Journal of Theoretical and Applied Information Technology
15 May 2012. Vol.39 No.1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

PERFORMANCE COMPARISONS OF INTERFACE CIRCUITS FOR MEASURING CAPACITANCES

[1]PRABHU RAMANATHAN, [2]MARIMUTHU.R, [3]R. SARJILA, [4]SUDHA RAMASAMY and [5]P.ARULMOZHIVARMAN

[1]Assistant Professor (Senior), School of Electrical Engineering, VIT University, Vellore - India
[2,4]Assistant Professor, School of Electrical Engineering, VIT University, Vellore - India
[3]Lecturer, ECE Department, Ganadipathy Tulsi's Jain Engineering College, Kaniyambadi, India
[5]Associate Professor, School of Electronics Engineering, VIT University, Vellore - India

E-mail: [1]ishupa@gmail.com, [2]rm_ei@rediffmail.com, [3]r.sarjila@yahoo.com, [4]ishuma@gmail.com

ABSTRACT

This paper reviews some of the recent signal conditioning and Interface circuits for the capacitive type sensors. This paper gives the brief idea of advantages and limitations of interface circuits for the various capacitive sensors. The sensor output may be either current or voltage but it has to be converted to the desired output range only by the signal conditioning circuit. Signal conditioning circuits provides the analog output in the desired range; this can be converted to digital through Analog to Digital converter. The signal conditioning circuit should able to produce not only the convenient of output voltage or current levels but it has to provide the isolation, impedance matching, linearization with the input, proper gain adjustment with the amplification, filtering of unwanted signals, etc. Here we reviewed the four different methodologies of the proposed signal conditioning and interfacing circuits with its advantageous and limitations.

Keywords: *Signal Conditioning, Interfacing Circuits, Capacitance to Digital Converter, Sigma Delta Modulator, Capacitive Sensors, and Capacitance Measurement.*

1. INTRODUCTION

Capacitive sensors gives the output when change in the capacitance with respect to the change in the input or physical parameter of the sensor. Capacitor sensors have wide applications in the industry like measuring the humidity, pressure, various position sensors and liquid level measurement. In medical and manufacturing equipment the capacitance sensors are used from the high performance to the low performance end and proximity sensing, finger printing, materials property and all kind of motion sensors. It gives us the very high accuracy output with a low cost but the designing of the signal conditioning circuit is bit complex. First we need to convert the capacitance to a voltage and to digital output through ADC's. For converting from the capacitance to voltage usually they will convert it capacitance to frequency or time conversion. This type of conversion takes the specific circuit design. This leads us to a complex design and end up with a bulky prototype models. To avoid this, new approach of the design is Sigma- Delta (∑- Δ) modulator which can able to measure the capacitance directly. There are designs which include the capacitive sensors also as one of the integrated element. Capacitance to voltage otherwise capacitance to digital converter is needed for interfacing the signals of the capacitive sensor. For this type of circuit implementation basically we need the specific circuit design based on the specifications of low noise operational amplifiers with high speed comparators and analog switches with having less ON resistance. In recent years, several interface circuits for capacitive sensors have been proposed where the sensor is directly connected to a microcontroller unit (MCU), which converts from capacitance to digital without any external circuit for signal conditioning or analog-to-digital voltage conversion [1].These types of circuits having the advantageous of simple with compact and low cost. Here in this paper we reviewed different types of interfacing circuits for the capacitive sensor which is having less complexity and gives the reliable and linear output.

Gaitan *et all* [1] proposed a method is, the charging of the unknown capacitor in directly proportional to the reference voltage is applied across the capacitor. R. Nojdelov *et all* [2] proposed a high accuracy and

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

stability method to measure the capacitance up to the value of 1pF. J. O'Dowd *et all* [5] proposed the technique in Fig.3 shows the structure of the basic Sigma – Delta Converter.

This article is intended to review and analyze all the above techniques of capacitance measurement. Section 2 explains the Capacitance measurement technique through Charge Transfer Method. Section 3 is about Capacitive Sensor Interface Based On Reference Charge Amplifier Circuit. Section 4 explains about the Interfacing Circuit Based On Sigma Delta (∑ - Δ) Converter. Section 5 summarizes all the three capacitance measurement techniques discussed.

2. MEASURING THE CAPACITANCE THROUGH CHARGE TRANSFERRING METHOD

Gaitan *et all* [1] proposed a method is, the charging of the unknown capacitor in directly proportional to the reference voltage is applied across the capacitor. This measuring unit having a switched capacitor circuit where the Cs is the unknown capacitance and Cr is the reference capacitance. When charge is transferred from Cs to Cr, from the known value of capacitance and the charge from Cr we can able to measure the unknown value of capacitance. Here we need assume all the capacitances are constant for the measurement cycle.

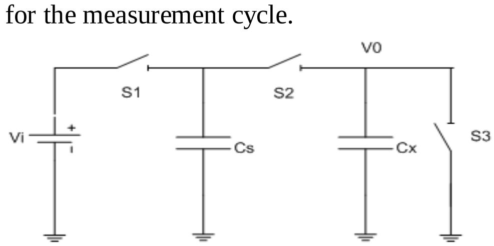

Fig1. Capacitance measuring circuit based on the charge transferring method [1].

Here the input supply is connected through the switch S1 to the unknown capacitor Cs. Initially assume all the switches are open. First close the Switch S3 to discharge the known reference capacitor Cr to zero. Then open S3. Now close the switch S1, then the unknown capacitor Cs has to be charged to the value of Vi and open S1, close S2, the charge in Cs will be shared by Cr and open S2. This leads the output voltage V0 will be directly proportional to the charge transferred from Cs to Cr. By repeating the above cycle again and again the voltage across Cr will be exponentially reached to Vs. By counting the number of charge transfer cycle we can able to calculate the capacitance of Cs.

By calculating the voltage across Cr for N number of charge transfer cycle is,

$$Vo[N] = \frac{Cs}{Cs+Cx}Vi + \frac{Cx}{Cs+Cx}Vo[N-1] \quad (1)$$

From eq(1), the Vi term is charge transferred during the first cycle and the Vo term is charge transferred to the previous N-1 cycles. At t=0, S3 is closed so that time Vi(0) = 0, Then

$$Vo[N] = Vi - Vi\left(\frac{Cx}{Cs+Cx}\right)^N \quad (2)$$

The charge transfer process will goes on until the Vo(N) should equal to Vi, Applying this into eq(2), We get,

$$1 - \frac{Vo}{Vi} = \left(\frac{Cx}{Cs+Cx}\right)^N \quad (3)$$

Here initially we took, Cr>>Cx, Now the value of N approximately given as,

$$N \approx \frac{Cx}{Cs}\ln\left(\frac{Vi}{Vi-Vo}\right) \quad (4)$$

From eq(4), If Cs is increases based on Number of charging cycles also increases, then

$$Cs = \frac{k}{N} \quad (5)$$

From the equation (5), k = Cx ln [Vi / (Vi-Vo)] is the factor of capacitance to digital value. If Cs is lesser value, then large number of charge transferring cycles required.

This method interface with the MCU directly, there are three stages of the measuring capacitance values. First Reset the Reference Capacitor Cx, then Charging of Cs and the charge distribution from Cs to Cx. The advantages of this method are we can able to measure the capacitance from 2 pF to 1 nF values in three different measurement ranges. 2–10 pF, 10–100 pF, and 100 pF to 1 nF. All measured capacitors had ceramic dielectric and 10% tolerance [1]. The limitations of interfacing directly with MCU, input currents and surface leakage currents along the printed circuit board may contribute to nonlinearity, but their inclusion in the circuit model would complicate it too much [1].

3. CAPACITIVE SENSOR INTERFACE BASED ON REFERENCE CHARGE AMPLIFIER CIRCUIT

R. Nojdelov *et all* [2] proposed a high accuracy and stability method to measure the capacitance up to the value of 1pF. The implemented circuit tolerates cable capacitance of up to 1 nF and the conversion time will take only 39 to 100 μs based on the mode [2]. The interface result has to be in high accuracy, so the multiple capacitive sensors are used up to the maximum of

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

1pF and to increase the resolution a multi slope ADC is used.

The working principle of the Fig 2; the capacitance measurement can be achieved through applying the reference excitation source (V) to the unknown value of the capacitors (C) and by measuring the charge (Q) in it. The gain of the charge amplifier fixed 50 and is connected on the other side of the unknown capacitance array circuits through the input multiplexer. The output of the charge amplifier which is amplified by 50 times is summed with the reference charge generator and gives the input to the integrator. The output of the integrator feds to the 1 bit comparator, it gives either high or low output based on the integrator. The comparator manages the reference charge output to make the integrator output is zero, this condition implies the reference charge output is equal to the charge amplifier output. From this value we can able to calculate the value of unknown capacitance. We can operate this method in two modes, fast mode and normal mode. In fast mode 12 bit counter is sampled 16 times whereas in the normal mode the

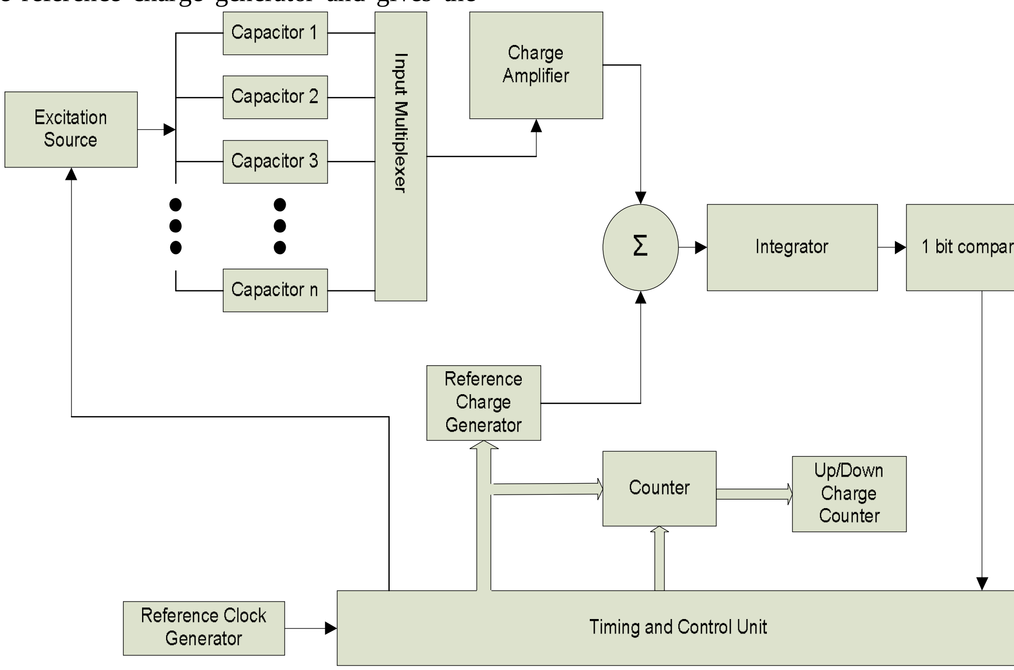

Fig 2. Block diagram of capacitance measuring circuit based on the reference charge method [2].

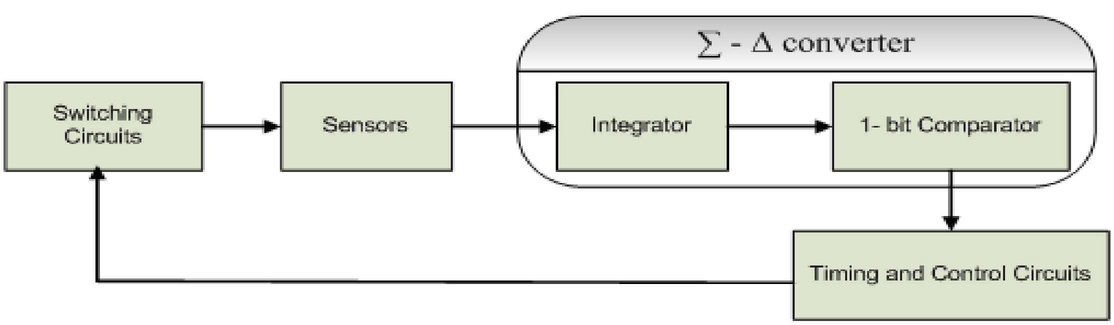

Fig3. Block diagram for basic Signal conditioning circuits based on ∑ - Δ Converter.

counter will be sampled by 64 times to increase the resolution. The measurement can be done within 2 cycles. Because of that the input offset voltage is cancelled and noise introduced due to low frequency for the input charge amplifier and integrator is reduced. The advantage of this method

Journal of Theoretical and Applied Information Technology
15 May 2012. Vol.39 No.1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

is two reference charge generator is used for "coarse and fine tuning". This reduces the conversion time; it has very high thermal stability, negligible integral non linearity and compensation for leakage currents of the capacitive sensor [2]. The limitation of this method is the measurement speed and noise level. Using this technique we able to achieve the measuring capacitor level is up to 1 pF but we can easily increase the next higher range.

4. INTERFACING CIRCUIT BASED ON SIGMA DELTA (∑ - Δ) CONVERTER

J. O'Dowd *et all* [5] proposed the technique in Fig.3 shows the structure of the basic Sigma – Delta Converter. Here the switching circuits gives the input to the sensors, the output of the sensor converter to a 1 bit output by analog to digital converter based on the integrator and the operational amplifier comparator.

The comparator gives either high or low signal which can be given as the input of the timing and control circuits driven by the flip flops. The output of the timing and control circuit is given to drive the switching circuit which provides the signal to the sensor. The circuit which provides linearity in the output and offers very high resolution is the Sigma – Delta Converter. For the capacitive sensor the physical parameter can be measured based on the equation (6)

$$C = \frac{\varepsilon A}{d} \quad (6)$$

ε - Relative permittivity of the medium

A – Area of the capacitor plates and

d – Distance between the capacitor plates.

If A or d is varied the sensors works based on this is called the position sensor otherwise if only A is varied that type of sensors are called the pressure sensors. For the humidity sensors only the ε varied.

The capacitive sensors are connected through the switching circuits. The switching circuits actions can be operated by the timing and control circuits. The output of the sensor given to the integrator and that output fed to the 1 bit comparator. Based on the 1 bit comparator output the timing and control circuitry made by flip flops control the switches by charging and discharging of the capacitor. Based on the charging and discharging time of the capacitor we can able to calculate the capacitor value. An integrator with a 1 bit comparator is called the Sigma Delta converter.

Most of the measurement circuits provides the voltage as the output and converts to the digital through an ADC. This type of conventional circuits has the high signal to noise ratio and provides very high sensitivity. Here the amplifier offset can be eliminated in the modulator cycle itself [5].The measured range of the capacitors is very less, its in the order of pico – Farads or lesser. Here the interfacing task is a challenging because the measuring capacitor value is very much smaller than the parasitic capacitance which is present in the circuit. To measure this small value of capacitance we can modify the Sigma Delta ADC slightly to a Monolithic Capacitance to Digital Converter (CDC). This circuit can able to produce the precise output which is not affected by the parasitic capacitor which is present. The proposed CDC contains the 2^{nd} order fully differential Sigma-Delta Modulator followed by a 3^{rd} order sinc filter. The modulator is driven by the 32KHz clock frequency and which is taken from 64KHz relaxation oscillator.

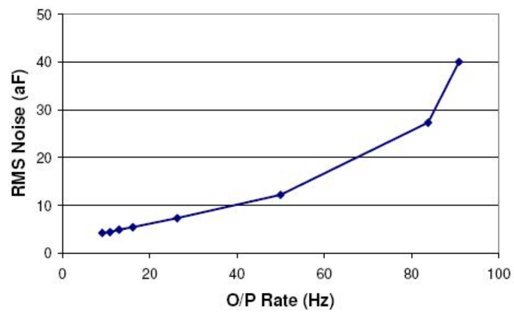

Fig 4: Noise vs. output rate [5].

5. SUMMARY AND DISCUSSION

This paper gives the brief idea about the smart interfacing circuits to measure the change in the capacitances. We have reviewed very few papers and discussed about the smart interface circuits. Each of this paper is having their own advantages and limitations. If we could measure the digital output directly from the sensor it will be the increasing advantage of interfacing with any digital components. It can concluded that the methods which we discussed here high precision circuits with low cost. It could able to measure even the small change of the capacitance. The researcher can able to modify easily and make it more precise. In addition to that the front end of the interface circuits can be easily modified to measure the very small changes in the capacitance. As a further improvement reduction of timing pulses that would cause the increase in throughput or response time of the total measurement circuitry.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

REFRENCES:

[1]. J. E. Gaitan-Pitre, M. Gasulla, and R. Pallas-Areny, "Analysis of a Direct Interface Circuit for Capacitive Sensors," IEEE Transactions on Instrumentation and Measurement, vol. 58, pp. 2931- 2937, Sep 2009.

[2]. R. Nojdelov and S. Nihtianov "Capacitive-sensor interface with high accuracy and stability", IEEE Transactions on Instrumentation and Measurement., vol. 58, no. 5, pp.1633 - 1639 , 2009.

[3]. X. Li and G. C. M. Meijer, "An accurate interface for capacitive sensors,"IEEE Trans. Instrum. Meas., vol. 51, no. 5, pp. 935–939, Oct. 2002.

[4]. Z. Ignjatovic and M. F. Bocko, "An interface circuit for measuring capacitance changes based upon capacitance-to-duty cycle (CDC) converter,"IEEE Sensors J., vol. 5, no. 3, pp. 403–410, Jun. 2005.

[5]. J. O'Dowd , A. Callanan , G. Banarie and E. Company-Bosch "Capacitive sensor interfacing using sigmadelta techniques", Proc. Sensors, 2005 IEEE, p.4 , 2005.

[6]. Richred Schreier, Gabor C. Temes, "Understanding Delta-Sigma Data Converter," IEEE Press, 2005, New York.

[7]. H. U. Meyer, "An integrated capacitive position sensor," IEEE Trans.Instrum. Meas., vol. 45, pp. 521–525, Apr. 1996.

[8]. D. M. G. Preethichandra and K. Shida, "A simple interface circuit to measure very small capacitance changes in capacitive sensors," IEEE Trans. Instrum. Meas., vol. 50, no. 6, pp. 1583–1586, Dec. 2001.

[9]. F. Goes and G. Meijer, "A novel low-cost capacitive-sensor interface,"IEEE Trans. Instrum. Meas., vol. 45, no. 2, pp. 536–540, Apr. 1996.