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Optimized Rc-Timing Technique for Accurate Measurement of Minute Capacitance Changes

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Abstract: This paper presents a technique for accurate measurement of small capacitive changes. This is based on selecting the most linear part of the curve obtained by charging through a known resistor value the capacitive element undergoing changes as a result of sugar level. This measurement is part of the design of a system for measuring blood glucose content non-invasively. The technique is based on measuring ultra-low glucose levels in the blood as capacitive changes converted into RC timing constant optimized using a circuit set to trigger at an appropriate time activating a counter. The measured data is captured instant later, selecting the most linear part of the charging curve. The results thus obtained are compared with the ones obtained through RC-timing standard technique. The result reported here are with a remarkable low error of about 2.25% when compared with 11.78% by the standard RC-timing technique.

Keywords: Distance learning, cloud computing, E-learning, M-learning, P-learning.

1. INTRODUCTION

Relative permittivity, □r, is a frequency dependent parameter, but at a low frequency, it becomes constant to characterize an insulation material. Assuming other dimensions constant, the capacitance of a parallel plate capacitor can be made dependent on relative permittivity, a parameter that varies with glucose levels (Karacolak 2015, Pimentel 2013, Sathyanath 2015 and Choi 2015). Glucose measurement has been investigated in the past using the invasive procedure through pathological tests in laboratories. The invasive procedure is time-consuming and carries the risk of contamination besides being associated with the inherited level of inaccuracy and inconvenience. Also, such methods suffer from errors as a result of manual entries. The invasive procedure is painful for the patient as it is normally repeated multiple times a day for reliable data. An additional drawback of the invasive technique is that it is unable to furnish continuous and real-time data for effective control of diabetes. Many applications of capacitive transducers are already used in biomedical engineering as well as oil industry just to measure the supply of water schemes and level of other liquids. Following are the other examples of capacitive transducers application such as measurement of liquid level, blood pressure, displacement, acceleration and also the moisture of material under certain condition (Arshad, 2016).Capacitance is an important parameter in electronics and therefore many techniques have been established for converting capacitive changes into measurable electrical signals or accurate values.

There are many types of sensors being used in the detection technique of parameters such as proximity, humidity, acceleration, position or displacement and fluid level. Among the capacitive sensing include track pads (Baxter, 2000), which have to be replaced by computer mouses making up a great example of a human-computer interface. Many others examples of these sensors form the digital part like a digital audio player, computer tablets, and mobile phone used the same technology as input devices (Wilson, 2009) and it can also change with mechanical buttons.This paper presents an experimental setup for measuring accurately the blood glucose level through non-invasive measurements made in real time by microcontroller-based measurement board using the RC-timing technique. Capacitive sensing measurement can be realized by various methods, such as voltage ramp, resonant frequency, and RC timing. The solution proposed here uses minimal hardware and software, which utilizes available resources of microcontrollers and also improves the system's accuracy.

2. RCTIMING FOR ACCURATE MEASUREMENT

The RC-timing method is explained as shown in **(Fig.1).** In general, in the RC-timing method, the time taken to charge up the capacitor under test to a certain threshold level is manipulated to estimate the capacitance value. Theoretically, this can easily be proved by using the general capacitor charging equation such as (1).

$$v_c = V_o + (V_s - V_o)\left(1 - e^{-\frac{t}{\tau}}\right)$$

Where $\tau = RC$ is called time constant.

Making initial voltage, $V_o = 0$ V,

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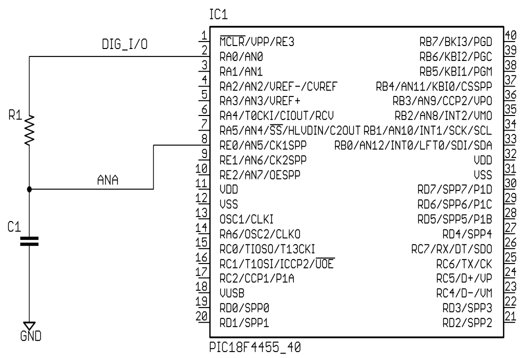

Fig 1: Typical Standard RC-timing circuit

Equation (1) can be rearranged as

$$e^{\frac{t}{RC}} = 1 - \frac{v_c}{V_s} \qquad (2)$$

By substituting v_c equal to 2.5V and V equal to 5V, (2) can be written as

$$e^{-\frac{t}{RC}} = 0.5 \qquad (3)$$

Taking the natural logarithm (ln) for both sides of (3)

$$\frac{t}{RC} = 0.693147 \qquad (4)$$

Therefore, C can be reduced to $C = \dfrac{t}{R \times 0.693147}$ (5)

Whereas in a real implementation, the microcontroller is used to discharge the capacitor prior to every measurement cycle. The charge and discharge of the capacitor, C1, takes place through the resistor, R1, pulling down/up the DIG_I/O while measuring ANA. With zero on DIG_I/O, the capacitor is discharged until ANA reaches 0V. Later, pulling up the DIG_I/O 5V charges the capacitor up. The CCP pin is applied to the positive input of two comparators within the microcontroller board as shown in Fig. 5. The negative input of the CMP1A is set to 2.5V while that of CMP1B is alternatively set to 0V, 0.5V and 1V. With the logic ‘1’ on the output of CMP1B, the timer is set to count up until logic ‘1’ appears on the output of CMP1A to stop it. The time taken to charge up the capacitor from 0 to 2.5V is calculated by multiplying the timer value, *p*, with the reciprocal of system clock operating frequency, F_{osc}, and the timer count, N_t as given in (6).

$$t = \frac{4}{F_{osc}} \times p \times N_t \qquad (6)$$

Where

F_{osc} is the operating frequency

p Prescaler value of the timer

N_t timer count

The whole process as discussed is repeated for the next measurement for the next two measurements in which the threshold to the negative of CMP1B is set to 0.5V and 1V.

3. TIMING DIAGRAM OF EXPERIMENTAL SETUP

The RC-timing method is simple in implementation and cost-effective for capacitance measurement. For this purpose, microchip downloader is used for programming the microcontroller. Though the linearity issues are addressed, however, the accuracy of the technique is estimated through producing an error plot. The main reason for inaccuracy is due to the uncertainty in the reading of the exact start and end values of the time. Additionally, the delay caused by the analog module in sampling and converting into digital make another source of error to this effect. The simple filtering technique such the sum averaging filter method can be applied to reduce the problem. But, the inclusion of the sum averaging filter method to the system has introduced drawback to overall system performance. It is clear that the time to compute the final measurement is prolonged by a number of data sampled. Therefore, in this paper, the modification in sampling the exact start and end timer values is proposed to improve the system accuracy performance. The concept is replacing the analog module to start and stop comparator unit. **(Fig. 2, 3 & 4)** shows the experimental setup of the Standard and Modified capacitive sensing circuit.

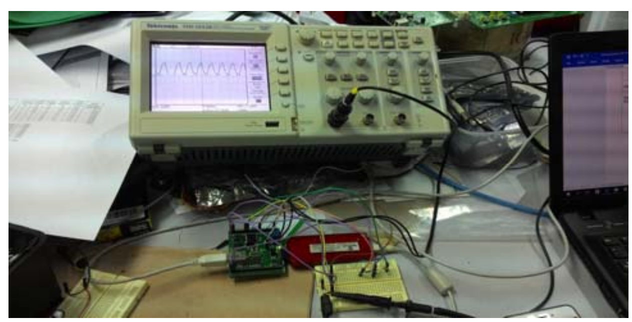

Fig 2: The experimental setup of capacitive sensing circuit

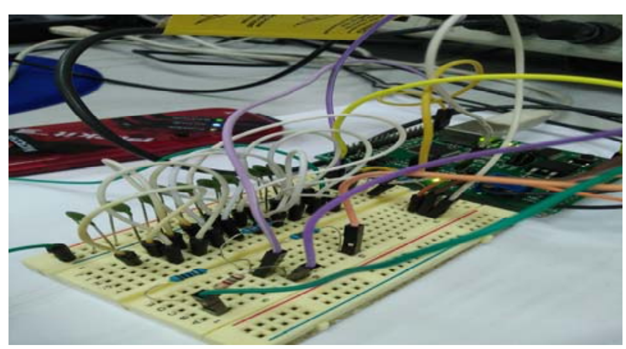

Fig 3: Standard RC-timing circuit

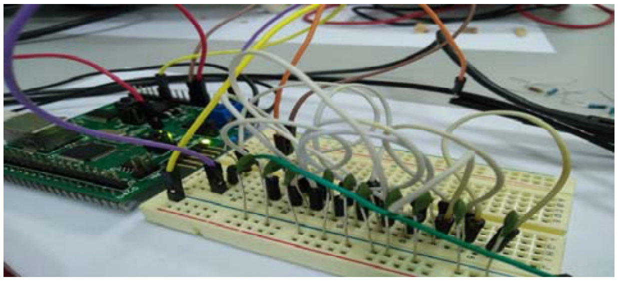

Fig 4: Modified RC-timing circuit

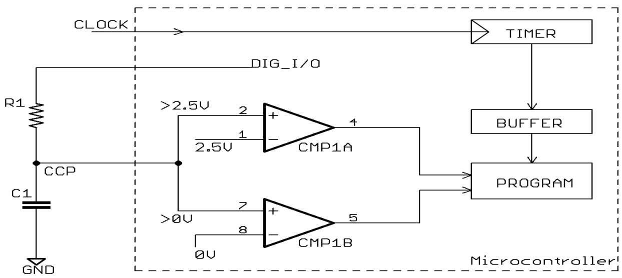

Fig5: RC-Timing Method using Compare

As shown in **(Fig. 5)**. in the modified RC-Timing method, the analog channel module routine of controlling the block of reading the start and end timer values are replaced with the comparator module. As in the previous method, the same principle of discharging and charging capacitor is applied. Pulling down the DIG_I/O pin until the threshold voltage becomes zero discharges the capacitor. When the threshold voltage reached zero, both comparator outputs are zero. Then, pulling up DIG_I/O pin to 5V charges capacitor up. The charging of the voltage across the capacitor is measured against the threshold values of 0V, 0.5V and 1V. The microcontroller is programmed to measure the capacitance value for the three-threshold voltage values applied to the negative input of CMP1B. Finally, the microcontroller calculates the measured capacitance as discussed previously. The timing diagram for the charging and discharging is given as in Fig. 6. The measured capacitance values for the timing diagram of **(Fig. 4a)** are listed for comparison against similar values obtained through the standard RC-timing procedure.

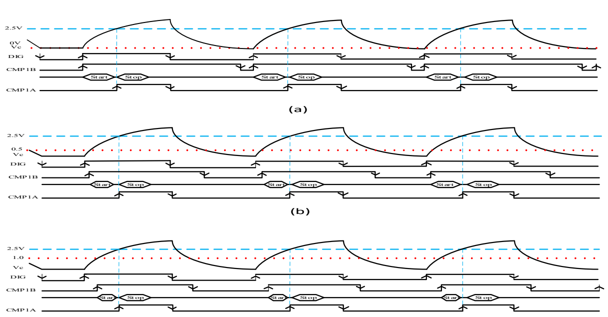

Fig 6: Timing Diagram for Capture/Compare Method

(Fig 6) shows the waveforms obtained under different voltage levels applied to the negative input of CMP1B, showing that accuracy increases for increased voltage level or reduced non-linearity. **(Fig 6a)** is for 0V, **(Fig 6b)** is with 0.5V, and **(Fig 6c)** is with 1.0V, showing improved linearity and more accurate results.

4. RESULTS AND DISCUSSION

The capacitance varies with relative permittivity with frequency as shown in **(Fig 7).** The relative permittivity of the blood of sugar level 800mg/dL stands is 32 at 20GHz Variation of relative permittivity with frequency, as shown in **(Fig 7),** is affecting the change in capacitance values to be measured by the reported techniques, as reported in **(Table 1).**

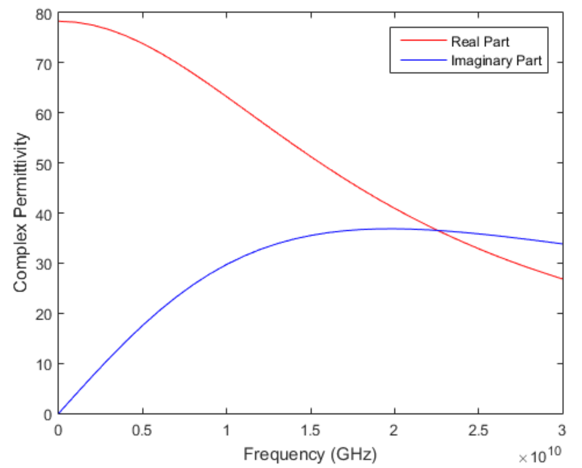

Fig 7: Relative permittivity of distilled water with the Debye model

(Table 1) shows the actual value of the capacitors being measured by the two techniques of standard RC timing and modified RC-timing. There are seven different values of capacitors ranging from 0.1uF to 33uF are selected for the experiment, and measured by the two techniques as shown in **(Fig 8).** Using the standard capacitance meter does the measurement of actual capacitor value. Close examination of row-5 and row-6 shows that the error in SRCT is increasing by decreasing the capacitance value being measured; while the error in MRCT is almost similar at any capacitance measured. The average error in SRCT is about 11.78% while the average error in MRCT is about 2.25%.

As shown in **(Fig 9),** it is concluded that smaller capacitance value indicates the larger error compared to the larger size capacitance for SRCT. For instance, with a capacitor 0.1uF, the error by SRCT is 16% whereas for 22uF the error by SRCT is 8.09%.

VALUE OF CAPACITOR (uF)	STANDARD RC TIMING (uF)	MODIFIED RC TIMING (uF)	MODIFIED RC TIMING - Linearization (uF)	MEASURED CAPACITANCE (uF)	ERROR STANDARD RC TIMING (SRCT)	ERROR MODIFIED RC TIMING (MRCT)	ERROR MODIFIED RC TIMING - Linearization(MRCT)
0.1	0.145	0.127	0.126	0.125	16.00%	1.60%	0.80%
1	1.267	1.11	1.095	1.09	16.24%	1.83%	0.46%
2.2	2.543	2.17	2.23	2.21	15.07%	1.81%	0.90%
4.7	4.1	4.71	4.65	4.62	11.26%	1.95%	0.65%
10	12	10.8	10.9	11	9.09%	1.82%	0.91%
22	25.4	23.9	23.7	23.5	8.09%	1.70%	0.85%
33	35	33.3	33.1	32.8	6.71%	1.52%	0.91%

Table 1: The experimental measurements of capacitance using SRCT and MRCT

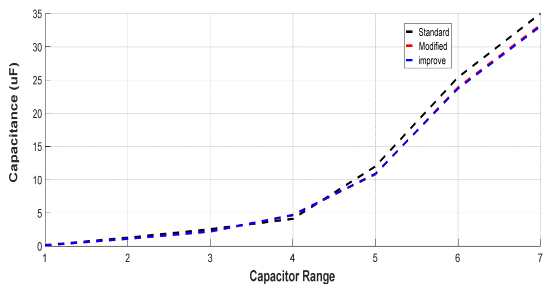

Fig 8: The RC-Timing, Modified, and Measured Plot

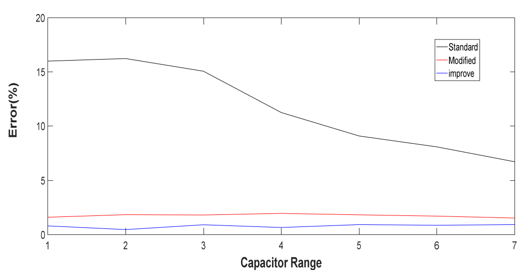

Fig 9: The Error between Standard and Modified RC Timin

5. CONCLUSION

Two capacitance measurement techniques are introduced in this paper with a marked difference of accuracy in the modified RC-timing method. The standard RC timing using the analog module suffers from effects of delay in reading the capacitor. To overcome the sluggishness, introducing comparator-based method modifies the technique. Replacing the analog module of the basic RC timing with the comparator does this. The comparator's output is used for starting a counter until the output another comparator turn logic ‘1’. The comparators used are biased such that the most linear part of the charging curve is selected. The two techniques are used for accurate measurement of seven capacitance values as representative of the sugar levels. The comparative results of the two techniques shown in **(Fig. 8 and 9)** make the main contribution, which is based on results derived from the further part of work already reported by the same authors in (Zaharudin, 2017). The average error in Standard RC Timing (SRCT) is about 11.78% while the average error in Modified RC Timing (MRCT) is about 2.25%, which is reflective of the improved accuracy in the Standard RC Timing procedure.

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