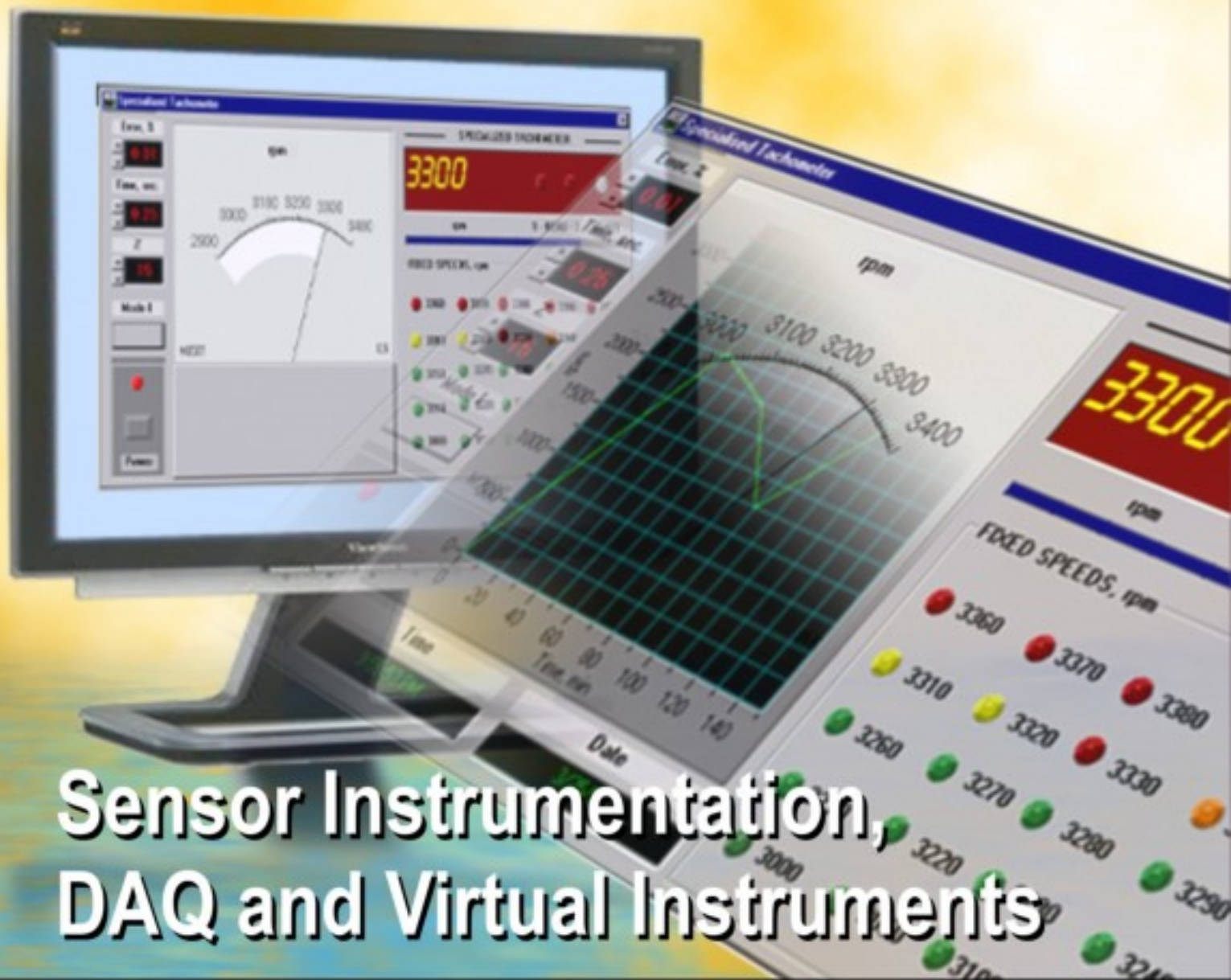


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Design of High-Speed Pulse Input Based Capacitance Measurement for Electrical Capacitance Tomography

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Abstract: The High Speed pulse input based capacitance measurement has been designed for electrical capacitance tomography. It has a high resolution with low offset and extremely low gain drift, compared with a charge/discharge and AC based Transducer designed for same purpose. This paper focuses on the development of new sensing methods to measure the capacitance range from femto farad up to 100nfarad. All functions are programmed in an embedded controller (PIC16F874A/877A), which can be easily translated in to the capacitance with noise level to 0.2 % and sensitivity of the measurement up to 0.18-femto farads/micro volt ranges.

Keywords: Electrical Capacitance tomography, Sensor design, Capacitance measurement, Time-to-Digital Converter, Embedded Controller.

1. Introduction

Electrical Capacitance tomography (ECT) is a relatively new imaging technique, which can be used for visualizing the internal structure and behaviors of various industrial processes involving non conducting materials [1-4], such as gas/oil flows in oil pipe lines, gas/solid flows in fluidization processes in fluidized beds. Measuring the electrical capacitance between sets of electrodes placed around its periphery and converting them into an image showing the distribution of permittivity can do it. ECT can be used with non-conducting materials such as plastics, hydrocarbons, sand or glass and often used with mixtures of two different dielectric materials. The sensor consists of a set of electrodes

symmetrically mounted outside on insulating pipe. The sensing electronics measure the capacitances for all possible electrode combinations. The cross section of the 8-electrode ECT sensor for investigation is shown in Fig.1.

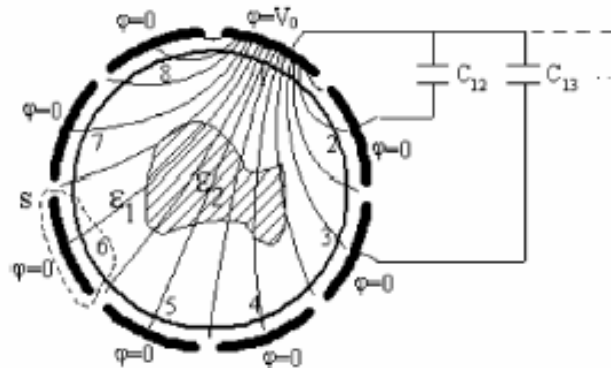


Fig 1. Schematic diagram of ECT sensor.

There are three types of Capacitance transducer have been developed and functioning in ECT system. 1) Charge / discharge based type [1, 2], 2). Ac based type [2, 4] and 3) Active differentiator based transducer [5]. This paper is concerned with High Speed pulse based capacitance measurement up to Femto farad level with high precision and high measuring rates.

2. Sensor Design and Capacitance Measurement

Modeling and design studies of sensor for measuring the electrical properties of material are critical steps for ensuring the desired sensor performance under real conditions. Electrical sensor is nowadays widely used in a variety of industrial application as well as for research purposes. A common theme among all applications of electrical sensor is an inherent interaction between the electrical field generated by the sensor and the environment in which the sensor operates. This study includes the external condition of the sensor; geometrical feature of the sensor, such as the thickness of the insulating pipe, guarding methods and material present inside of the pipe.

2.1 Sensor Design

The ECT sensor is designed by methods of electroplating and etching method to form a sensor with 8 electrodes. The designed 8-electrode sensor is shown in Fig. 2. The procedure can be extended to make a sensor with higher electrode combination such as 12 and 16. A cylindrical section of PVC pipe of 50 mm diameter and 500 mm length is initially electroplated with copper. Then etching process is used to form electrodes of length 100 mm and width 20 mm. The spacing between electrodes is maintained at 2.5 mm. The radial screen of 1.5 mm width is formed. This configuration leaves a spacing of 0.5 mm between copper coatings and ensures continuity on electrical field. The electrical connections are made by wrapping a 2 mm thick flexible sheet with projections for electrical connection on inner side and electrical path on the outer side. This arrangement makes the sensor mounting easy and more robust.



Fig. 2. Electrical Capacitance Tomography sensor.

2.2 Capacitance Measurement

The resolution of the ECT system depends upon the how fast the transducer senses the small change in capacitance with higher degree of accuracy and the number of electrode plates used in the system. The conventional ECT sensor use charge discharge principle developed by Huang [3] to measure the capacitance, in this method charge.

Injection problem will occur by CMOS switch. Some charging voltages accumulated during discharge period, measurement error from stray capacitance and sensing speed is low. W.Q.Yang [1, 2] has developed capacitance tomography with out CMOS switch; the principle of circuit is each electrode of the sensor connected to the invert input of an opamp with capacitance and resistance feedback paths. The non-invert input of the opamp is connected to the output of an amplitude-controllable sine wave signal generator, which is constructed from a digital to analog converter (DAC) and an analog multiplier. In AC based capacitance transducer developed by J. C. Gamio, [4] it has high signal to noise ratio, measurement error from stray capacitance and drift gain affect the measurement.

3. Proposed Method

The present work is aimed at designing a fast responding sensor for on-line control applications. This involves selection of suitable method for measuring capacitance, electrode driving circuit and a fast analysis of measured data. The process response speeds of at least 1 MHz are required for multi-phase systems to capture hydrodynamics and monitoring process parameters.

3.1 Principle of Pulse Input Based Measurement

The block diagram representation of pulse-based measurement is shown in Fig.3. The micro controller generate the short pulse signal is applied to the measured capacitance C_x , producing charging peak voltage. The charging peak voltage digitized and interfaced with computer for image reconstruction and analysis.

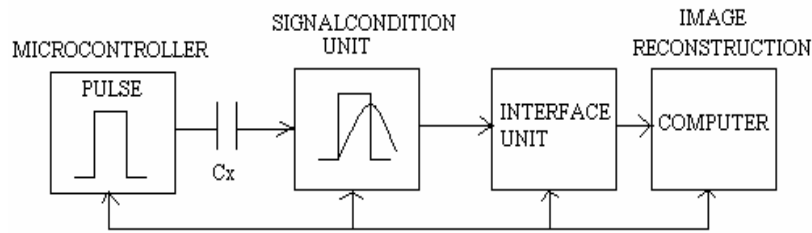


Fig. 3. Block diagram representation of pulse based measurement.

The single set capacitance measurement for ECT system is like a first order system. The overall system gain governed by the equation:

$$G(s) = K/\tau s + 1, \quad (1)$$

where $\tau = RC$ is the time constant of the system, C is the capacitance between inter electrode and R is the resistance drop. K is the overall gain of the system. When the pulse input is given to the system with δ (pulse period) and amplitude A . function of the input equation is given:

$$X(t) = A\{U(t) - U(t - \delta)\} \quad (2)$$

The inter electrode capacitance is charged during δ (pulse period) and discharged. The charging voltage depends on the capacitance and is calculated from the following equation.

$$Y(t) = KA\{1 - e^{-t/\tau} - U(t - \delta) - (1 - e^{-(t - \delta)/\tau})\} \quad (3)$$

For detecting peak value substituting the value of $t = \delta$, the output equation of the inter electrode system is given:

$$Y(t) = KA\{1 - e^{-t/\tau}\} \quad (4)$$

3.2 Experimental Work

The above-mentioned principle designed and takes real time reading by using micro controller. The measuring principle is a direct derivative of the capacitance (nano strain) measuring principle. The source signal with an amplitude of 5 V and 400 nanosecond short pulses is generated by a high speed Embedded controller (PIC16F874A/877A). The capacitor are charged to the supply voltage and discharged suddenly. The analog multiplexer (ADG528AKN) can be used to select the source and detector electrode. The multiplexer are operated with very high speed according to the channel selection by the micro controller. Data from the multiplexer transmitted to the computer by using the parallel communication. The 16 bits Analog to digital converter (ADS7805P) used convert analog signal to digital and interfaced to the computer for image reconstruction. The circuit diagram of measurement system as shown in Fig.4. First excitation pulse is applied to electrode 1 while keeping all other at zero potential and measure charging voltage between the electrode 1 and 2 at 300 nanosecond after giving starting time of pulse. The output of the multiplexer (charged voltage) is given to ADC. The ADC converter takes 10 micro sec times to convert digital signal for one measurement. After getting status signal from computer, the controller sends the control signal to the multiplexer to select detecting electrode 3 and this process continues until electrode pair 1-8 is measured. Next, excitation electrode 2 is selected and electrode pairs 2-3, 2-4... 2-8, are measured.

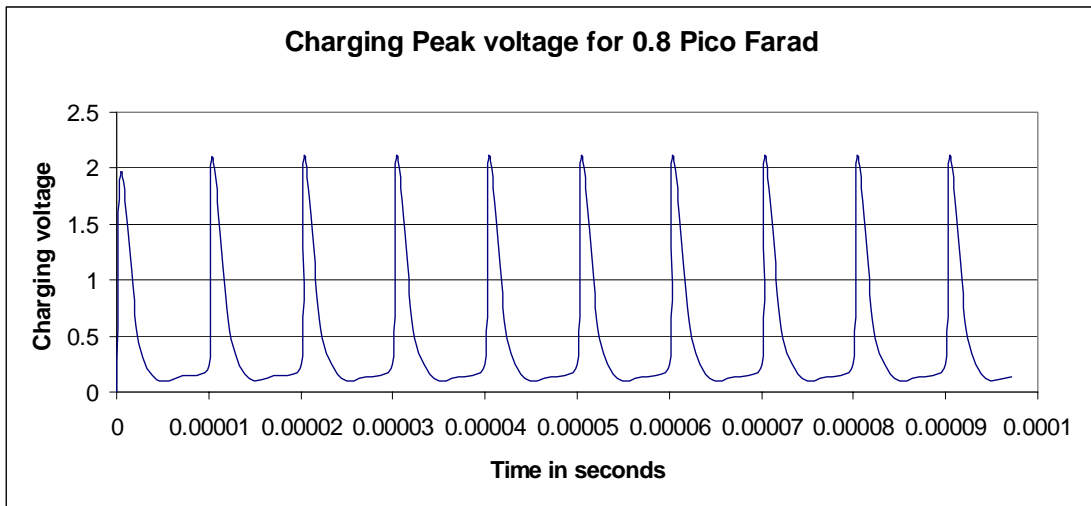


Fig. 6. Pulse response of the capacitance measurement.

The charging peak voltage is detected for different values capacitance and drawn the graph between capacitance and charging voltage as shown in Fig.7. The high value of capacitance will take more time to fully charge since the peak voltage at $t=\delta$ is very small (large slope). The low ranges of capacitance are quickly charged since the peak voltage is high. The response of the capacitance versus charge voltage exponentially in nature, sensitivity of low range capacitance is very high.

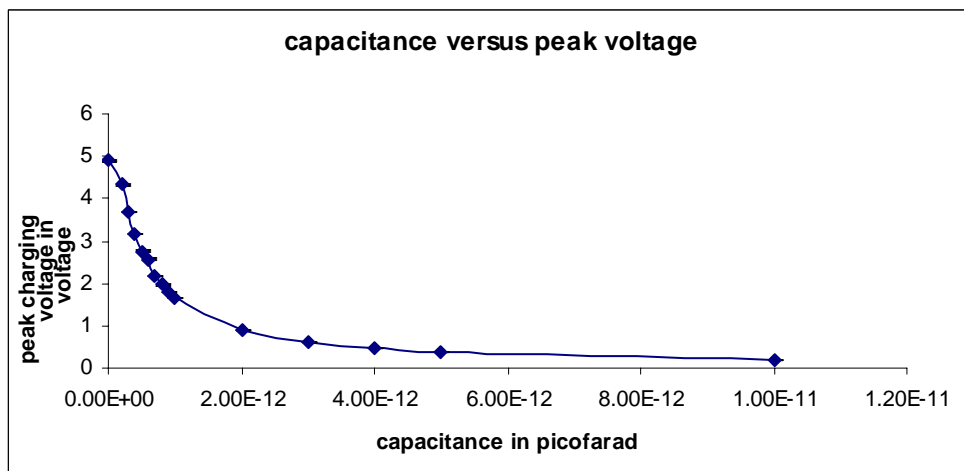


Fig. 7. Capacitance versus charging voltage.

The performance of an ECT sensor was analyzed for the range of dielectric material ($1 \leq \epsilon_r \leq 80$). Measurements performed by the ECT system are based on a two-point calibration procedure. The sensitivity studies are carried out and reported. It is found that the selected method is sensitive to detect 0.18fF. The difference in permittivity can be estimated for different multi-phase system is given in Table 1.

Table 1. Permittivity difference detectable for various two-phase systems.

0.0012 - 0.064	Air-water
0.007 - 0.04	Air-glass
0.003 - 0.016	Air-polymer beads

The maximum capacitance, occurs between adjacent electrodes, for the given sensor size is estimated as 2.65 pF from Numerical simulations using ANSYS 9. The response curve shown in Fig. 8. indicates a sharp fall in sensitivity for capacitances above 3pF. The selected method for measuring capacitance is of agreeable accuracy.

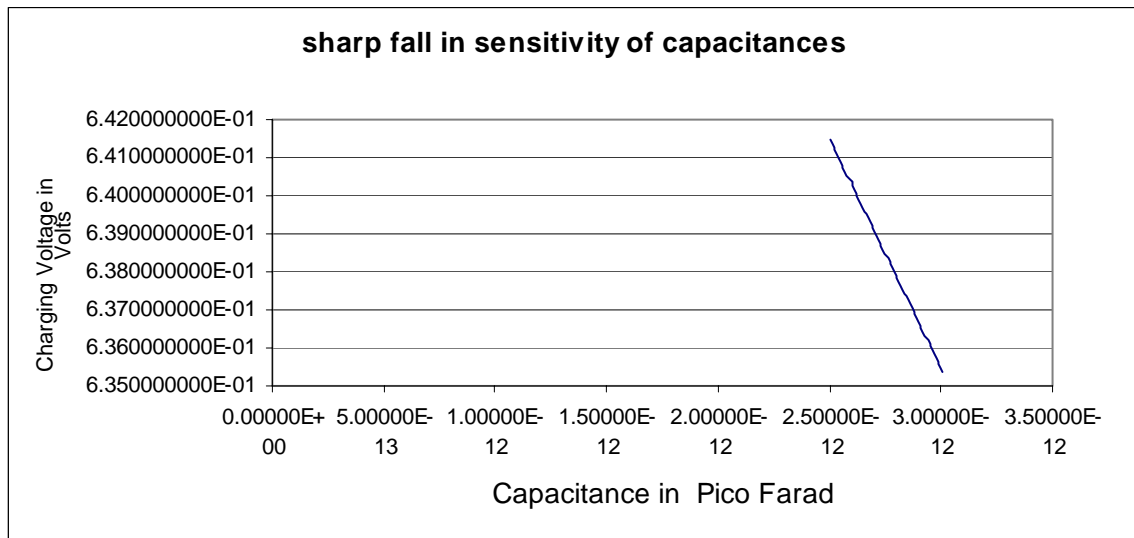


Fig. 8. Sharp fall in Sensitivity of Capacitance Measurement.

In this technique maximum speed of data conversion are 3500 frames per sec for static system (28 measurements). The speed of this system is high compared to all other system. This research results show that the measurement of capacitance range from femto farad up to 3 pico farad, high resolution, and high sensitivity and less measurement error.

5. Conclusions

The research of our short pulse based capacitance measurement has reduced the noise level, stray immune, and no offset voltage and wide capacitance range femto farad level. In this system enables very high data capture speeds to be achieved. A pulse based capacitance circuit was completed the capacitance measurement with in 6μsec but more time to be taken for data conversion and computer interface for image reconstruction. If we used very high-speed processor for data conversion, operating speed may be increased to higher level and reduce the noise level. The system can easily be extended to a large number of electrodes.

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Guide for Contributors

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Sensors & Transducers Journal (ISSN 1726- 5479) provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because it is an open access, peer review international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per annual by International Frequency Association (IFSA). In additional, some special sponsored and conference issues published annually.

Topics Covered

Contributions are invited on all aspects of research, development and application of the science and technology of sensors, transducers and sensor instrumentations. Topics include, but are not restricted to:

- Physical, chemical and biosensors;
- Digital, frequency, period, duty-cycle, time interval, PWM, pulse number output sensors and transducers;
- Theory, principles, effects, design, standardization and modeling;
- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
- Sensors interfaces, buses and networks;
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