International Journal of Enhanced Research in Science, Technology & Engineering
ISSN: 2319-7463, Vol. 5 Issue 5, May-2016

Discrete Capacitance Level Array Monitoring System in Cryogenic Propellant Tank

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ABSTRACT

The Level measurement system is used to detect the liquid level in cryogenic propellant tank. The boiling points of cryogenic liquids are at very low temperature range. It is very difficult to maintain the pressure and temperature of the cryogenic tanks at desired value during the process. Hence the normal level measurement systems used for non-cryogenic liquids are not suitable for cryogenic level measurement. The capacitance based discrete level measurement system is designed to measure the liquid level in cryogenic tanks. In this paper we propose a new method used to detect the liquid level at 15 discrete points in the cryogenic tanks. Discrete capacitance level measurement system contains 32 capacitance sensors connected in array. Each sensor having the equal capacitance at gas and capacitance value will change when the sensor is immersed in liquid according to the dielectric constant of the liquid. Signal conditioners are used to convert the change in capacitance into voltage. The signal conditioners are developed by using charge amplifiers the output of the signal conditioners will be proportional to input capacitance. The scope of the project is to develop the microcontroller based system for digitizing 32 channel signal conditioner outputs. The system is programmed to read all the 32 analog signals from the signal conditioner and compare the signals with predefined threshold and generate the binary output corresponding to the analog signals. In order to avoid wrong output due to faulty channel, error correction algorithm was implemented. The system will generate 5 bit digital output proportional to liquid level. All these analog values was transmitted to the control room through Ethernet. The above algorithm is implemented in dsPIC33FJ256EP710A microcontroller and programmed & compiled using microchip approved compiler and MPLAB .

Keywords: Discrete capacitance, Charge Amplifiers, Microcontroller, ADC, Signal Conditioner.

I. INTRODUCTION

Capacitive Level sensor

In this paper the simplest capacitive fluid level sensors shown comprises of two concentric tubes immersed in the fluid whose level is to be measured. Since the overlapping area between the plates and the distance between the plates is fixed, the capacitance becomes a function of the dielectric between the plates, i.e., fluid between the two concentric tubes. As the fluid level changes, the capacitance also changes. This capacitance becomes the function of the fluid level. The capacitive fluid level sensors is shown in fig:1

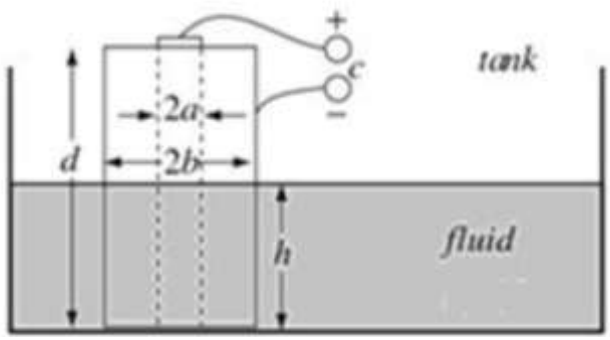

Fig:1 Capacitance Level Sensor Measurement System

In principle the level measurement system is classified into continuous and discrete type level measurements. Continuous type level measurement provides information on actual fluid level and discrete type provides information whether given critical level(s) have been reached. In this paper I have chosen discrete type level measurement system. Discrete type level switches are used in the propellant tank to provide alarms to prevent overfilling and depletion of propellant. If the volumes between two switches are known then these switches can be used for calibrating the flow meters. The discrete capacitance level Sensor is shown in fig:2

Fig:2 Discrete Capacitance Level Sensor

The Flow meters are usually calibrated in water, the calibration constant derived during water calibration leads to an error of 3 to 5 % in cryogenic flow measurement. It is inevitable to calibrate the propellant feed flow meters very accurately so as to predict the performance of cryogenic engine and stage[6]. The flow meters are calibrated by measuring the volume of cryogenic liquid passed through it. The discrete type capacitance based level measurement system mounted in run tanks provides the exact volume of liquid drained out from the run tank and the flow meter installed in propellant feed line reads the amount of liquid passed through it. On comparing the readings of flow meter and tank level measurement system the flow meter is calibrated accurately. The discrete capacitance level array system is shown in fig:3

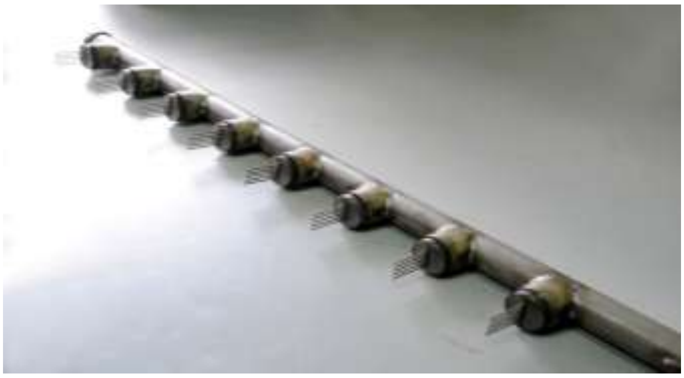

Fig:3 Discrete Capacitance Level Array System

In this paper we proposed a new method used to detect the liquid level at 15 discrete points in the cryogenic tanks. Discrete capacitance level measurement system contains 32 capacitance sensors connected in array. Each sensor having the equal capacitance at gas and capacitance value will change when the sensor is immersed in liquid according to the dielectric constant of the liquid. Signal conditioners are used to convert the change in capacitance into voltage. The signal conditioners are developed by using charge amplifiers the output of the signal conditioners will be proportional to input capacitance. Discrete capacitance level array monitoring system shall read the 32 analog signals from the signal conditioners by using built-in ADC available in the microcontroller**.**

Due to the change in dielectric property of the cryogenic vapor to liquid is more (given in table 1) when compared to dielectric property change due to pressure and temperature (with in 0.5%) of the same fluid at the operating condition. This phenomenon is used to detect the liquid level at the discrete points without applying any correction factor for change in pressure and temperature. Where as in capacitance based continuous level measurement system, the on-line correction factor has to be applied by reading the process pressure and temperature to get correct level.

Since this level measurement system is used for flow meter calibration, the measurement of liquid level within ± 1 mm accuracy with a response time of 100 msec is mandatory for calibrating feed line flow meters within ± 0.6 % accuracy. To meet this stringent requirement the discrete type capacitance based level sensor array[14] is designed with 15 numbers of sensors located at an array having vertical distance of 100 mm.

II. SYSTEM DESIGN

The sensing capacitance is in the order of few pico farads and it has to be measured under the cable capacitance of around 2000 pF, the general bridge configuration or voltage divider configuration will leads to an erratic measurements. Hence charge amplifier based electronics is designed. In order to meet the fast response requirement, an individual charge. amplifier for each channel is incorporated in the electronics.

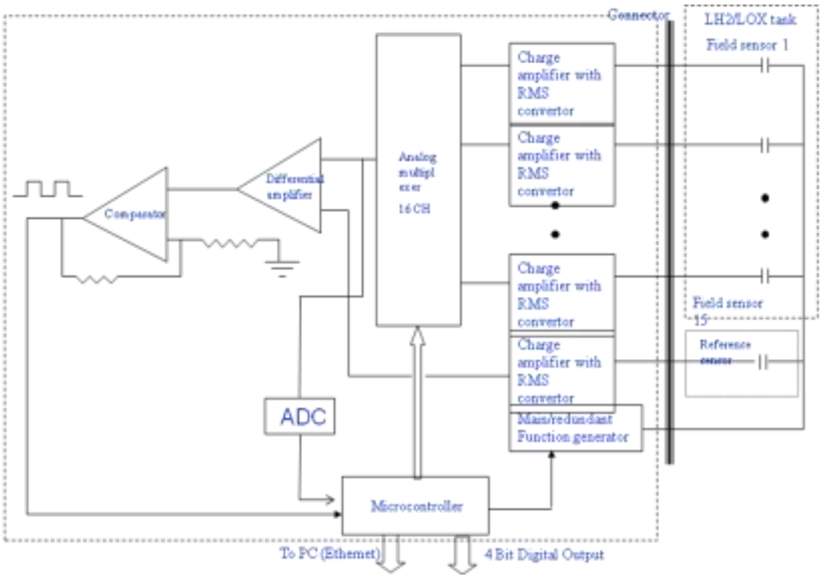

Fig: 4 Schematic Diagram Of Level Monitoring System

The schematic diagram of electronics designed for the discrete level measurement system is shown in fig:4 The system consists of a excitation unit, which excites all the field capacitance simultaneously, charge amplifiers with RMS converters and micro controller based control electronics is used to execute error correction algorithm and generate isolated final BCD output. Single excitation unit in Main/Redundant configuration is planned for the entire system. In case of failure of main excitation unit, the redundant excitation unit will be activated manually by 24 V command from the control system. The excitation unit is designed to generate TTL pulse at the frequency of 1 KHz.

Since the sensors are placed inside the propellant tank, which is falling under zone 0 in hazardous area classification and the electronics need to be intrinsically safe. Hence the energy limiting circuit is implemented in the electronics and obtained the approval from CMRI, Dhanbad. The maximum output voltage is limited to 5 V and the output current is limited to 1 mA to make the system intrinsically safe. Even at the failure of any component the system will ensure the energy available at the field is below the ignition level of the atmosphere. In this paper the Charge amplifier uses an operational amplifier at the input stage. The configuration of the operational amplifier with the capacitor in the feedback loop operates as an integration network and integrates the current at the input. The input current is the result of charge developed across the sensor. The circuit diagram of the charge amplifier is given in fig:5

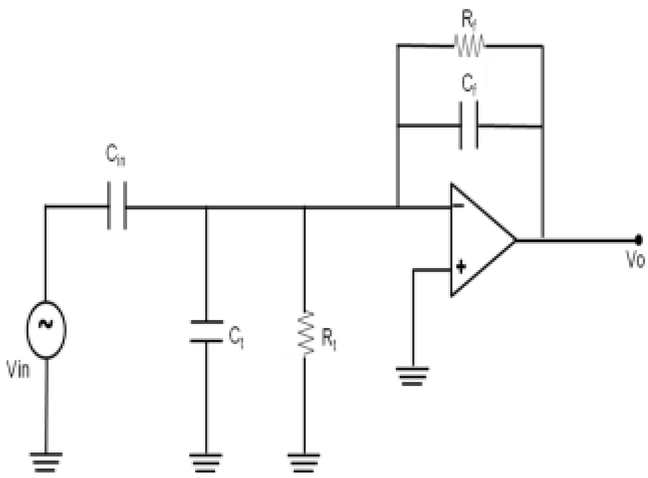

Fig: 5 Circuit Diagram of the Charge Amplifier

The resistance is added in the feedback circuit to avoid charging of feedback capacitance due to bias current of the amplifier[15]. To avoid more DC offset in the charge amplifier output the operational amplifier is selected with bias current of 1 pA. The output voltage equation for the charge amplifier is :

$$Vout = -\frac{Cin * Vin}{(1+\frac{1}{A})(Cf + \frac{1}{jwRf}) + \frac{1}{A}(Ct + \frac{1}{jwRt})}$$

Cin – Input (Sensor) capacitance

Cf – Feedback capacitance

Ct – Cable capacitance

A – Open loop gain of the amplifier

Rf – Feedback resistance

Rt – Effective resistance of cable, amplifier and sensor

w – operating frequency

Vin – Excitation voltage

It is evident from the above equation, if the open loop gain of the amplifier is sufficiently high, then the output will be independent of cable capacitance. The voltage output of the charge amplifier is proportional to the input capacitance and the gain is controlled by the feedback capacitance [4]. The low frequency response of a charge amplifier is determined by the time constant set by the feedback circuit of the operational amplifier and is unaffected by the changes in the input load conditions.

$$Fc = \frac{1}{2 * pi * Rf * Cf}$$

The high frequency response is affected due to high cable capacitance. The resultant AC voltage from the charge amplifier is converted into DC voltage using RMS convertors. Each channel generates the DC output voltage proportional to sensing capacitance.

In order to compute the liquid level from the sensor array, the controller scans the voltage output from the entire charge amplifiers through analog multiplexer. The instrumentation amplifier is used to find the difference between sensing and reference capacitor. If the output of the sensing capacitor is more compared to reference output, then it is the indication of sensing element is immersed in Liquid otherwise it is in gas.

The output from the instrumentation amplifier is compared using zero cross detector to get the digital output corresponding to the selected sensor. The sensor is selected one by one and its corresponding digital status is updated by the controller[10]. The controller finally executes the error correction algorithm, computes the liquid level and generates the isolated BCD output proportional to the liquid level for recording. An analog to digital convertor (ADC) is interfaced with the micro controller to digitize the output voltage of the charge amplifiers and it transmits the analog and digital status of the sensor array through Ethernet interface for on-line display and recording[13]. The controller is programmed to execute the entire task with in 100 msec.

III. HIGH PERFORMANCE DSC CPU

The dsPIC33F has a Modified Harvard architecture. They provides a C compiler optimized instruction set. It consists of 16-bit wide data path and 24-bit wide instructions[3]. Linear program memory addressing up to 4M instruction words. Linear data memory addressing up to 64 Kbytes. It has 84 base instructions: mostly 1 word/1 cycle.

dsPIC33FJ256GP710A MICROCONTROLLER :

In this paper the system is implemented by using the dsPIC33F device family that employs a powerful 16-bit architecture that seamlessly integrates the control features of a Microcontroller (MCU) with the computational capabilities of a Digital Signal Processor(DSP)[12]. The resulting functionality is ideal for applications that rely on high-speed, repetitive computations, as well as control. The dsPIC33F architecture is shown in fig:6

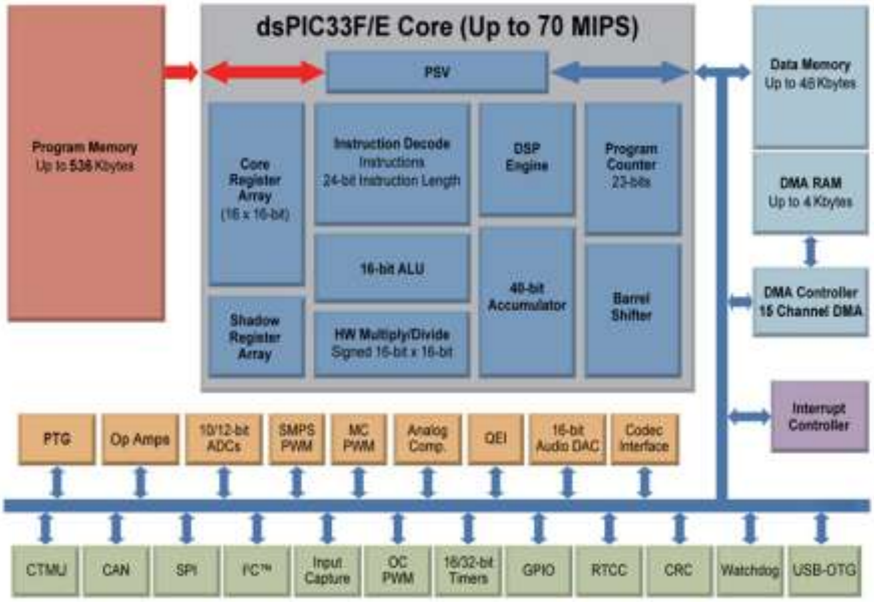

Fig:6 dsPIC33F Architecture

The DSP engine, dual 40-bit accumulators, hardware support for division operations, barrel shifter, 17 x 17 multiplier, a large array of 16-bit working registers and a wide variety of data addressing modes, together provide the dsPIC33F Central Processing Unit (CPU) with extensive mathematical processing capability[11]. Flexible and deterministic interrupt handling, coupled with a powerful array of peripherals, renders the dsPIC33F devices suitable for control applications. Further, Direct Memory Access(DMA) enables overhead-free transfer of data between several peripherals and a dedicated DMA RAM. Reliable, field programmable Flash program memory ensures scalability of applications that use dsPIC33F devices[1]. The 100-pin configuration of dsPIC33FJ256GP710A is shown in fig:7.

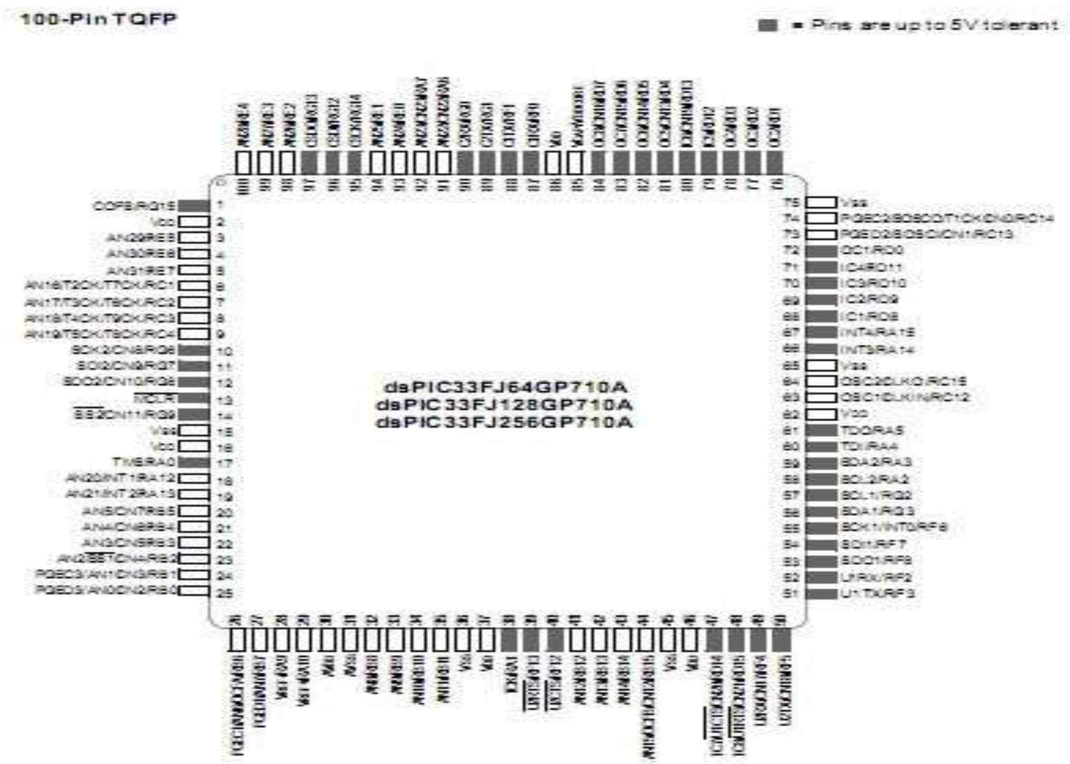

Fig:7 Pin Configuration of dsPIC33F

The dsPIC33F family devices have 32 input channel devices[2] . The two ADC modules , they ADCx , X=1 or X=2. The ADC module has 10 bit (or) 12 bit operation mode (AD12B) bit in the ADC control 1 (ADxCON1) register allows each of the ADC modules to be configured by the user app as either as 10 bit , 4 Sample/Hold ADC (or) 12bit, 1 Sample/Hold.

In this paper 12 bit operation mode (AD12B=1) is used for ADC configuration.

12 BIT CONFIGURATION (AD12B=1)

The conversion speeds of upto 500ksps. The 12 bit configuration consists of only one Sample/Hold circuit[8]. It contains only one Sample/Hold, so simultaneous sampling of multiple channels is not supported.

IV. ICD 2 IN-CIRCUIT DEBUGGER/PROGRAMMER

Traditionally, embedded systems engineers use in-circuit emulators (ICE) to develop and debug their designs and then programmers to transfer the code to the devices. The in-circuit debugging logic, when implemented, is part of the actual microcontroller silicon and provides a low-cost alternative to a more expensive ICE. However, it has the following trade-offs:

Use of some target system resources such as I/O pins, program memory, data memory, and stack space. As a result, some portions of an embedded application may not be debugged[7]. Triggering and breakpointing are limited to the built-in capabilities of the in-circuit debugging logic. The target chip must be running with a clock and a supply voltage. Often an emulator probe can run without external hardware.

MPLAB IDE allowing source level debugging with MPLAB Real ICE emulator with source level debugging. Debugging is performed using MPLAB ICD2. They low cost In-circuit debugger(ICD) and (ICSP) In-circuit serial programmer. ICD is a cost efficient alternative to an ICE. It provides a low cost hardware debugger. The MPLAB ICD2 with targeted IDE is shown in fig:8. As opposed to an ICE, some of the requirements of ICD are

Fig: 8 MPLAB ICD2 with targeted IDE

ICD requires exclusive use of some hardware and software resources of the target.
Target PICmicro MCU must have a functioning clock and be running.

DEBUGGER/PROGRAMMER:

The MPLAB ICD 2 (In-Circuit Debugger 2) allows debugging and programming of PIC and dsPIC Flash microcontrollers using the powerful graphical user interface of the MPLAB Integrated Development Environment (IDE), included with each kit. The MPLAB ICD 2 is connected to the design engineer's PC using USB or RS-232 interface and can be connected to the target via an ICD connector. The connector uses two device I/O pins that are shared between In-circuit debugging and In-Circuit Serial Programming[3].

TARGET APPLICATION PC BOARD:

Target PICmicro MCU must be running with an oscillator for MPLAB ICD 2 to function.
If the PICmicro MCU has AVDD and AVSS lines, they must be connected [5]for MPLAB ICD 2 to operate.

An ICD also employs software running on the target to do ICE like functions and as a result relies upon the target relies upon the target microcontroller for some memory space CPU control, stack storage and I/O pins for communication.

MODULAR INTERFACE CONNECTIONS:

MPLAB ICD2 is connected to the target PICmicro MCU with the modular interface cable , a six conductor cable . ICD cable has mirror imaged connections on each end and connection on the MPLAB ICD2 module are the opposite of connections.

MULTIPLE DEBUGGING CHANNELS:

dsPIC33F Digital Signal Controllers use Microchip's low-cost development tool, MPLAB ICD 2 In-Circuit Debugger for both programming and in-circuit debugging. MPLAB ICD 2 provides a 5-pin interface to the dsPIC33F device. These pins are: VDD, VSS, MCLR,PGC/EMUC and PGD/EMUD. The PGC/EMUC and PGD/EMUD pins are used to communicate clock and data signals, respectively, between the MPLAB ICD 2 unit and the dsPIC30F device during programming and debugging operations[6]. To give you flexibility in board layout, dsPIC33F DSC devices provide multiple options for connecting the MPLAB ICD 2 to your target board for in-circuit debugging.dsPIC33F devices are available in packages ranging from 18 to 80 pins. Devices in small packages often have several peripheral functions multiplexed on each pin . In certain cases, the default programming and debugging pin functions, PGC/EMUC and PGD/EMUD, are multiplexed on pins that may be used by other peripherals like the I2C™, SPI™,or UART modules. In such cases, the application isable to use these pins for programming, however theycannot be used for in-circuit debugging. In-circuitdebugging should then be performed using alternate debugging channels[9]. You shouldnote that the device programming and connect operations using MPLAB ICD 2 will continue to require the use of the PGC and PGD pins. The Pin configuration of MPLAB ICD2 is shown in fig:9

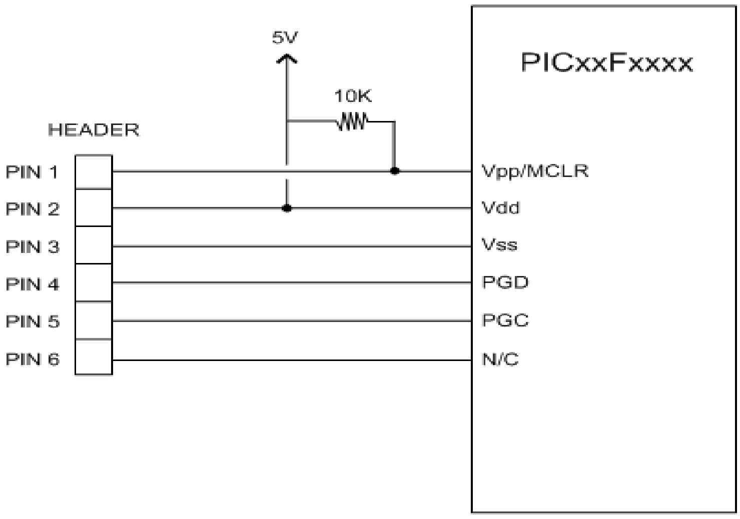

Fig:9 Pin Configuration of MPLAB ICD2

Established according to user's behavior and trust degrees will be calculated by the trust model. In trust based multi-domain access control model, when a user logs in, the system shall verify user's identity first. If the identity is trusted, the user's identity will be authorized. Trust levels reflect users' behavior trust in this model.

V. ERROR CORRECTION ALGORITHM

The error correction algorithm is proposed to implement in the controller to eliminate faulty BCD output due to a fault either from sensor or in the electronics. The algorithm takes the actual digital status of the 15 sensor and shifts it to right by one bit and stored in register and the resultant data is once again shifted to right by one bit. The bit level majority logic is implemented on actual digital status register, shifted data and the resultant data is shifted to left by one bit to get the corrected data. The algorithm corrects the error and generates the valid output only if the adjacent channels are healthy.

Case 1 : One bit is high due to error
111 1100 0001 0000 error at bit 5
111 1110 0000 10000 shift by one bit
111 1111 0000 010000 shift by one more bit

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111 1110 0000 00000
Shift the result one bit by left
111 1100 0000 0000 error in bit 5 is corrected

Case 2 : One bit is low due to error
111 1101 1111 1100 error at bit 10

111	1110	1111	11100

shift by one bit

111	1111	0111	111100

shift by one more bit

---

111 1111 1111 11100
Shift the result one bit by left
111 1111 1111 1100 error in bit 10 is corrected
Case 3 : Error on MSB and LSB
011 1111 1111 0001 Error at MSB and LSB

101	1111	1111	10001

shift by one bit

110	1111	1111	110001

shift by one more bit

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111 1111 1111 10000
Shift the result one bit by left
111 1111 1111 0000 Error on MBS and LSB is corrected

VI. EXPERIMENTAL RESULTS

The performance of the individual sensor is evaluated in laboratory by connecting the sensor with the LCR meter the dry and wet (cryoliquids) capacitance is measured. The value is compared with the theoretically calculated values.

The charge amplifier output is measured by connecting different values of capacitance at the charge amplifier input (1 to 5 pF). Finally the sensor is connected with the electronics and the output voltage is measured and is compared with the theoretical value corresponding to the sensors dry capacitance.

Test result at CryoLiquid :

Two channels of discrete level measurement system is connected at cryoliquid bath is tested. Both sensors were placed in the same plane for redundancy to measure the presence of liquid inside the cryoliquid bath. The corresponding change in output due to cryogenic liquid is measured and is shown in below fig:10

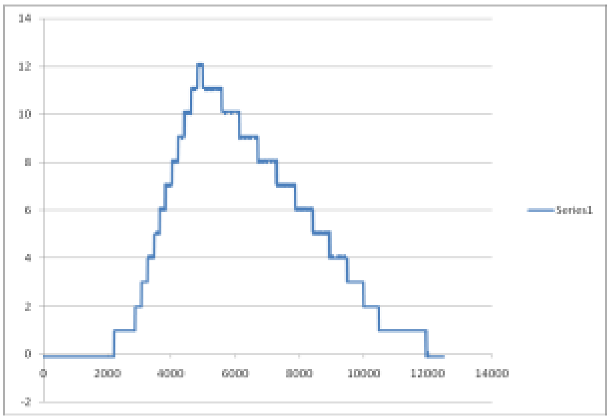

Fig:10 Output voltage of Capacitance Level Sensor.

CONCLUSION

In this paper we present a discrete capacitance level measurement system which can measure the cryogenic liquid level in a tank up to 15 discrete points. The project is developed and performance is evaluated in LH2 and is given in test result. The system is programmed to read all the 32 analog signals from the signal conditioner and it compare the signals with predefined threshold and generate the binary output corresponding to the analog signals. The results are analyzed and are meeting the requirements of cryogenic level measurement system.

PERFORMANCE ENHANCEMENT

In this paper the level measurement system is evaluated using analog output from the charge amplifier. In order to avoid wrong output due to faulty channel, error correction algorithm is implemented. The system will generate 5 bit digital output proportional to liquid level. All these analog values are transmitted to the control room through Ethernet. Thus the above algorithm was implemented in dsPIC33FJ256EP710A microcontroller and programmed & compiled using microchip approved compiler and MPLAB. The implementation of error correction algorithm in the controller and generation of BCD output is also progressed successfully.

REFERENCES

[1]. Datasheet of dsPIC33F, "16-bit Digital Signal Controllers with Advanced Analog", Microchip Technology Inc.
[2]. Datasheet of dsPIC33F, "dsPIC33F Analog-to-Digital Converter ", Microchip Technology Inc.
[3]. Datasheet of dsPIC33F, "dsPIC33F In-Circuit Debugging Interface Options With dsPIC DSC", Microchip Technology Inc.
[4]. Ayob Johari and Mohd Helmy Abd Wahab (2011), "Tank Water Level Monitoring System using GSM network", IJCSIT vol.2,no.3.
[5]. Data sheet of dsPIC30F2012 by Microchip Technlogy Inc
[6]. Modern Sensors Hand book by Pavel Ripka and Alois Tipek
[7]. Data sheet of OPA 124 by Burr Brown
[8]. Data sheet of XR 2206 by EXAR Corporation
[9]. Data sheet of AD7680 by Analog Devices Inc
[10]. Ejiofor Virginia Ebere , Oladipo Onaalapo Francisca (2013), "Microcontroller Based Automatic Liquid Level Control System",vol.1, no.6.
[11]. G.Prathyusha , B.Ram Murthy (2015), "Embedded Based Level Measurement and Control Using Float Sensor", vol.4, no.4.
[12]. Salih ARSLAN . Koray Kose (2009), "A Design of DSPIC Based Signal Monitoring and Processing System" JEEE, vol.9,no.1.
[13]. S. M. Khaled Reza, Shah Ahsanuzzaman Md(2010), "Microcontroller Based Automated Water Level Sensing and Controlling: Design and Implementation Issue", World Congress on Engineering and Computer Science vol.1.
[14]. Level Sensor, "Tank Monitoring Solutions", Available at http://www.astsensors.com
[15]. Mark Serridge , Torben R Licht, "Piezo Electric Accelerometers and Vibration Pre-amplifiers" Handbook 1999.