Communication Protocol on 64-Channel ECVT Data Acquisition System

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***Abstract*— This research relates to tomography based on capacitance measurement namely Electrical Capacitance Volume Tomography (ECVT). This paper discusses the communication protocols in the 64-channel ECVT data acquisition system (DAS ECVT). The communication protocol is divided into two type, first, communications protocols between the master and slave microcontrollers within the DAS ECVT. The second is the communication protocol between the DAS ECVT and the personal computer (PC). The design of protocol communication is a simple protocol consisting only of headers, command data, end of command (eoc), and enter characters. The speed of the command depends on the speed of the baud rate, the higher baud rate the smaller the total time of command. The maximum baud rate that can be given is 921600 bps with the total time is 159 µs.**

Keywords*— *ECVT, capacitive sensor, data acquisition system, communication protocol

I. Introduction

Electrical Capacitance Volume Tomography (ECVT) is one of tomography based on capacitance measurement using capacitive sensor. The principle of capacitance tomography as shown in Fig. 1 is based on injection of square wave or sine wave signal to the electrode pair resulted in fringing electric field inside the sensor [1]. This signal is detected by other electrodes and controlled by an electronic circuit to be processed into an image using a specific reconstruction algorithm.

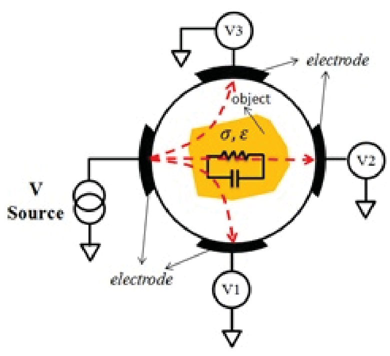

Fig 1. Principle of capacitance tomography

Currently, the ECVT data acquisition system has been developed accommodating 12, 16, 24, 32, [2]–[4] and up to 64 [5], [6] channels, in which each channel shall measure the capacitance independently. The ECVT data acquisition system, hereinafter referred to as the DAS ECVT, has function to acquire data from sensors, controls the scanning process, converts analog signals to digital data, and sends them to personal computers (PCs) as illustrated in Fig. 2.

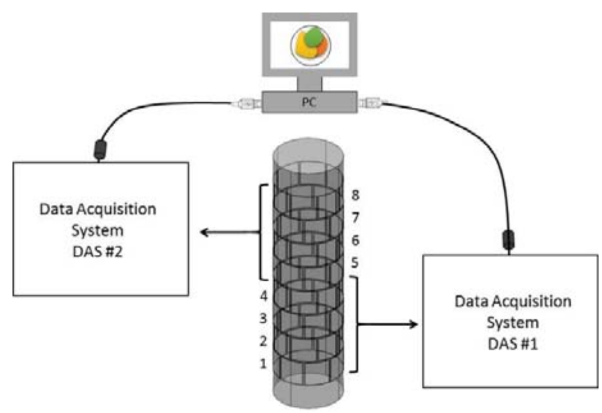

Fig 2. 64 channels ECVT system

This system has 64 channels so it takes two DAS ECVT, where each DAS ECVT contains two microcontrollers that handle all processes, such as controlling analog switches, direct digital synthesizer (DDS), multiplexers, amplifying, and controlling analog to digital conversion (ADC). The main problem controlling 64-channel capacitive sensor is the limited input output ports (I/O) in Microcontroller, which in one microcontroller is contain only 64 pins I/O. For the reason to handle the process of measuring the signal is needed some microcontroller.

According to the above issue, communication protocols are required between the microcontrollers in the system to manage the signal measurement process. In addition, a communication protocol between the two DAS ECVT is required to measure all the electrodes in the capacitive sensor. From the communication protocol design, it can calculated the speed of the system to acquiring and process the signal.

II. BLOCK DIAGRAM SYSTEM

The diagram system of each DAS is shown in Fig. 3 which is capable of handling 32 channels of capacitive sensors. The system consists of the main block of the front end circuit (analog switch and charge amplifier circuit) which has function to convert the signal from the capacitive sensor into a voltage signal. Analog switches has function to distribute the excitation signal to the electrode and also receive the detection signal from the electrode and forward it to the charge amplifier circuit [7]. The output of the charge amplifier circuit is a sinusoidal signal, then connected to the multiplexer (MUX) and the peak detector circuit to obtain the magnitude of the signal. The signals are then amplified by an analog amplifier (Gain) and convert it into digital signal by using Analog-to-Digital Converter (ADC).

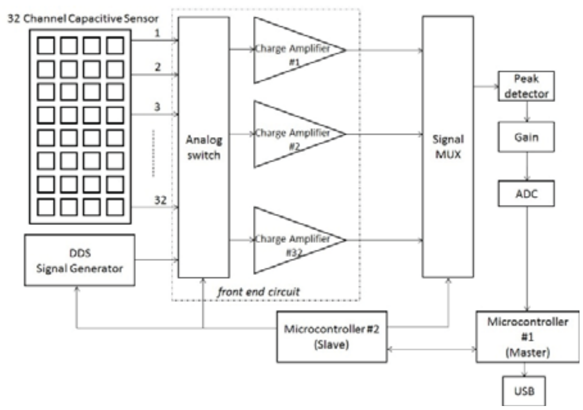

Fig 3. Block diagram data acquisition system each DAS

Each DAS requires two microcontrollers to control all the parts. Microcontroller # 1 (master) is used to control signal gain, convert analog to digital, send data packets to PC, and control microcontroller # 2 (slave). While microcontroller # 2 (slave) is used to control DDS, analog switch, and multiplexer.

III. COMMUNICATION PROTOCOL

The communications protocol is a rule that allows two systems to transmit information by defining syntax, semantics, and synchronization. In the ECVT system there are two communication protocols, the first, communication protocol between two microcontrollers within each DAS ECVT, and the second, communication protocols between PCs and two DAS ECVT to scan 64-channel capacitive sensors.

A. *Communication Protocol between Master and Slave Microcontroller*

As previously explained that each of the DAS ECVT has two microcontrollers to control the signal measurement process of the capacitive sensor. Communication between the two microcontrollers are using parallel communication by utilizing Port A as shown in Fig. 4. The 8-bits data and two control signals are enable (ENA) and clock (CLK) are used. ENA has function to activate microcontroller #2 (slave), while CLK is used to control the 8-bits data sending command.

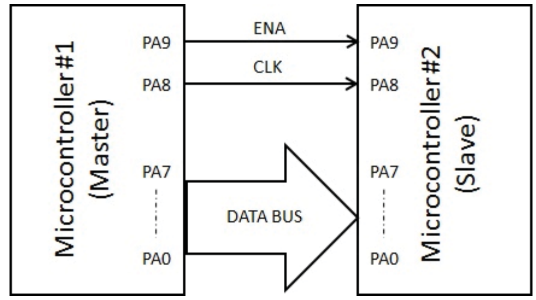

Fig 4. Diagram connection master & slave microcontrollers

To communicate between microcontrollers #1 (master) and microcontroller #2 (slave) required format data which both can understood. A simple data format is made and consists enable, clock, and data. In the design, the microcontroller #2 (slave) is in standby mode and ready to accept command from microcontroller #1 (master). The timing diagram of a communication protocol signal is shown in Fig. 5 where the number of data packets is 4 bytes, so it is called a four-byte protocol.

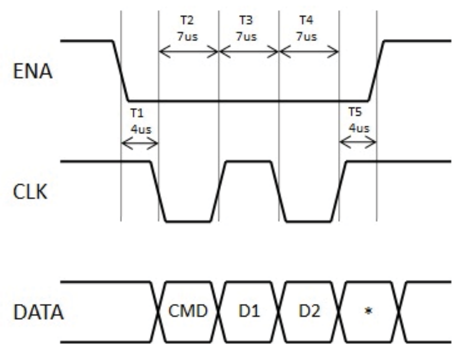

Fig 5. Four-byte protocol

The first data is 'command code', whereas D1, D2 is 'command function', and ends with 'end of command (eoc)' i.e. '*' asterisk character as the final sign of data packets. Communication can occur if the enable (ENA) logic is zero. The four-byte protocol will be sent to microcontroller #2 (slave) in the event of clock transition changes from high to low and from low to high (toggle). Thus, sending a four-byte protocol is only needs 2 clocks periods that each time is: $t_1 = t_5 = 4\mu s$, $t_2 = t_3 = t_4 = 7\mu s$. 'CMD' is command code with value 0 - 4 witch function as:

#0: all switches off; its means the sensor not connected to excitation source nor detection circuit.

#1: sensor testing; measurement testing for one channel pair.

#2: scanning process; measurement scanning for all channels pair.

#3: excitation voltage setting; used for setting the voltage excitation.

#4: frequency setting; used for setting the frequency excitation.

While command function (D1, and D2) is a value whose function depends on the command code given. Example: DAS ECVT will be used to scan the sensor with electrode pair 1 to 24, then the command is as follows:

CMD	D1	D2	eoc
2	1	24	*

B. *Communication Protocol between Data Acquisition System and Personal Computer*

Both of the DAS ECVT are made in standby mode which is ready to receive orders from other equipment. Controlling both of the DAS ECVT is done by personal computer (PC) with the data format as shown in Figure 6.

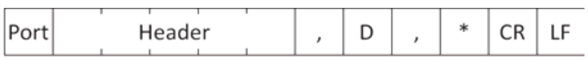

Fig 6. Format data of communication protocol between DAS ECVT with PC

There are 12 bytes of data formats in the communication protocol that is preceded by a 'port' which shows the serial port name detected by the PC. Second, is the 'header' which is the command code to run the ECVT DAS function that contains five bytes. Then 'D' with the floating point of data type whose function depends on the given command, where 'D' is flanked by ',' comma characters. The next byte is the final sign of the command (eoc) which is an asterisk '*' character. Last, the protocol is terminated by the 'enter' character i.e. <cr><lf>. Examples of commands can be seen in Table 1.

TABLE I. EXAMPLES OF COMMAND BETWEEN DAS ECVT AND PC

Command	Function
$BAUD,115200,*,<cr><lf>	Setting baud rate
$GAIN,8,*, <cr><lf>	Setting gain
$RANG,15,*, <cr><lf>	Setting range measurement
$FREK,500,*, <cr><lf>	Setting frequency
$CAPT,100,*, <cr><lf>	Scanning sensor with 100 data
$MEAN,16,*, <cr><lf>	Setting measurement average

IV. RESULTS AND ANALISYS

Prototype of the proposed 64-channel ECVT data acquisition system are shown in Figure 7 which consists of 64 electrode capacitive sensors, two data acquisition systems, and experimental objects. Experiments were performed using objects with high contrast dielectrics, therefore selected pvc (polyvinyl chloride) cylinder tube material filled with water (εr = 80) and dry rice (εr = 3.5). The two data acquisition systems are linked to one personal computer (PC) via serial communication. In each of these DAS ECVT has two microcontrollers to control the scanning and measurement of the signals, where the communication protocols have been described above. The connecting cable between the DAS ECVT and PC is use a USB cable of approximately 2 m long.

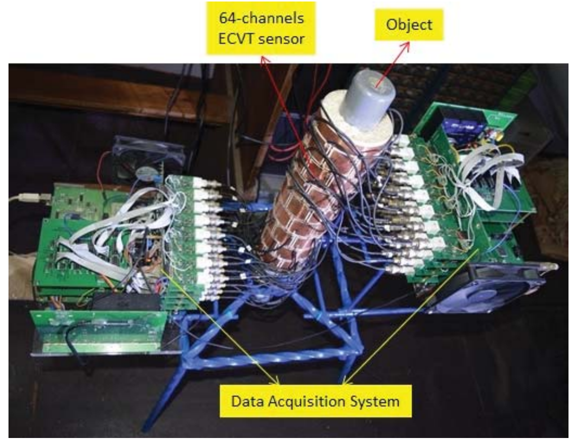

Fig 7. Prototype of 64-channels ECVT Data Acquisition System

The communication protocol between DAS ECVT and PC, as well as between the master and slave microcontroller in the 64 channel DAS ECVT has been designed. Thus, the total time of the communication protocol can be calculated. Communication between DAS ECVT and PC uses rs232 line through serial USB, consequently, there are 10 bits in a data packet consisting of 8 data bits, one start bit, and one stop bit. The speed of the command can be calculated by using equation 1 to 3.

$$t_{com} = t_{pc} + t_{mc} \tag{1}$$

Where:

$$t_{pc} = \frac{\sum packet}{baudrate} 10 \tag{2}$$

$$t_{mc} = t_1 + t_2 + t_3 + t_4 + t_5 \tag{3}$$

Where t_{com} is the total time of the all command giving to the DAS ECVT, t_{pc} is the total time of communication between the DAS ECVT with the PC, t_{mc} is the total time of communication between master and slave microcontroller, $\sum packet$ is the number of data packets in the format data of communications protocols DAS ECVT and PC, whereas, $t_1 + t_2 + t_3 + t_4 + t_5$ is the time period of the signal in the communication protocol of master and slave microcontroller. For example the 115200 bps baud rate is used, it will be obtained $t_{pc} = 1042\mu s$, $t_{mc} = 29\mu s$, hence $t_{com} = 1071\mu s$. The speed of communication protocol can be increased by increasing baud rate speed. Some command speeds with some baud rate can be seen in Table 2.

TABLE II. EXAMPLES OF COMMAND TIME BETWEEN DAS ECVT AND PC

Baudrate	t_{mc} (μs)	t_{pc} (μs)	t_{com} (μs)
115200	29	1042	1071
230400	29	521	550
460800	29	260	289
921600	29	130	159

The protocol communication design is a simple protocol consisting only of headers, command data, end of commands (eoc), and enter characters. There is no feedback communication both of them, nor is the error checking algorithm such as sum check or cyclic redundancy check (crc), so the communication is vulnerable errors. To overcome the issue, the connecting line between the master and slave microcontrollers as short as possible and also the distance between the DAS ECVT and the PC is made as close as possible. Nevertheless, sometimes some command errors are found, the DAS ECVT does not respond the given commands so that the command must be given twice in order the systems to respond.

Having analyzed the error in the command between the DAS ECVT and PC is caused by the incorrect serial timer interrupt timing algorithm so that the DAS ECVT does not respond. The solution is to send the command twice. Because the protocol used is very simple and only a few bytes, then the delivery of command as much as one or two times the system can already respond.

Serial communication is influenced by the usage of cable types and cable length, where each cable has a very influential capacitance in the serial communication. In general, the length of the cable that can still be allowed is 15 meters for 9600 bps speed with 2500 pF cable capacitance. If the speed is higher like 38400 bps, the maximum cable wire is 4 m. This system is designed using rs232 serial communication with USB converter, so transmission between DAS ECVT and PC can use USB cable with 5 m of maximum length.

V. Conclusion

A communication protocol for the 64-channel DAS ECVT has been designed. There are two kinds of communication protocols, first between master and slave microcontrollers in each DAS ECVT, and second DAS ECVT with PC. The speed of the command depends on the speed of the baud rate, the higher the baud rate the smaller the total time of command. The maximum baud rate that can be given is 921600 bps. The designated communication protocols have not used error-checking algorithms, therefore vulnerable to command errors. However the system is still able to receive the command.

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