Intl. J. Engg. Sci. Adv. Research 2019 June ; 5(2):21-24 ISSN NO: 2395-0730

Modelling of An Electronic Level Transmitter Using An Inter Digital Capacitor As Primary Sensing Element

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***Abstract*—An electronic level transmitter is proposed using an Inter Digital Capacitor (IDC). The Inter Digital Capacitor works as a primary sensor which converts the height of the liquid level into change in capacitance. The IDC is fabricated based on the design specifications. A modified De Sauty bridge is used to convert the change in capacitance into an electrical signal. In this paper the HART protocol is followed , It is one of the most important protocols in instrumentation systems. This liquid level measurement technique is a cost effective method and the liquid being used is water. Theoretical analysis of the work has been presented in this paper. The working principle of the transmitter is described by theoretical equations. The level of water taken is from 0-50cm.The characteristics obtained are linear in nature.**

***Keywords*—Inter Digital Capacitor (IDC), Modified De Sauty Bridge, Signal conditioning circuit, Voltage to current converter**

I. INTRODUCTION

The measurement and control of liquid level stored in tanks plays a vital role in industrial applications and automation [3]. It is also a necessary part of a process plant in chemical industries. There are different types of technique available exploiting in different principle but those system needs frequent calibration. The problems are addressed and the effect of parasitic parameters such as perpendicular capacitance effect, humidity, atmospheric condition are minimized in this innovative method of liquid level measurement [3]. This method is free from measurement errors and with good linearity characteristics. Liquid sensors have many applications but they are expensive and complicated. Therefore capacitive sensors are applied to some liquid level measurements as the dielectric constants of liquids are different from that of air. Accuracy of these measurements can be improved by calibration and correction. Proposed design of low-cost comb-electrode capacitive sensing device for the measurement of the liquid level as in [5]. The main advantage of this is that the capacitance changes according to the rise in level of the liquid and thus improves accuracy of the measurement. By using comb electrode simplicity and linearity are obtained. The modified version of non-contact capacitive sensor in [2] minimizes the parasitic parameter in measurement and fringe effect which is the problem present in every capacitive sensor occurs during calibration. The proposed technique is low-cost method which is simpler in design and has good linearity and repeatability. The sensor has been studied for a non-metallic storage tank in this paper. This novelty in design of non-contact capacitive sensor has more accruable measurements than other conventional technique. In [4] the sensor developed for the measurement of liquid level is done by a combination of no-core fibre (NCF) with fiber bragg-grating(FBG).Here the NCF has a temperature compensation property. Upon variation of liquid height the interference fringe of NCF changes and the bragg wavelength doesn’t changes whereas when the temperature is varied there is a simultaneous change in interference fringe of NCF as well as the bragg wavelength This proposed sensor has a simple design of fabrication so can be used without complexities. The dynamic temperature compensation characterisation ensures a large potential of liquid measurement. The application of interdigital capacitive sensor for insulation damage detection in power system cable has been studied in [1]. Rashed H Bhuiyan developed a capacitive sensor which had two kinds of electrode structure which was used to detect the insulation damage in PVC cable and PUR cable. The results of this experiment shows the designed sensor is capable of detecting the insulation damage effectively. One such class of sensors called pulsating sensors are developed for continuous type liquid level measurement is studied in [8] for specific industrial applications. .These sensors detects the primary signal as in digital form. This system results in high precision of measurement using differential pressure sensor which is in interaction with the liquid. The technique in which microcontroller unit is designed to measure the liquid level and to improve the efficiency of motor pumping unit has been studied in [10]. The temperature sensor is also used to measure the temperature inside the liquid tanks. This system can measure the water level which is upto 25cm and works at supply voltage of 5V range. Stating from these consideration a flexible two-wire probe for real time using time-domain reflectometry (TDR) for monitoring the liquid level measurement inside tanks is proposed in [11]. The proposed system is tested for both metallic and non-metallic containers. These configurations are non-invasive and applicable for industrial applications involving toxic and hazardous liquids.

The simulation results evaluates the output of the proposed design in experimental conditions with respect to reflectrometer. For simultaneous measurement of liquid level and temperature, Mengling xiong constructed a Mach-Zehnder Interferometer (MZI) by fabricating it with a long period fiber grating in the center of two spherical- shaped fiber structure[6].Among the sensors for liquid level measurement the optical fiber sensor is widely used due to its compactability, high sensitivity and resistivity to corrosion. In this paper the experimental test of two MZI with different length are conducted. The results shows that the proposed design has high sensitivity of -0.214nm/mm and temperature sensitivity of 0.059nm/°C in range of 35-70°C. A method of simultaneous measurement of water level and temperature has been proposed in [7] .Two FBG sensors are used which have central wavelength of 1550 nm are used. The sensor output is displayed as a function of bragg wavelength shift .When the diaphragm is dipped in water ,there is strain in d the diaphragm that causes deformation .For the water level in the range of 0-100 cm the response of the sensor is linear. As the thickness of the diaphragm increases the sensitivity of the sensor decreases. The integration of graphene diaphragm in silica FBG results in high sensitivity and this sensor is highly sensitive for hydrostatic pressure above 9.81 kPa. The coaxial cylindrical capacitive sensor fabricated using shielded cable for measuring the liquid level has been developed in [9]. The theoretical analysis and the calculation of physical parameters of this sensor has been derived. The Backward difference calculation is an effective method to counteract the effect of parasitic capacitance. The linearity of this technique is tested by adaptability of liquid in different containers such as ground metallic and plastic. The performance of the wide range measurement is satisfactory in this technique. In this paper the method of approach, methodology, simulation results and conclusion are mentioned in sections II, III, IV and V repectively.

II. METHOD OF APPROACH

In this paper the IDC functions as a sensor. The liquid level in the container is converted to the corresponding capacitance. It is placed in the container. When there is no liquid in the container, At h=0;

$$C_T = \frac{\varepsilon_0}{d} A \quad (1)$$

C_T-total capacitance

ε_0-air permittivity

A-area of IDC at h=0

d-spacing between fingers

$$A = L(H - ND) \quad (2)$$

H-total height of IDC

L-length of finger

N-no of finger

Using (2) in (1)

$$C_T = \frac{\varepsilon_0 LH}{d} - \varepsilon_0 LN \quad (2a)$$

When there is rise in liquid level at ht 'h',

Total capacitance = liquid capacitance at ht h+Air capacitance at H-h

$$C_T = C_\square + (C_{air})_{H-\square} \quad (3)$$

$$C_\square = \frac{\varepsilon_0 \varepsilon_r (l - nd)}{d} \quad (4)$$

Here n=no of fingers immersed in liquid

$$(C_{air})_{H-\square} = \frac{\varepsilon_0 L\{H - \square - (N-n)d\}}{d} \quad (5)$$

For IDC sensor , nd=h\2,

Adding (4) & (5),

$$C_T = \frac{\varepsilon_0(\varepsilon_r - 1)L\square}{d} - \frac{\varepsilon_0(\varepsilon_r - 1)L\square}{2d} + \frac{\varepsilon_0 \square L}{d} - \varepsilon_0 Ln \quad (6)$$

From (2a) & (6),

$$C_T = k_1\square - \frac{k_1\square}{2} + (C_{air})_H$$

$$\text{where } k_1 = \frac{\varepsilon_0(\varepsilon_r - 1)L}{d} \quad (7)$$

$$C_T = k_2\square + (C_{air})_H$$

$$\text{where } k_2 = \frac{k_1}{2}$$

Now change in capacitance $\Delta C = C_T - (C_{air})_H = k_2\square = \frac{\varepsilon_0(\varepsilon_r - 1)L\square}{2d}$ (8)

The above equation specifies the width and spacing is inversely proportional to capacitance value. As the change in capacitance is coupled to one arm of bridge, the output of modified bridge circuit is

$$V_B = R_f[j\omega \Delta C]V_{in} \quad (9)$$

R_f- feedback resistance

ω- operating frequency

V_{in}- supply voltage

From (8) & (9),

$$V_B = R_f[j\omega\, k_2\square]V_{in}$$

$$V_B = k_3\square$$

$$\text{where } k_3 = R_f j\omega k_2 V_{in} \quad (10)$$

Output of the signal conditioning circuit is given by,

$$V_s = k_4 + k_5 V_B \quad (11)$$

From (10) & (11)

$$V_s = k_4 + k_5 k_3 \square$$

$$V_s = k_4 + k_6 \square$$

where $k_6 = k_5 k_3$ (12)

Output of V-I converter is given by,

$$I = k_7 V_s \quad (13)$$

Using (11) & (13)

$$I = k_7 k_4 + k_7 k_6 \square$$

$$I = \alpha + \beta \square$$

where $\alpha = k_7 k_4$

$\beta = k_7 k_6 = k_7 k_5 k_3$

$$\beta = k_7 k_5 . \frac{\varepsilon_0(\varepsilon_r - 1)L}{d} R_f \omega V_{in}$$

III. DESIGN METHODOLOGY

The IDC with the following dimensions is fabricated:-

Length of IDC=50 cm; Length of finger=20mm; Width of finger=space between the fingers=0.3mm

The modified De-sauty bridge circuit (shown in Fig.) is provided with a sinusoidal input of 5V and 1Khz.It changes the capacitance to an electrical signal. A precision peak rectifier is constructed using op-amp 741IC.It rectifies the ac output of bridge circuit to dc signal.The signal conditioning circuit converts the dc signal to 1-5V standard voltage(shown in Fig.).The voltage to current converter(made with op-amp 741IC) converts the standard voltage signal to current signal of 4-20 milliampere.

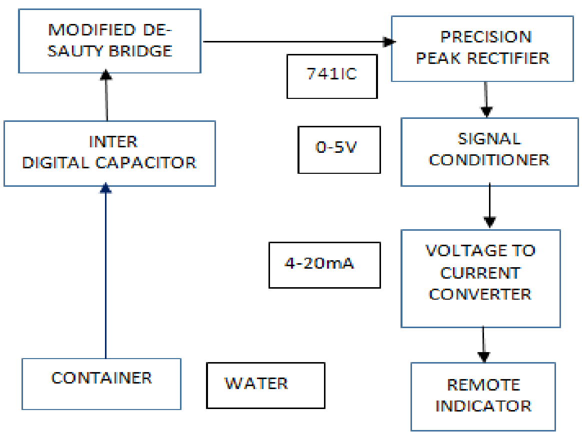


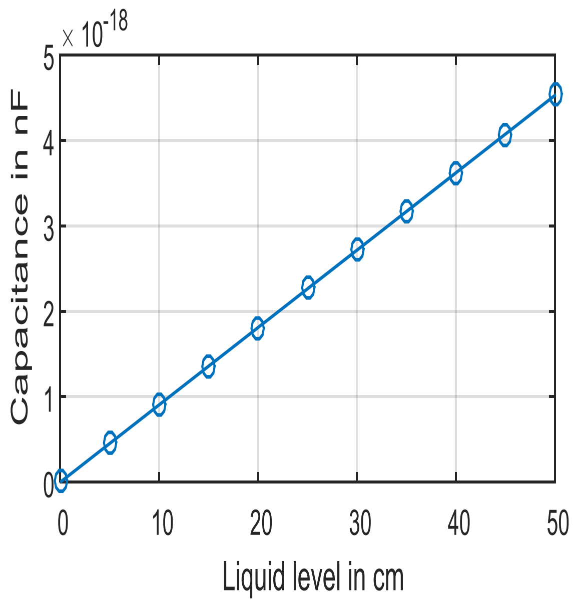
Fig.1: Block diagram of proposed transmitter

IV. SIMULATION RESULTS

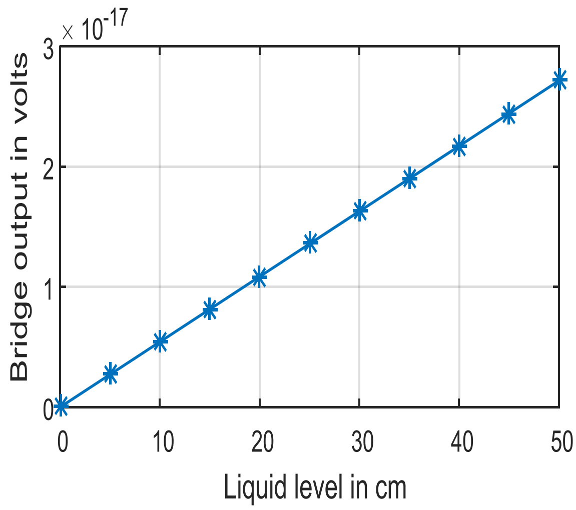
The proposed transmitter characteristics based on the design equations have been plotted in MATLAB.By plotting change in capacitance with respect to liquid height, the linear characteristics of the IDC is presented in Fig.2 (a)

Further the change in capacitance is coupled to one arm of modified de-sauty ridge circuit and is converted to an electrical signal. The plot of electrical signal with respect to the liquid height is presented in Fig.2(b)

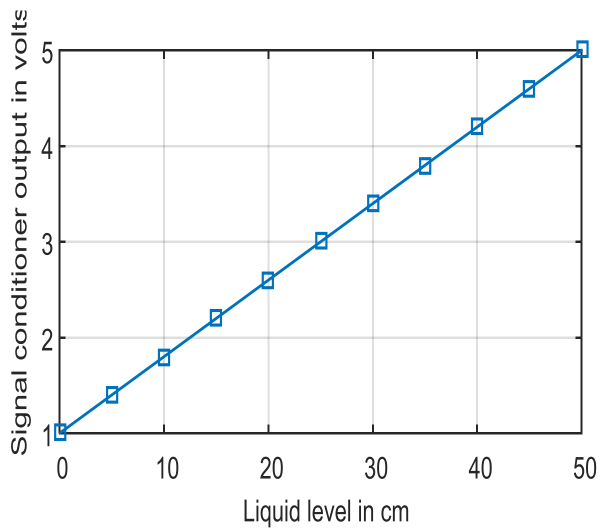
The output of bridge circuit is converted from ac signal to dc signal by the precision peak rectifier and is fed to signal conditioning circuit to get standard voltage of 1-5V value for liquid level of 0-50 cm.The signal conditioning output voltage with respect to the liquid height is presented in Fig.2©



(a)



(b)



(c)

IV. CONCLUSION

An Inter Digital Capacitive sensor has been proposed and designed for measurement of the liquid level. Measurement of various liquids are possible with the help of this technique. The height of the liquid is within the range of 0-50cm. The sensor used is high in linearity and sensitivity and can be installed by a simple method. This sensor can detect the level of liquid regardless of water type. We obtain three theoretical plots (height of the liquid vs change in capacitance, height of the liquid vs bridge voltage, height of liquid vs signal conditioning voltage). The linearity of the plots is proved by matlab.The robustness,lifetime and environmental conditions are yet to be studied to achieve better results and measurement of a higher range of liquid level can be achieved.

V. ACKNOWLEDGMENT

The authors would like to thank their guide Dr..Brajesh Kumar and the department of electronics and communication engineering,SRM Institute Of Science And Technology, Chennai for providing us with the facilities to carry out this work.

REFERENCES

[1] Liu Yonghong, Huang Yunzhi, Tang Rui and Wang Beibei "Applications of interdigital capacitive sensors for detecting power cable insulation damage" Proceedings of 2015 IEEE International Conference on Mechatronics and Automation August 2-5,China.

[2] Sudipta Chakraborthy , Saikat Kumar Bera , Nirupama mandal "Study on further modification of Non-contact capacitance type-level transducer for a conducting liquid" IEEE Sensor Journal,vol. 15,No. 11,November 2015.

[3] S.Chalaborty, N.Mandal , S.K.Bera, B.C.Bera and M.Chatopadhyay "An innovative method for the measurement of liquid level of a conducting liquid", 2016 International conference on computer and Electrical and communication engineering(ICCECE)

[4] Chao Li, Tigang Ning, Chan Zhang, Jing Li, Xiaodang wen, Li pei, Xuekai Gao and Heng Lin "Liquid level measurement based on a no-core fibre with temperature compensation using a fiber bragg grating" Sensors and actuators volume 245,1 July 2016,Pages 49-53

[5] Cihun-Siyong Alex Gong, Huan Ke Chiu, Li Ren Huang, Cheng Hsun Lin, Zen Dar Hsu, and Po-Hsun Tu "Low-cost comb-electrode capacitive sensing device for liquid level measurement" IEEE sensors journal, vol. 16,No. 9,May 1,2016

[6] Mengling Xiong, Huaping Gong, Ziheng Qian, Chun-Liu Zhao, Xinyong Dong "Simulataneous measurement of liquid level and temperature based on spherical shape structure and long period fiber grating" Sensors and Actuators volume 239,1 march 2016,pages 196-200

[7] Odai Falah Ameen, Marwan Hafeedh Younus, M.S. Aziz, Asrul Izam Azmi , R.K.Raja Ibrahim,S.K.Ghoshal "Graphene diaphragm integrated FBG sensors for simultaneous measurement of water level and temperature" Sensors and actuators volume 252,1 december 2016, Pages 225-232

[8] K.Praveen,M.K.Rajniganth, A.D.Arun, P.Sahoo, N.Murali "Continous-type liquid level measurement system using pulsating sensor" 2015 International conference on Industrial instrumentation and council,college of engineering pune,India , May 28-30,2015

[9] Baoquan Jin, Zeyu Zhang, Hongjuan Zhang "Structure design and performance analysis of a coaxial cylindrical capacitive sensor for liquid-level measurement" Sensors and actuators volume 223,1 March 2015,Pages 84-90

[10] K.A.Mohd Annuar, N.A.Ab hadi, I.M.Saadon and M.H.Harun "Design and construction of liquid level measurement system" Journal of advanced research in applied mechanics,ISSN:2289-7895 vol. 12,No. 1,pages 8-15,2015.

[11] Andrea Cataldo, Emanuele Piuzzi,Egidio De Benedetto and Giuseppe Cannazza "Experimental characterization and performance evaluation of flexible two-wire probes for TDR monitoring liquid level" IEEE transactions on instrumentation and measurement,vol. 63, No. 12,December 2014.