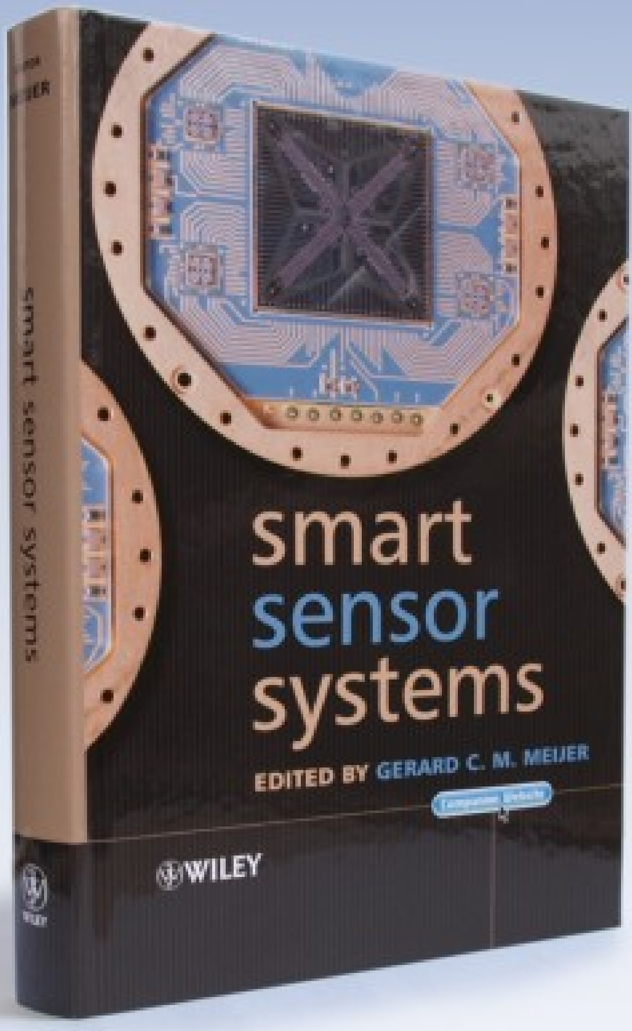

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