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LOW VALUE CAPACITANCE MEASUREMENT SYSTEM FOR THE APPLICATION OF MONITORING HUMAN BODY

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ABSTRACT

The core focus of this work is to design and develop a reliable capacitance sensing system for measuring very small capacitive changes at low frequencies. The sensing system is applicable in monitoring and characterizing human body movement. The interface circuit measures very small capacitive variation. Some capacitive values have been fixed and the produced capacitive changes have been measured for validating the possibility to monitor and detect the presence of human bodies. A variation in capacitance causes a variation in the output voltage. Due to the variation of output voltages, the presence or absence of the human body can be detected. Primary simulation results show that the measurement of little capacitance variation using an interface circuit is precise and linear. With the presence of a human body in the area right above the sensor, a capacitance variation as well as output voltage can be observed.

Keywords: human body, timer, frequency-to-voltage converter, capacitance-to-voltage converter, capacitance.

INTRODUCTION

Capacitance measurement technique is one of the most crucial parameters in the industrial applications. From the measurement perspective, the change in some factors namely dielectric, area, distance between capacitor plates is used for measuring different properties of material. Capacitive sensors use electrodes that are constructed in such a way that the parameter to be measured causes a change in the capacitance of capacitive sensors which results to producing a voltage. A measurement circuit is linked to the capacitive sensors which can thereby provide information on the sensor changes. The signals obtained at the output of the sensing devices may become a source of information for monitoring the elderly's. Consequently enabling the services' personnel to predict, diagnose, and timely respond to adverse or soon to be deteriorating health conditions. Capacitive measurement technique for human body monitoring is initiated on the fundamental principle based on conversion of measured physical parameter (displacement) into capacitance. The measured capacitance can be used to visualize the movement of the person being monitored. Hence, the capacitance to be measured is actually proportional to the physical parameter by electrical method. The measured capacitance is transformed into electrical signal (generally voltage). Researchers have reported various capacitive sensing techniques to determine little capacitance variation from the capacitive sensors and process it. Precise measurement of very little capacitance variation has always been a major issue. A very little capacitance variation can change the output. This very small variation should be taken into account in industrial sectors and also in real time applications. A good degree of linearity, accuracy and resolution demands for a precisely designed circuit and good layout of the full system. To achieve such a system,

several efforts have been made on the measurement circuit, the commonly known solutions for measuring small change in capacitance are based on AC bridge method, double differential principle, charging and discharging methods, the switched capacitor technique and capacitance to phase angle conversion.

In selecting and designing the capacitance measuring circuit, it is important to note that the measuring system should be sensitive to measuring small changes in capacitance, a good reliability, linearity and accuracy is needed as well as able to deal with issues of stray capacitance.

CAPACITIVE SENSING TECHNIQUE FOR SMALL CHANGE IN CAPACITANCE MEASUREMENT

For measuring small capacitance change, many capacitance measurement schemes were implemented in an Integrated Circuit (IC). A research by [1], has reported a method which measures very small capacitance change in capacitive sensors. The measurement technique was based on double differential principle. The measured capacitance is not based on the initial capacitance of the sensor. This technique has the benefit of automatically cancelling the sensor-connecting parallel plate capacitances. Figure-1 illustrates a schematic diagram of the circuit.

The excitation signal is applied to sensor's capacitance as well as to a reference capacitance. A gyrator circuit has been used to realize reference capacitor. For both the arms an active rectifier along with a low pass filter are used to reduce the error. From there the rectified DC output voltage is given to 24 bit sigma-delta ADC. It transforms the time varying output to an average DC output signal. The computer's memory stores the output of ADC. With this ADC output, the capacitance variation is measured which does not depend on the initial

capacitance. In case of some capacitive sensors in Pico Farad range, a very high resolution that is the change of output (ΔC) in the range of 10^{-18} Farads is found. Here the observed output does not depend on the initial capacitance and also very precise. This circuit has a very simple design, provides very good sensitivity and accuracy and is of low cost as well as it implements a 24 bit ADC to provide a high resolution. However, the proposed circuit is only applicable to single element capacitive sensors.
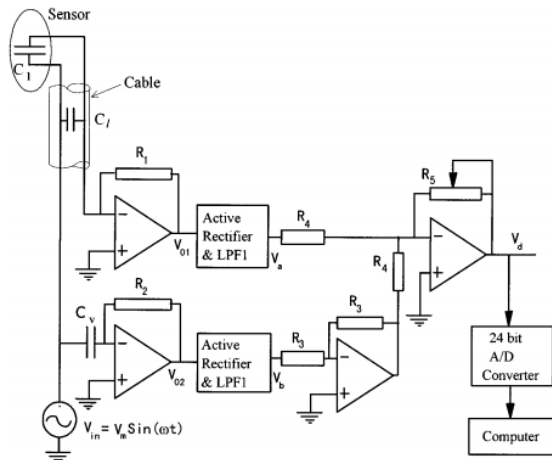

Figure-1. Schematic diagram for measuring capacitance using double differential principle [1].

In [2] another promising capacitive sensing technique on measuring small capacitance has been proposed. The researchers developed a low power consumption capacitance measuring circuit that computes very low capacitance with high resolution and high level of linearity. The application of such capacitance measurement technique could be in bio medical sectors. The differential arrangement of the circuit reduces even order distortions. Basically two current sense amplifiers have been used in the circuit which has two PMOS-diode rectifiers and an instrumentation amplifier. Figure-2 illustrates a schematic diagram of the circuit. The circuit consists of a sensing capacitor and reference capacitor.

The excitation signal is implied such that one of the capacitive plates is common terminal for both the capacitors. The other capacitor plates are connected to current sense amplifiers; the output of which is given to PMOS diode rectifier for transforming it into DC signal. In lieu of NMOS diode, PMOS diode is used due to its small flickering noise. The DC signal is then given to an instrumentation amplifier which has adjustable gain. Due to the variable gain, the sensitivity can also be enhanced or lowered accordingly. The prototype circuit was fabricated using TSMC 0.35 μm bulk CMOS process which has been designed and simulated by Cadence Spectre simulator. Generally a reference capacitor of pF range is used in this technique. The circuit is able to make a variation of 1.32 mV for a variation of 1 fF. The circuit can be crucial for measuring very little capacitances in the range of fF (10^{-15}

Farads). Because of its high Common Mode Rejection Ratio (CMRR) this is quite suitable for bio medical sensor applications.
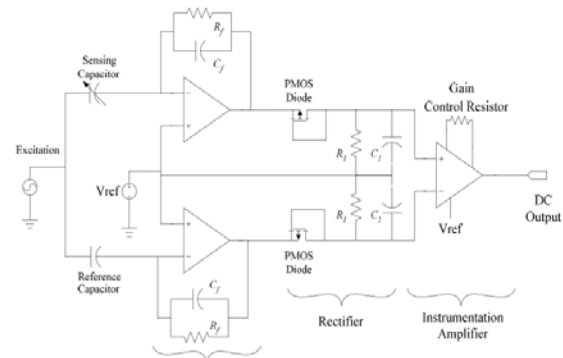

Figure-2. Schematic diagram for sensor read-out circuit [2].

In [3], a capacitance measuring system based on RC phase delay was developed. The proposed system uses the technique of charging and discharging the unknown capacitor through an RC network. The RC network delays the change in state of the reference input square wave signal to obtain a pulse width modulated signal based on the phase delay by passing through the RC network. The schematic diagram of the circuit is shown in Figure-3.

When the input is low, the output stays low till the input becomes high. With high input, the output becomes high and stays high, i.e., duty cycle becomes proportional to unknown capacitance. To eliminate the nonlinearity issue a MOSFET switch has been used by discharging the unknown capacitor during each cycle of measurement.

The prototype circuit was built on a surface mounted PCB using CMOS hex inverter IC and n channel MOSFET. A variable capacitor of 0.7-20 pF has been used. The obtained circuit output is a pulse width modulated signal where the duty cycle is actually proportional to the capacitance variation.
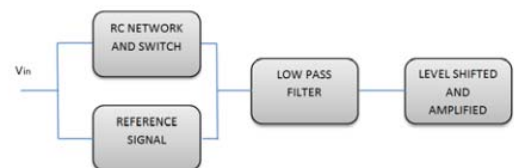

Figure-3. Block diagram for capacitance measurement based on RC phase delay [3].

A sensitivity of 246 mV/pF has been obtained for the prototype circuit. The output PWM signal has been low pass filtered, level shifted as well as amplified.

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The circuit is quite effective for measuring capacitance in the range of tens or pF or smaller. The calculated output shows a linear response with high sensitivity. CMOS electronics has been used in the circuit which can be effortlessly implemented as an ASIC in chip. The measurement method needs small amount of components and the circuit is simple structured.

Ali Heidary *et al.* proposed an integrated interface design for grounded capacitive sensors [4]. This technique is based on a feed-forward method to lessen the parasitic cable capacitance effects and also gives immunity along with a front-end amplifier. The researchers designed a standard 0.7 μm CMOS technology circuit as well as implemented using an integrated circuit. This circuit has been verified theoretically and also simulation has been carried out to analyze experimental data for parasitic capacitance found from connecting cable. The circuit comprises of a new capacitance-to-voltage converter, a voltage-to-period converter, a multiplexer as well as a control unit. A three signal calibration technique has been used in this circuit. The multiplexer is used for switching capacitance for input to C to V converter. Thus the effect of parasitic capacitance can be eradicated without any instability issue. Then comes the voltage-to-period converter which can be optimized regardless of the sensor capacitance range.

According to the achieved results, for capacitance of 10 pF range with connection cable of 30 m can be computed with error smaller than 0.3 pF. The measured capacitance nonlinearity ranges from 10 pF to 330 pF with cable length of 30 m which is less than 3×10^{-4}. The circuit can be applied for measuring very small capacitance variation in capacitance transducer applications.

This work proposes a simple method, which can easily integrate capacitance measurement into the application of human interface. The capacitance needs to be converted into electrical signal (usually voltage) for computing the capacitance using electrical method. A capacitance - to - voltage converter (CVC) performs this operation. By using the National Semiconductor IC Code LM2917, a linear relationship between small changes in capacitance and the output voltage can be produced. An overview of the theoretical background of capacitive sensing technology is presented; simulation is carried out using Proteus software.

SYSTEM DESCRIPTION

The system is developed with the aim to discriminate and characterize human movements on the basis of the distance change between the electrodes. This is obtained by means of capacitance measurements taken from sensing electrodes buried under the floor, initially isolated from human contact. The height, weight and so on, makes each person unique in this matter, thus different human body will affect the capacitance of the sensing electrodes measured by a purposely developed electronic interface system. A sequence of capacitive value has been

set in the proposed system and the generated capacitance variations have been measured in order to verify the possibility to discriminate the different human bodies. Moreover this system will allow the characterization of different human bodies when more than one person is present.

The use of 555-timer circuit [6] is known to be one of the simplest methods to convert capacitance to frequency. The output frequency of the astable 555 timer can be changed into voltage using a linear frequency-to-voltage (F/V) converter circuit, which is the LM2917 IC [5]. However, in a work conducted by [7], the author describes that this method is not reliable since the capacitance-to-frequency (C/F) characteristic curve of 555 timer is non-linear and the characteristic curve of the IC LM2917 is linear. Hence, it becomes difficult to recover the value of the measured capacitance. The author in [7] further suggests using the IC LM2917 as a capacitance-to-voltage converter instead of its usual use as frequency-to-voltage converter.

An astable 555-timer is configured to operate at 1 kHz. The combination of the two 4.7 kΩ resistors and 0.1 μF capacitor make up the RC timing required for the 555 to produce this clock speed. The clock pulse becomes the input of the IC LM2917. The circuit diagram in Figure-4 forms a linear capacitive-to-voltage converter circuit.
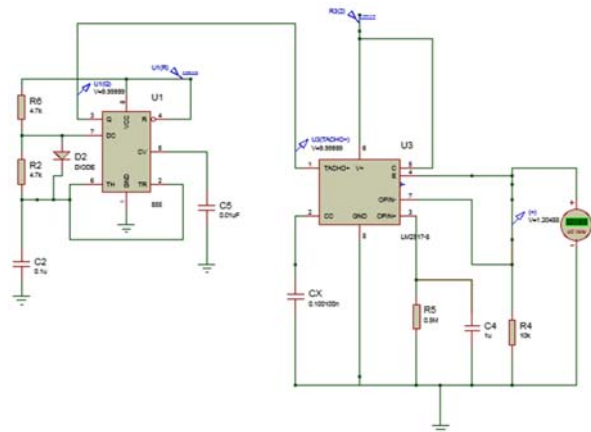

Figure-4. Capacitance to voltage converter circuit diagram.

The mathematical expression for determining the output voltage of the circuit is given in Equation (1) [5],

$$V_{OUT} = F_{IN} \times V_{CC} \times R \times C_X \qquad (1)$$

Assuming the input frequency F_{IN}, voltage supply V_{CC} and resistor R values are made to be fixed. In this application $V_{CC}=10V$, the C_X value is tested for capacitance in the range 0.1 ηF to 10 mF.

By means of Equation (1) the linear relationship between change in capacitance and output voltage can be

calculated, with DC corresponding to 0V as a minimum limit and maximum range of C_X corresponding to Vcc as a maximum limit. The capacitance measurement circuit can be linked to a first order low pass filter in order to eliminate noise and to obtain a clean DC output.
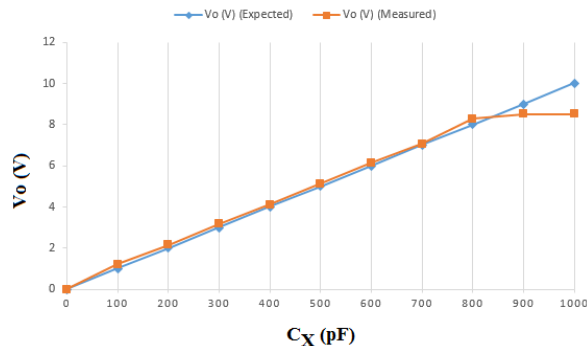
RESULTS AND DISCUSSIONS

Figure-5. Capacitance to voltage characteristic curve.

The circuit in Figure-4 is tested via proteus simulation software for different ranges of Cx. An illustration of the attained results for the measured capacitance Cx in the range of 0.1 ηF to 10 mF is presented in Figure-5. From this Figure, it is easy to perceive that this C/V converter has a linear capacitance-voltage characteristic.

The graph in Figure-5 comprises of expected result, obtained via mathematical analysis by using Equation (1) and measured result through simulation analysis. The graph is plotted for the change in capacitance value C_X against the DC output voltage. When $C_X=0$, the output obtained is $V_{out}= 0$, and for C_X of 100 pF its output is 1Volt similarly for input of 200pF its output is 2 volts, etc. This indicates that the output of capacitance to voltage circuit is a linear function. Measured capacitive values beyond 800 pF showed a flat response, this behaviour explains that the C/V circuit cannot withstand more than 800 pF and will output a constant voltage of 8 volts for a capacitance value of 800 pF or more. In order to improve this V_{CC} value of LM2917 can be increased further, but by doing this the voltage output will no longer be linear.

CONCLUSIONS

This paper presents the measurement results of very small capacitance variation. The technique applied obtain such result was by using a capacitance to voltage converter circuit. The method is of low cost, reliable and gives a precise linear measurement of the capacitance for a measured capacitance range of 0.1 ηF to 10 mF. The focus of this work was to use this capacitance measurement circuit for the application of measuring change in capacitance produced by the interaction of a human body

on capacitive sensors. It can be concluded that when a human body enters the vicinity area right above the sensor, a change in capacitance is observed. This change in capacitance changes with the distance between the human body and the sensors. A variation in capacitance results in a variation on the output voltage, hence, based on change in the voltage conclusion can be made regarding the presence/absence of the human body. Such that if the sensor indicates a change in capacitance of 0 pF, this can indicate the absence of the human body whereas when a slight change in capacitance is notice, it can be said that a human body is present.

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