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Development of Auto-Ranging DAS on 32 bit ARM Cortex Processor for X-Ray Detectors

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ABSTRACT: X-ray detectors analogous to ion chambers are used widely with the beam lines at Indus 2 (SRS-Synchrotron Radiation Source). Sensing process parameter is of vital importance for signal readout in radiation detectors, exclusively in the ionization chamber which are widely used for the measurement of flux of the ionizing radiations in SRS beam lines. The system is developed to sense and measure the current from the ion chamber in the range 10pA-10uA and its data logging using all in one 32-bit microcontroller STM32F401RE. The uniqueness of the system is auto-ranging of the current in the range pico to micro. To handle the large dynamic range, two freewheeling channels of amplifiers are interfaced which are controlled by microcontroller. The presented work aims to describe an advanced auto-ranging data acquisition system for accurate measurement of the ultra low current and displaying the current graphically using vb.net. This paper helps in obtaining the ion chamber current in digital as well as graphical format.

KEYWORDS: Auto-ranging DAS, Ionization chamber, STM32F401RE, Visual Basic.Net.

I. Introduction

X-ray detectors are the devices used to measure the flux, spatial distribution, spectrum and other properties of x-rays. Ion chambers in principle are the simplest of all gas-filled detectors. X-rays ionizes gas (He) as it having shortest wavelength and high energy that can ionize the gas and ions are formed which get attracted towards oppositely charged plates cathode and anode. The collected number of electrons at anode is measured to find current. The output of radiation detectors are weak current signals, and extremely low current signals. Its output current is proportional to the radiation flux, which depends on the chamber design; media filled inside the chamber and applied high voltage [5], [6]. To make uniform interface and portability across ion chambers of various size and geometry, an auto-ranging DAS is developed which consists of a 32 bit ARM controller STM32F401RE and internal programmable HV supply (0-2kV) to bias ion chamber.

Earlier systems for electrometer and DAS were built using microcontroller P80C552 or microcontroller ADuC832 but there were some drawbacks with the controller which were removed by replacing the system with ARM controller STM32F401RE. The remote sensing of process parameters that is ultra low current from ion chamber is done using NUCLEO F401RE, which is an open development platform having Arduino connectivity support and ST Morpho headers and the measured current is then plotted on the chart in Microsoft Visual Studio 2010 using vb.net.

II. Related work

In [1] author conversed about the embedded DAS, which was used for electronic signals measurements, they made use of MyRIO card instead of Arduino card. In [2] author discussed how Electrometer and DAS for ionization chamber for INDUS-2 RRCAT was developed. The system was built over the microcontroller P80C552, which would read the analog signals from electrometer. In [3] author considered ultra low current measurement with a large dynamic range from a few fA to µA and its design using the method of charge integration and for ADC chip with higher sample rate,

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MCU chip was replaced with a FPGA chip but they were able to measure the current in the range of pA to uA and not in fA to uA. In [4] author conferred about an automatic system developed for current integration measurement by the means of specially designed software ActMASTER H01and a commercial multi I/O card CAD 12/32. The best thing with STM32F401RE is, it is much cheaper than MyRIO, FPGA chip, multi I/O card and fulfil our objective. P80C552 is derivative of 8051 microcontroller having 10-bit ADC, 64KB ROM and 16MHz clock frequency, but our objective was more accuracy, memory and speed which were achieved using STM32F401RE of ARM Cortex M4 family having 12-bit ADC, 512KB ROM and 84MHz clock frequency[7]. The ARM Cortex-M4 processor is the latest embedded processor by ARM specifically developed to address digital signal control markets that demand an efficient, easy-to-use blend of control and signal processing capabilities in microcontroller applications. The STM32 Nucleo board is a low-cost and easy-to-use development platform used to quickly evaluate and start a development with an STM32 microcontroller in LQFP64 package [12].

III. SYSTEM OPERATION

The Ion chamber current monitor unit comprises of two operational amplifiers as shown in fig.2. Gating Integrating Amplifier (GIA) which integrates an analytical signal over a fixed time window, based on charge amplifier that is able to convert the very small charge stored within the capacitor to a voltage level that can be easily processed and Trans-Impedance Amplifier (TIA) which converts current into voltage and uses low value precision resistor in feedback path of the ultra low bias current amplifier, followed by programmable gain amplifier (PGA). PGA selects the new gain immediately on changing the logic input. The gain can be set from less than 1V/V to over 100V/V. Depending on the range either GIA or TIA gets selected. The current from the Ion chamber current monitor unit is sensed using the analog pin A2 of STM32F401RE and the analog signal is converted to digital using ADC. STM32F401RE is having 12-bit ADC. ADC adapts to Successive Approximation Register (SAR) concept for conversion. The HOLD, RESET and SELECT pins from the Ion chamber current monitor unit are connected to digital pins of STM32F401RE via RS232 for serial communication. The communication of ion chamber auto-ranging DAS with the PC takes place over RS232. The Baud rate is kept at 57600 bits/sec. The HOLD, RESET and SELECT pins are controlled by the microcontroller. The heart of the system is STM connected to computer via ST-LINK port, installed with Keil uVision5 software which is configured by programming in Embedded C++ language. The digital signal that is the measured current of the Ion chamber is transmitted to computer using serial communication. Data is sent as one bit a time. Time taken to print the sensed parameter is in microsecond to get the sensed parameter on screen. The “pc” object allows serial port (SERIAL_TX, SERIAL_RX) mapped on the pins on STM board to communicate. Fig.1. shows the serial communication class which allows the serial transmission in Embedded C++.

```
Serial pc(SERIAL_TX, SERIAL_RX);
```

Fig.1.Serial communication class

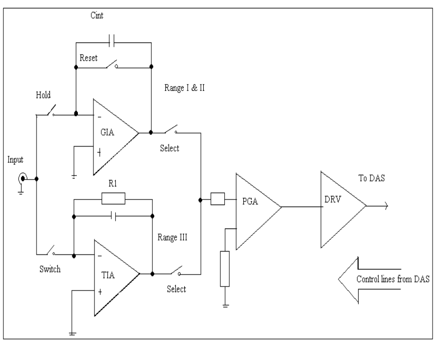

Fig.2. Part of Ion chamber current monitor unit showing GIA and TIA

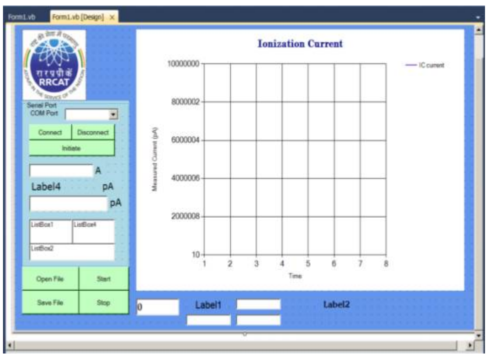

Fig.3. GUI form using vb.net

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A. *Workflow:*

- Mode 0 = 100nA-10uA = Trans-impedance mode (TIA)
- Mode 1 = 1nA-100nA = Gated Integrated Amplifier nano mode (GIA_nano)
- Mode 2 = 10pA-1000pA = Gated Integrated Amplifier pico mode (GIA_pico)

Fig.4. shows the workflow diagram. Auto ranging is done using STM F401RE microcontroller. Initially mode-0 i.e. Trans-impedance mode (TIA) is executed and checks whether the current is in 100nA-10uA range or not. If Ain< Ain_min then it jumps to mode-1. In Gating Integrated Amplifier nano mode (GIA_nano) i.e. 1nA-100nA if Ain< Ain_min it jumps to mode-2 and if Ain> Ain_max it jumps to mode-0 otherwise the current from the ion chamber is integrated by the switched GIA over a predetermined period of time and the output is hold allowing the circuitry to read the output, the integration time for GIA nano is 100ms with gain of 1. In Gating Integrated Amplifier pico mode (GIA_pico) i.e. 10pA-1000pA if Ain> Ain_max it jumps to mode-1 otherwise the current from the ion chamber is integrated by the switched GIA over a predetermined period of time and the output is hold allowing the circuitry to read the output, the integration time for GIA pico is 1s with gain of 10. After the signal readout, the integration capacitor is reset to allow the output to return to ground potential and integration cycle repeat again. The low current signal from the ion chamber is further enhanced with Programmable Gain Amplifier (PGA). The output noise while measurement of low current is minimized by averaging and the current is displayed on LCD. The selection of the mode between GIA and TIA, programmable integration time, HV from 0-2kV and necessary digital control signals like HOLD, RESET are generated using STM F401RE.

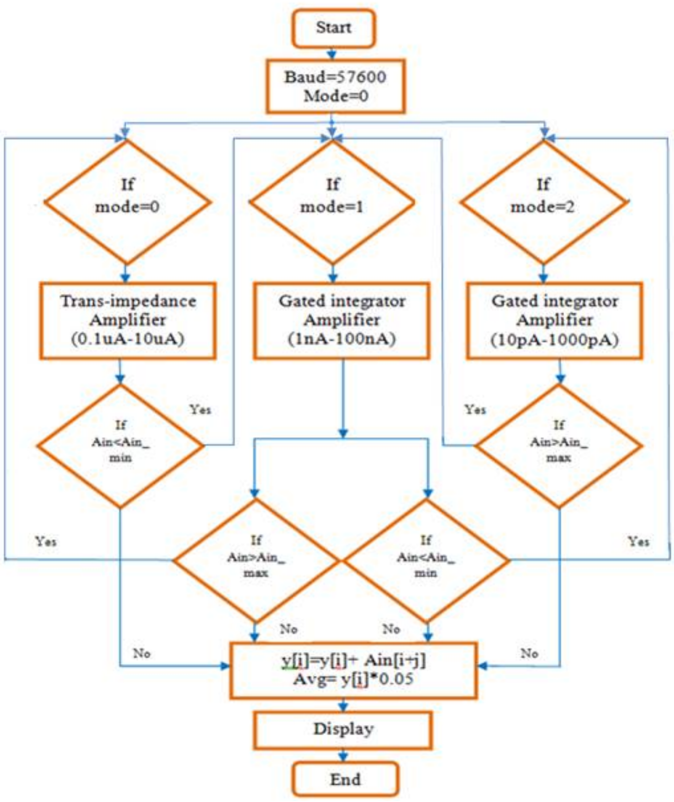

Fig.4.Workflow diagram

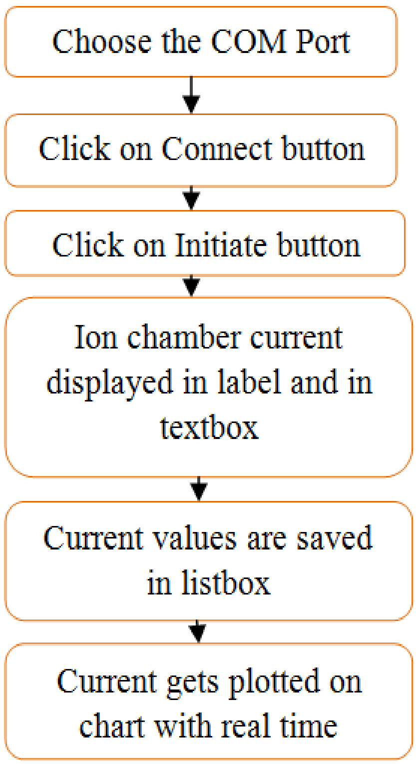

Fig.5. Flowchart for GUI using vb.net

IV. Overview of Technology

The graphical user interface (GUI) is developed using Visual Basic.Net 2010 serial communication. Vb.net is object oriented computer programming language that can be viewed as an evolution of the classic visual basic [11]

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implemented on the .NET framework. Vb.net is not only a programming language but also a complete graphical development environment. This environment allows users with little programming experience to quickly develop useful Microsoft Windows application. Fig.3. shows the GUI form using vb.net. The GUI form consists of serial port group box having COM Port selection drop box, connect button, disconnect button, initiate button, label and textbox for displaying the measured current and list box for storing the current values displaying in textbox; picture box for displaying institution logo and chart for displaying the real time ion chamber current on y-axis and time on x-axis. Open file, Save file Dialog box are also there for opening and saving the file in .txt format. Timer is included with a delay of 1000ms. Baud rate is 57600 bits/sec. Fig.5. shows the flowchart for GUI using vb.net. The measured current value will be serially transferred to pc on COM Port selection from the COM Port selection drop box and displayed on label as well as on textbox and simultaneously get plotted on the chart at an interval of 1s which is given by the timer. The measured values can be saved in list box on clicking the Save button, which saves the values in a .txt file. Fig.6. shows the command which allows serial communication in vb.net.

```
receivedText(SerialPort1.ReadExisting())
```

Fig.6. Serial communication in vb.net

V. RESULTS

The experimental setup of the project showing the Nucleo STM32F401RE, Keithley electrometer, Ion chamber current monitor unit, RS232 DB9 Connector and LCD is shown in the fig.7. STM is connected to PC via USB for GUI. Electrometer is connected to ion chamber current monitor unit by RG58 cable. STM32F401RE is linked to ion chamber current monitor unit by RS232 DB9 connector. LCD is connected to digital pins of STM. Power supply of 12V is given to the Ion chamber current monitor.

Calibration is done using Keithley current source model 6220 to analyze the amplifier's linearity. The source current is varied in step for TIA, GIA nano and GIA pico mode. For testing purpose, a current is set on electrometer in pico, nano or micro amperes and given to ion chamber current monitor unit, depending on the gain, hold and reset values the software selects the TIA or GIA from the ion chamber current monitor unit and the current is measured and displayed on LCD. 25pA current is rightly measured and displayed on LCD as 25.53pA. 33.12nA current is rightly measured and displayed on LCD as 34.17nA. 3.02uA current is rightly measured and displayed on LCD as 3.06uA. Fig.8, 9, 10 shows the timing diagram waveforms seen on the CRO for different current ranges where Channel-1 shows the reference output from the Ion Chamber Current Monitor IC-01A unit and Channel-2 shows the ADC signal from STM. Fig.8. shows the 10pA (GIA_pico) current range timing diagram waveform having hold time of 1000ms as required, fig.9. shows the 10nA (GIA_nano) current range timing diagram waveform having hold time of 100ms as required and fig.10.shows the 9uA to 2uA decreasing current (TIA) which is independent of hold time, so from fig.8, 9,10 we can conclude that auto-ranging is taking place smoothly without disturbing the timing diagram for different current ranges.

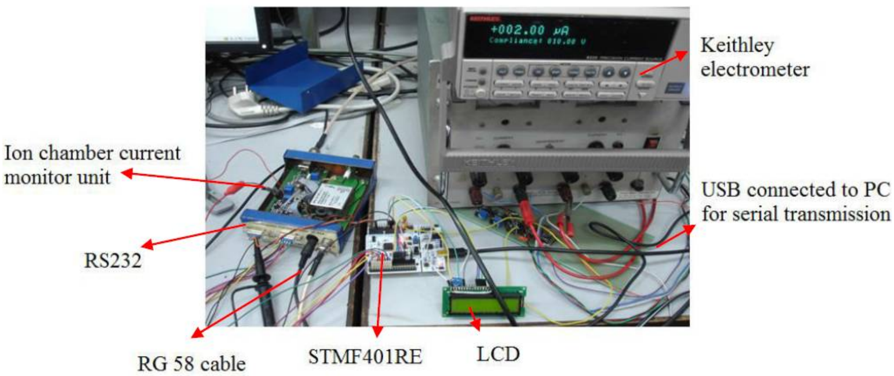

Fig.7 Chamber Current Monitor unit with the LCD displaying the measured current in micro amperes range

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The linearity of the different configurations of the amplifiers slope i.e. gain, in different ranges is plotted on the same graph. The characteristics graph of measured current versus time for low current measurement is shown in fig.11. Linearity of the current measured is better than 1%. Gain error is less in higher current range and it is the reverse in case of GIA mode as shown in fig.11.

Using STM32F401RE sampling time, number of samples, background subtraction, trigger generation and auto ranging are achieved in a simple manner using software. The acquired data can be stored in an array and transferred to PC for further analysis.

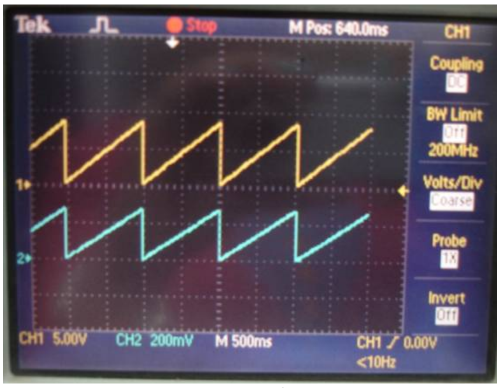

Fig.8. Timing diagram waveform for 10pA current

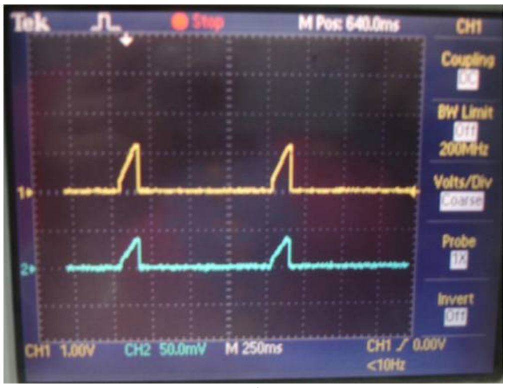

Fig.9. Timing diagram waveform for 10nA current

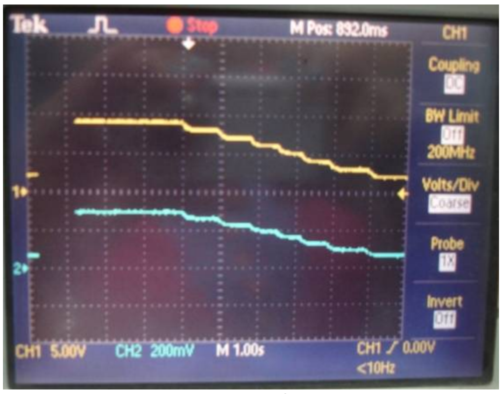

Fig.10. Timing diagram waveform for 9uA to 2uA current

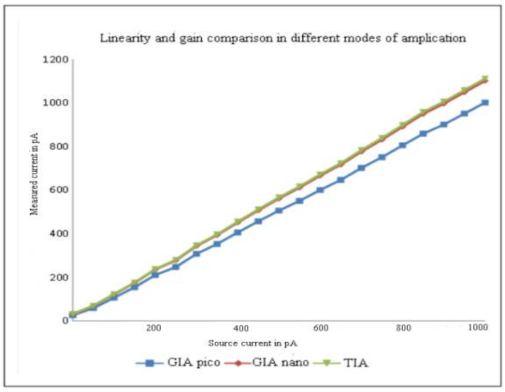

Fig.11. Linearity and gain comparison in different modes of amplification

The prime elements of chart controls in vb.net are titles, legend, series and chart areas. Title of the form is “Ionization current” as shown in fig.7.1.12. Legend is ‘1’ that means chart is not divided into more than one part as shown in fig.7.1.12. Series include chart type that is points as shown in fig.7.1.12. Chart areas include x-axis, y-axis, secondary x-axis and secondary y-axis. Form shows x-axis as real time and y-axis as measured current as shown in fig.7.1.12. Fig.7.1.12 shows the measured current in pico amperes and how the measured current is plotted on the chart with real time. Form shows the real time and date as label as shown in fig.7.1.12. There are different types of chart type like spline, points, bar, column, pie, polar, etc. Open button is used for opening any text file, document or jpg file. Save button saves the data in text file when save button is clicked. On the vb.net GUI the measured current is displayed in the text box and simultaneously plotted on the chart with real time. Y-axis measured current scale is kept in pico amperes. The value of y-axis is constantly changing so the points are dynamic that means the electrometer current is varied every second.

VI. Conclusion and Future Work

The developed system gives excellent linearity with minimum constant error over the whole measurement range, it is compact and faster. The circuit is compact so leakage current is very low. Operational amplifier used is best to get the dynamic range from 10pA to 10uA range. With STM32F401RE data acquisition at a faster rate up to 200 KHz is obtained. Data storage up to 30 days can be achieved i.e. data up to 512KB can be stored. It is possible to graphically visualize the data for particular time and consolidated graph can be generated in offline mode. Future scope for the auto-ranging DAS is number of channels can be increased from which the current is to be measured and the range can also be increased to fA to mA range.

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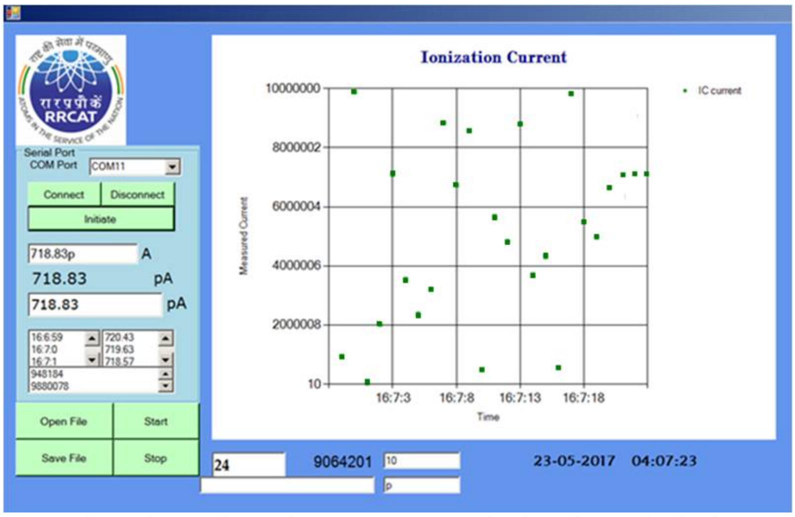

Fig.12. Form after execution in real time showing the serial port, current measured and simultaneously plot the measured current on the chart.

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BIOGRAPHY

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