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Development of Versatile Area Gamma Monitor for Radiation Industries

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Abstract - *Radiation Safety is prime importance of any radiation related industry for protection of the workers and public. It can be achieved by Radiation Monitoring instruments that always stand guard measuring radiation in ambience and by alerting people and enabling preventive measures in timely fashion to mitigate the causes and prevent any harmful effect on public, workers or property due to radiation. This article highlights the development of Industrial Area Gamma Monitors that are specifically tailor made for Radiation Industries that not only checks for ambient radiation and alerts us, also these have provisions for Industrial standard of communication protocols to interface with Industrial automation devices.*

1. INTRODUCTION

Use of Area Radiation Monitor is to detect gamma radiation dose rate above a certain threshold values to facilitate the experts in mitigating the source causes and protecting personnel from over exposure. For general public the exposure limit is 1mSv (1 milli Sievert) and for occupational radiation worker is 30mSv (30 milli Sievert) annually[5]. The concept of ALARA[5] (As Low As Reasonable Achievable) shall be followed. For this Radiation monitoring instruments are required and one such instrument i.e. Area Radiation Monitor that has been developed to alert and avert the unnecessary exposure to people. A radiation monitor is first line of defense against unnecessary radiation exposure. Safety and precaution shall be prime concern of any Radiation industry. To make sure we must use instruments in the field and ensure safety of workers as well as general population. Area Radiation Monitors are based on GM Tube or Geiger Muller Tubes. [2]

1.1 Concept

GM tube is gaseous ionization detector used to detect nuclear radiation by using Townsend Avalanche effect. The tube contains a gas mixture at low pressure of about 0.1 atm. The chamber contains two electrodes as shown in Figure 1.

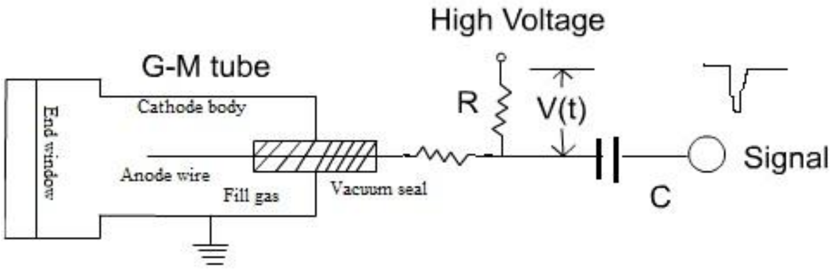

Fig.1 A GM tube construction

The wall construction of the tube is metal or glass with inside surface coated with a metal to form the cathode, while the anode is a concentrically placed Tungsten wire separated by cathode by an insulator in the centre of the tube.

Fig. 2 A small sized GM Tube LND7121 with energy compensation shield [4]

Fig. 3 A Longer GM Tube with higher sensitivity LND7807 with energy compensation shield [4]

When ionizing radiation strikes the tube, some molecules of the gas are ionized, either directly by the incident radiation or indirectly by means of secondary electrons produced in the metal walls of the tube due to photoelectric effect. Either ways positive charged ions and negative charged electrons are produced, or what we commonly know as ion pairs in the fill gas. Due to high electric field created by high voltage DC application across the GM tube terminals, an avalanche region exists close to the anode where the electrons gain sufficient energy and accelerate at high speed to hit and ionize additional gas molecules and create a large number of electron avalanches which multiply along the anode and effectively throughout the entire GM tube region. This is the Townsend Avalanche or Gas multiplication effect which gives the tube its key characteristic to produce a significant output current pulse from a single ionizing event. This short and spiked pulse of current can be counted as an event in the form of a voltage pulse developed across an external electrical load resistor as in **Fig. 4**. This can be in the magnitude of few volts. The voltage pulse is signal processed to give it a proper logic signal shape that makes electronic processing simple by the digital counters implemented in the system. The pulse train is counted for a specific time window and is translated in CPS/CPM or Counts per Second/Counts per Minute and is calibrated in terms of mR/hr (milliRoentgen per hour) or µSv/hr (microSievert per hour) which denote the radiation dose rate. The sensitivity of a GM tube is specified in terms of mainly CPS/mR/hr. e.g in **Fig. 2** LND7121 has sensitivity of 18cps/mR/hr and in **Fig. 3** LND7807 has sensitivity of 150cps/mR/hr.

2. Methodology

The Area Radiation Monitor, which is an instrument for measuring dose rate in the vicinity. It denotes Radiation dose rate in terms of either mR/hr or µSv/hr. The instrument uses a very rugged and well known Geiger-Muller tube (GM Tube). Apart from that High Voltage DC source for biasing the GM tube. Pulse shaper and counter circuit has been implemented.

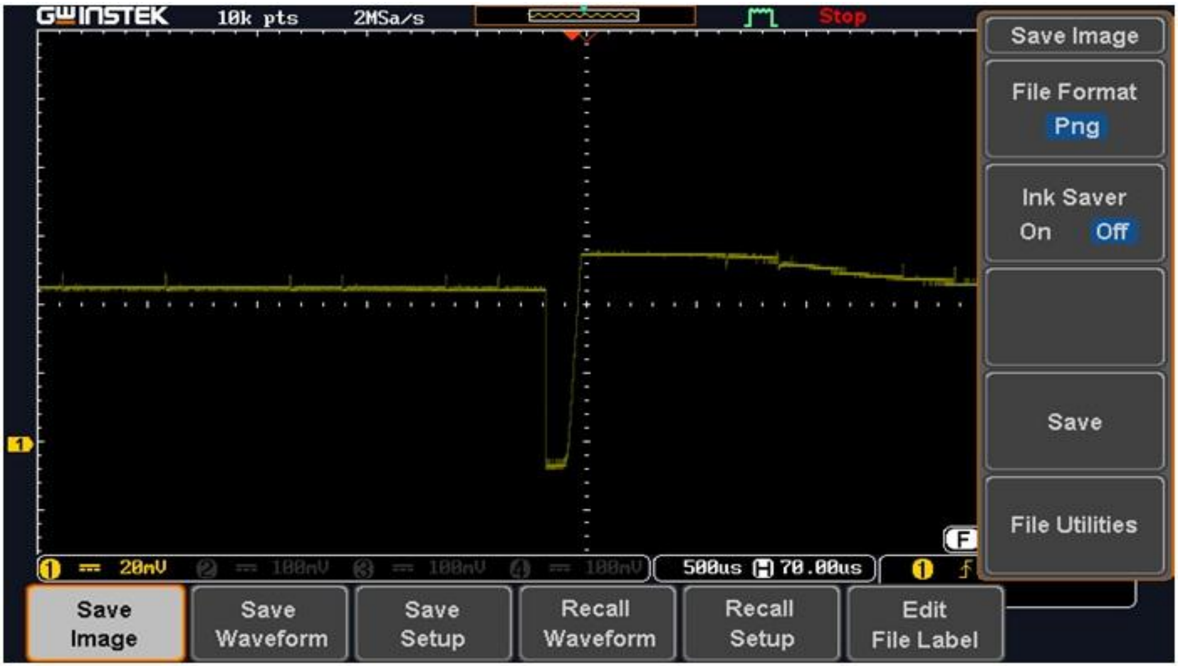

Fig. 4a

Fig. 4b Pulse Output of GM Tube and logic level translation of signal shaper unit.

In one model of GM Tube based Area Gamma Monitor, Microcontroller based LCD and optional Seven Segment readout and alarm generation is incorporated. Industrial communication modules such as RS-485 based MODBUS serial communication, 4-20mA industrial current loop, TCP/IP Ethernet and TCP MODBUS are implemented. Apart from that potential free relay output and Audio Visual alarm setup is also implemented in the instrument.

The GM Tube used is LND7121 that works from a range of 450V to 600V high voltage DC(HVDC). The HVDC circuit has been constructed using a boost converter that converts 9V DC to 500V DC and is a low ripple DC Voltage [1]. When radiation is incident on GM tube and inside the pulse output can be seen in **Fig. 4**. The pulses are processed and converted into Logic level compatible pulses using pulse shaper circuit as in **Fig. 4**, so that it can be read by Microcontroller based Counter assembly as CPM or CPS, as well as dead time compensation for GM tube is done [3]. The dead time is the time during which, after the detection of an event, the GM counter cannot detect a subsequent event. The Microcontroller contains calibration data that converts the respective counts in terms of mR/hr or µSv/hr. There is user set Alarm radiation threshold in the system, and if the incident radiation crosses this limit the Logic relay is activated for safety interlocking as well as the Alarm LED starts to blink and Alarm buzzer starts to sound. The entire data can be seen on Instrument local display that consists of a very high contrast OLED display screen as seen in Figure 7. A very reliable 4-20mA current loop module has been implemented for the instrument which is very useful for gathering instrument parameter value to a centralized PLC based system with Analog Input modules which would help to gather all the Plant Radiation data on to a single system and display on SCADA. The instrument also includes RS-485 based serial communication module that is essential for Industrial digital serial communication. However these modules are optional and maybe implemented as per user's choice. Operations flowchart has been depicted in **Fig. 5**. Further there was development of Area Gamma Monitor with Ethernet communication interface to implement MODBUS TCP and TCP/IP which give this instrument a versatility of mounting the same in industry as well as in Civilian area. It denotes Radiation dose rate in terms of either mR/hr or µSv/hr and generates local sound and light based alarm if radiation dose rate is high beyond permissible limits for various zones set as threshold. It also communicates the Radiation dose rate data and other instrument parameters through **TCP/IP Ethernet**. This particular communication protocol was chosen as there is Ethernet connectivity almost anywhere now a days, namely, offices, ports, labs etc. Proper signal isolation has been implemented in both the instruments models for reliable operation in industrial environment.

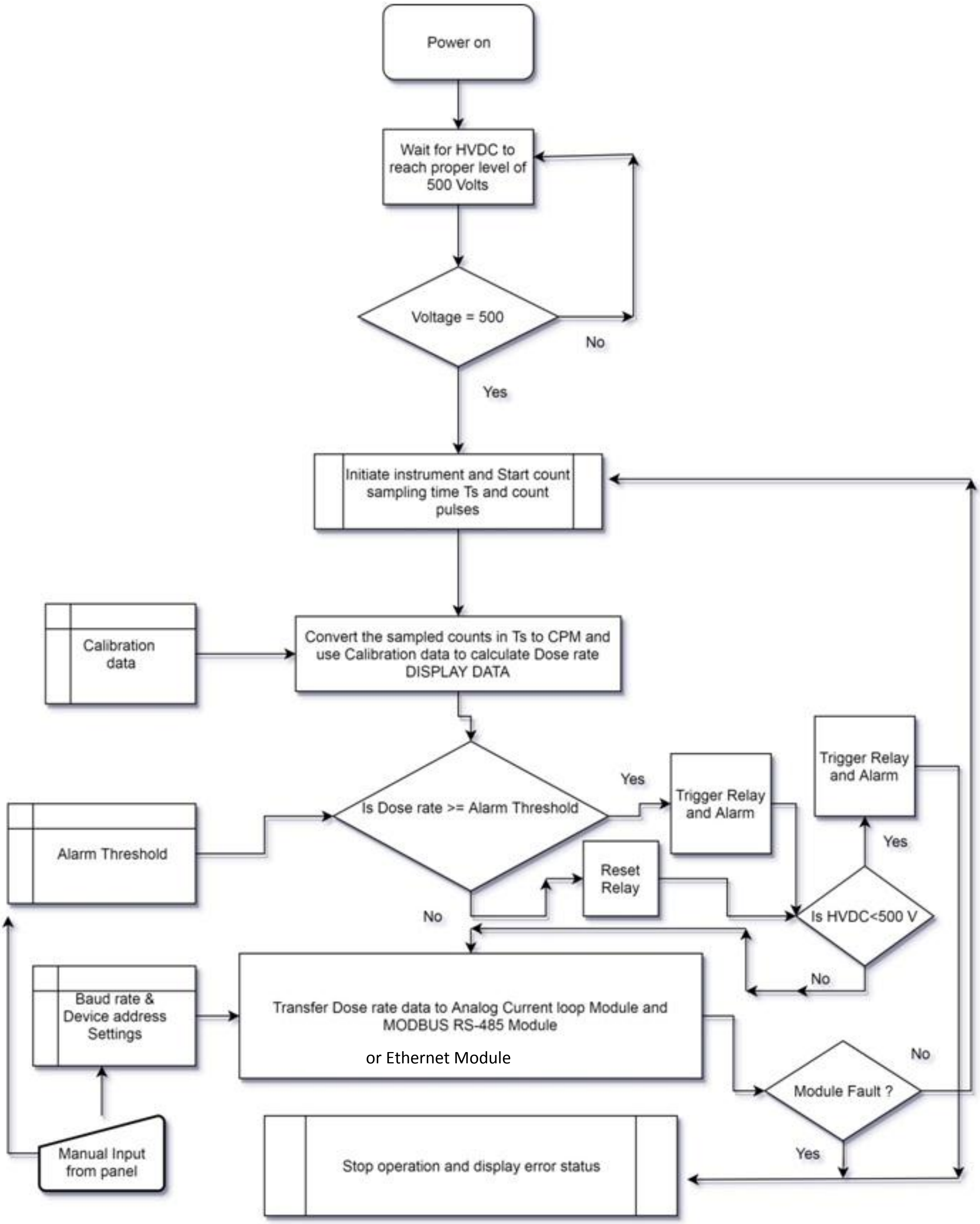

Fig. 5 Operations Flow Chart for the working of the Area Gamma Monitor models.

3. Implementation

A complete Instrument Block diagram for model with RS-485 MODBUS and 4-20mA communication has been shown in **Fig. 6.**

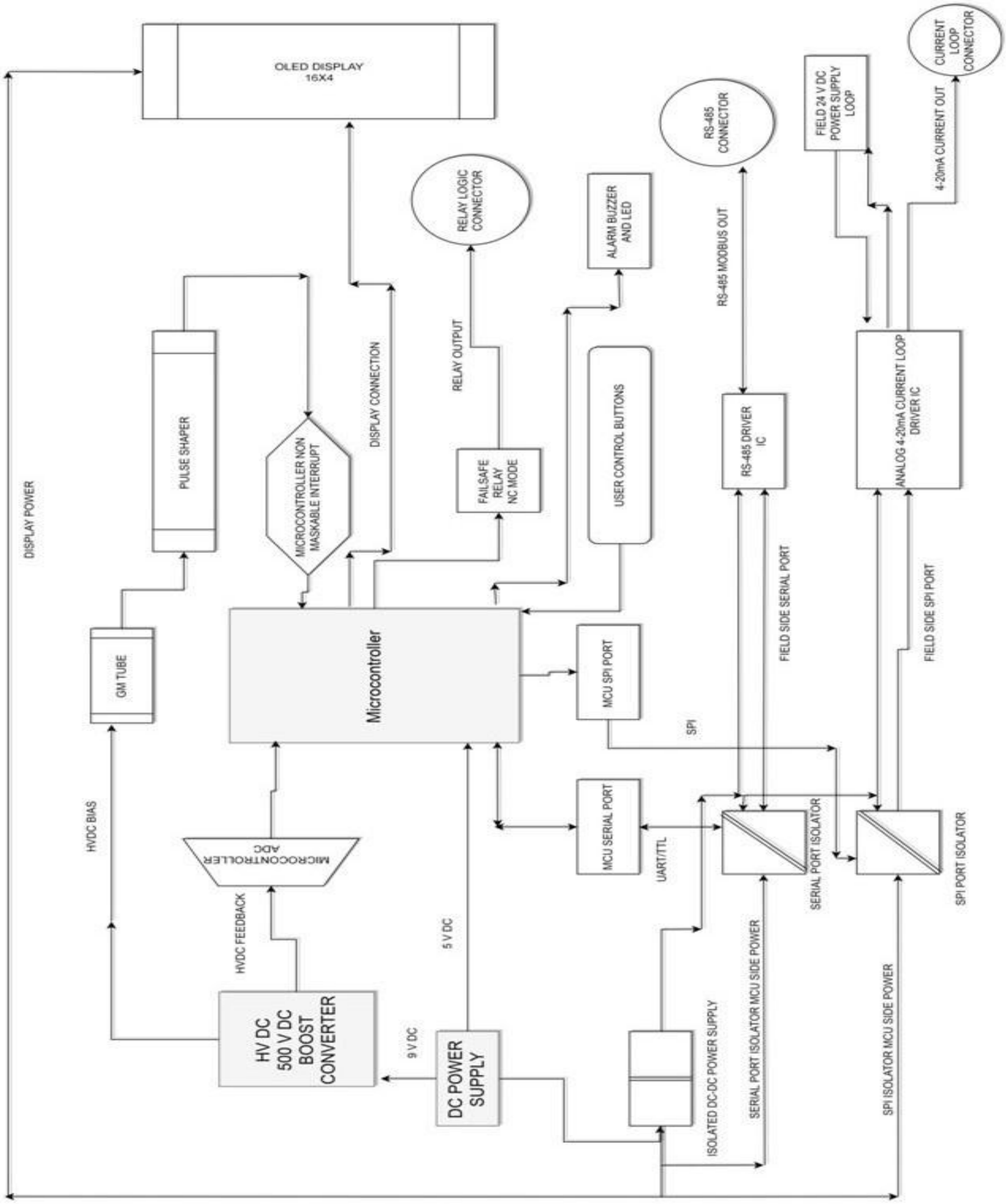

Fig.6 Block diagram of model with RS-485 MODBUS and 4-20mA current loop outputs

The printed circuit board for the same model as in block diagram of **Fig. 6** is shown in **Fig. 7**.

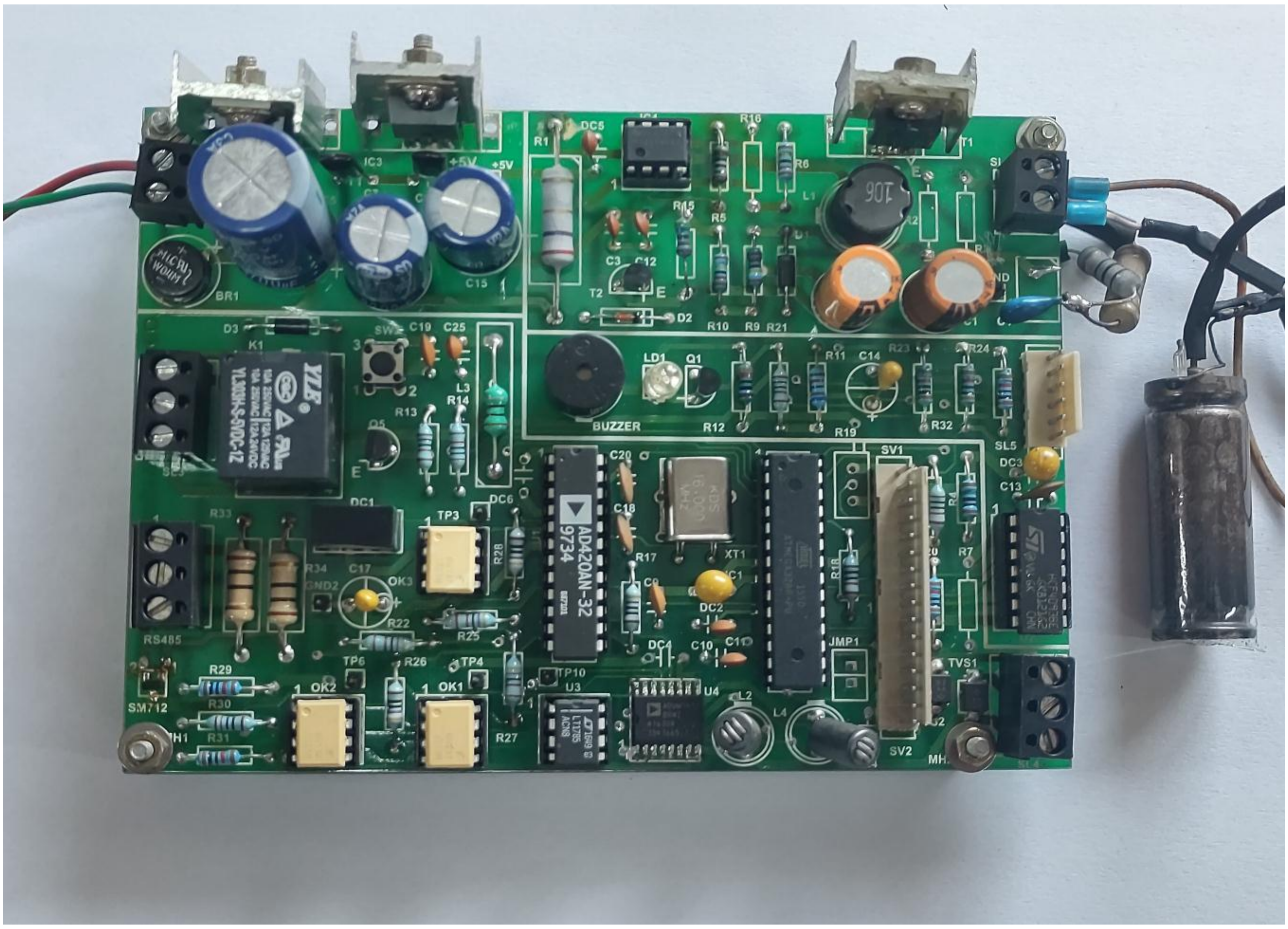

Fig.7 Assembled printed circuit board for one model with RS-485 MODBUS and 4-20mA current loop outputs.

Many iterations in design has been done to make HVDC power supply efficient for very high dose rate, proper component placement modifications has been done in order to reduce interference noise of DC to DC boost module, proper component selection for reliable data communication and alarm.

Use of OLED display in place LCD display has been done in order to provide very high contrast display for easy readability from all angles and at a given minimum distance as in **Fig. 8**

The Calibration graph has been plotted between CPS and Dose rate as per Figure 8 is found to be almost linear for a range of 0-100mR/hr.

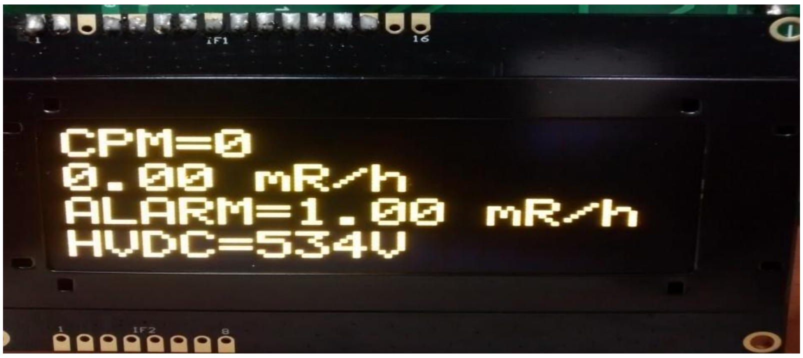

Fig. 8 Instrument readout screen with OLED display for high contrast.

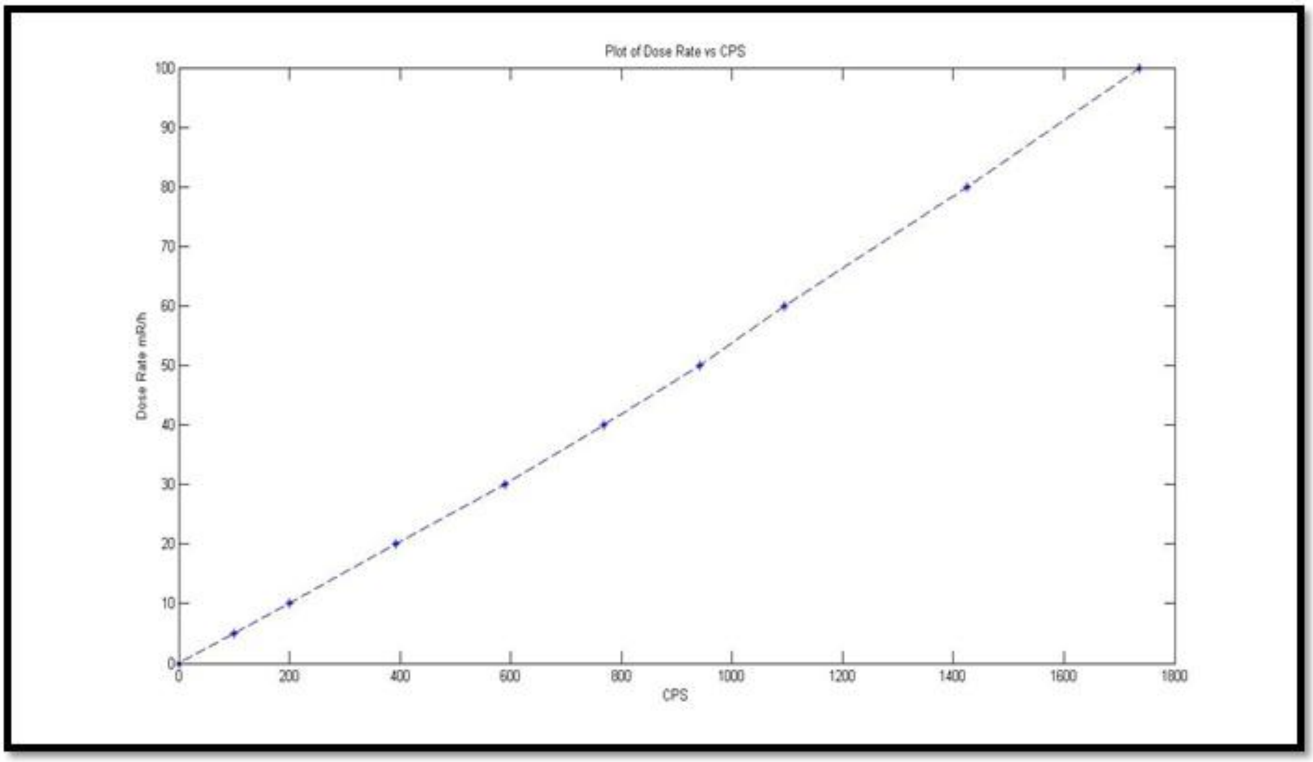

Fig 9. Plot of CPS vs Dose Rate in mR/hr during calibration of model with RS-485 MODBUS and 4-20mA current loop outputs

The Calibration was done for a range of 0mR/hr to 100mR/hr **Fig. 9** and after that instrument prototype was found to be accurate within 10% of Actual reading which is acceptable.

The Microcontroller contains calibration data that converts the respective counts in terms of mR/hr or µSv/hr. The calibration has been done at Calibration lab with Cesium source. There is preset Alarm radiation threshold in the system, and if the incident radiation crosses this limit the Logic relay is activated for safety interlocking as well as the Alarm LED starts to blink and Alarm buzzer starts to sound. The entire data can be seen on Instrument local display that consists of a very high contrast OLED display screen as seen in **Fig. 8** Further Ethernet communication capability over TCP/IP communicates system data and parameters to a central logging server running MySQL database where all the data is logged after sampled periodically, say after 15 seconds time gap. User can access the data and may visualize the same in graphs that are updated continuously.

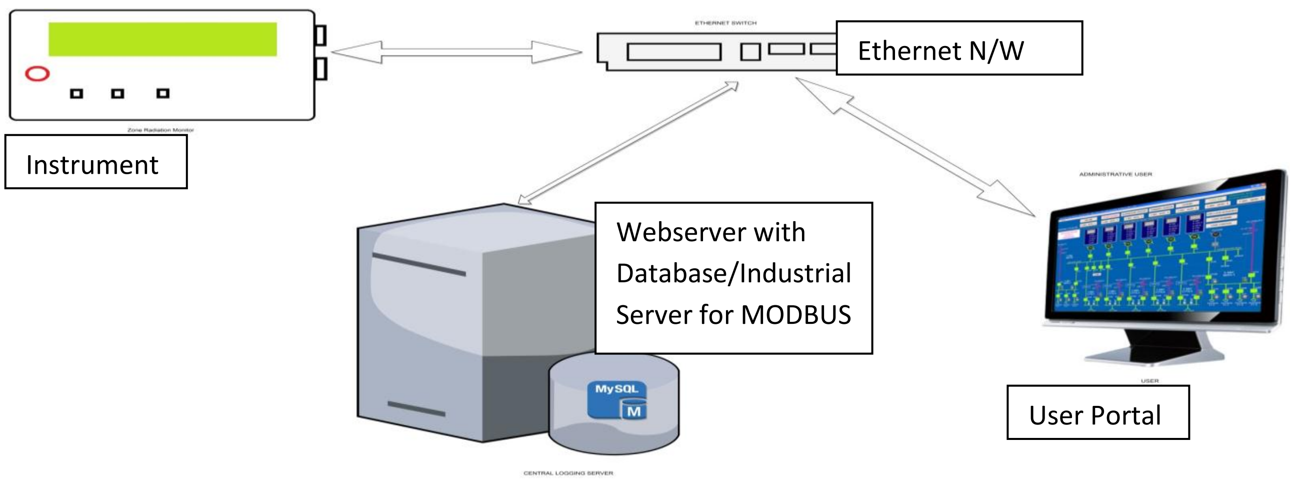

Fig. 10 Mounting scheme of Ethernet based Area Gamma Monitor

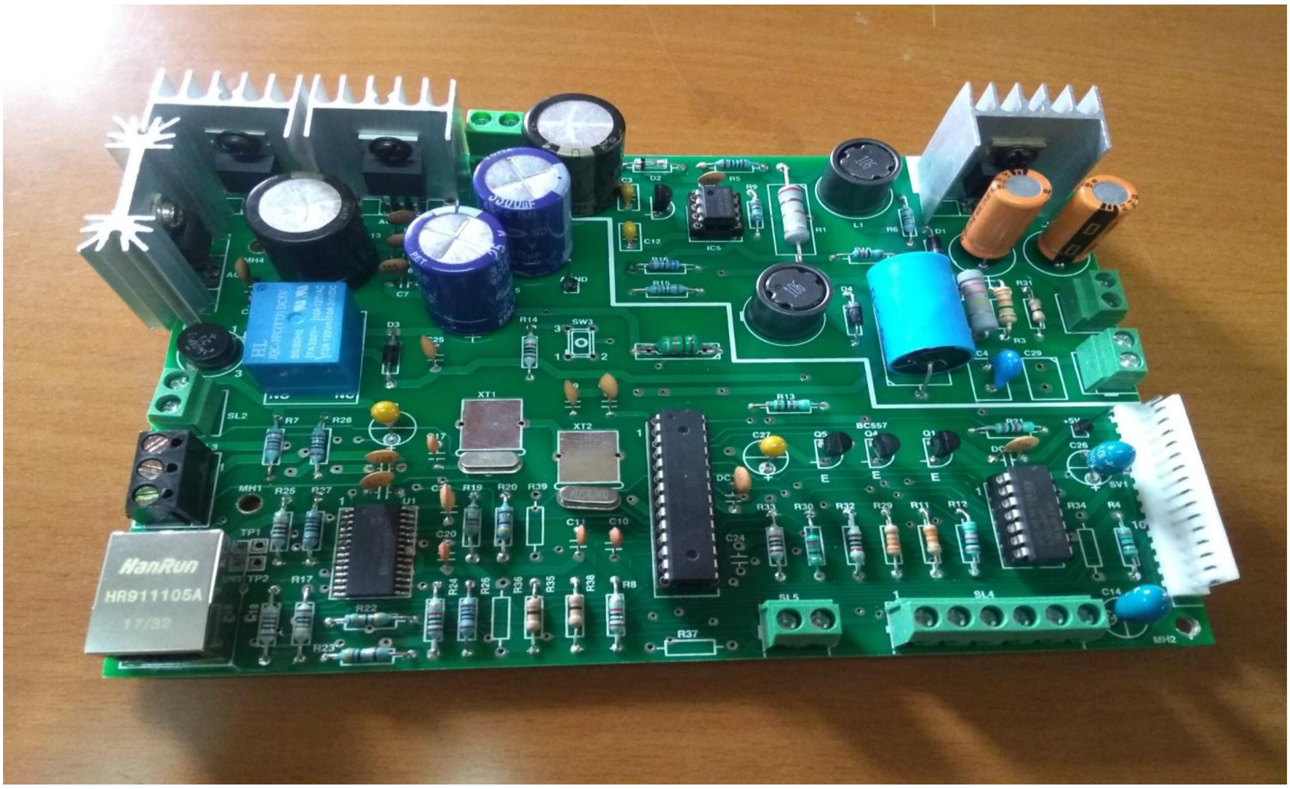

Fig. 11 Assembled Printed Circuit Board for the TCP/IP Ethernet and MODBUS Ethernet based model of Area Gamma Monitor

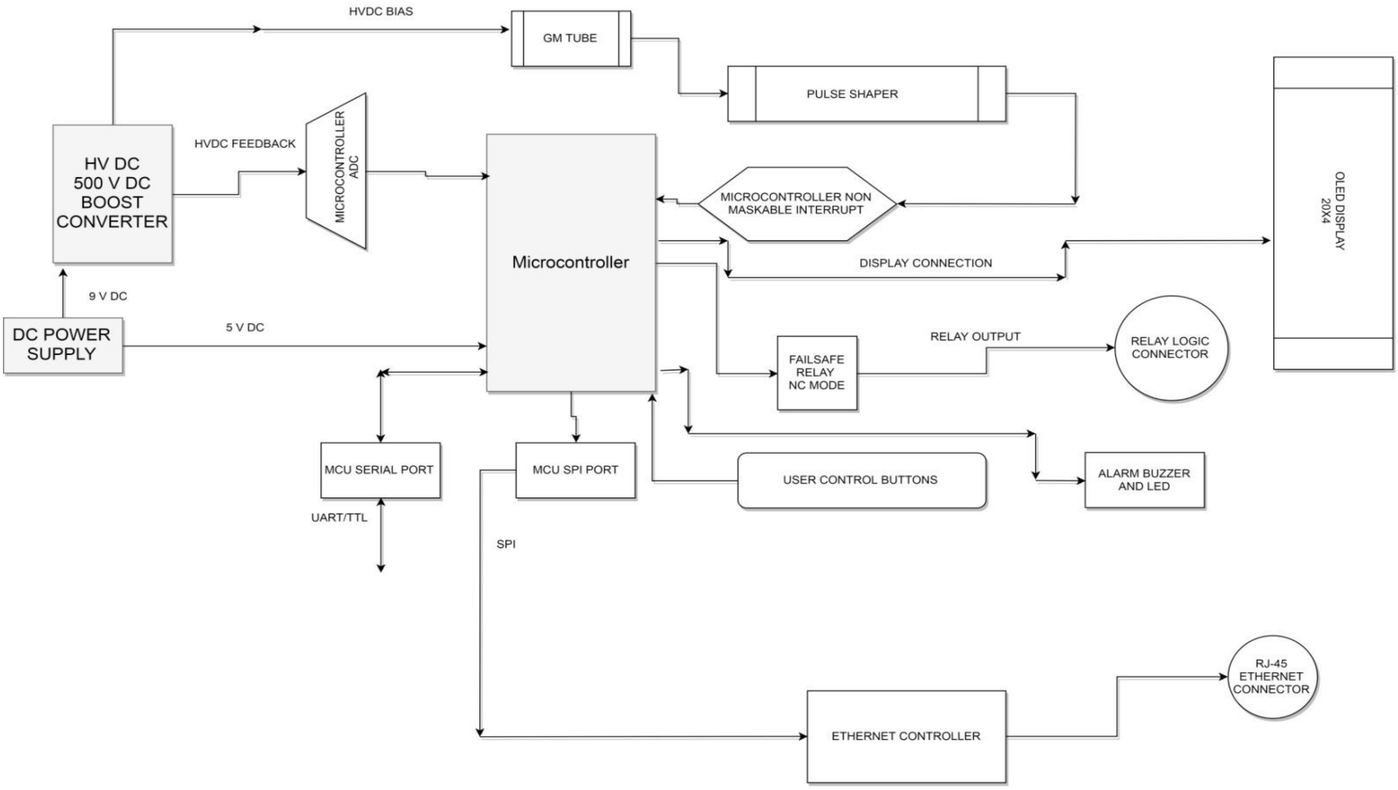

Fig. 12 Block diagram of model with TCP MODBUS or TCP/IP Ethernet interfacing

In **Fig. 10** we can see the scheme of mounting the instrument in the field. As this instrument is Civilian in nature the mounting and interfacing shall be compatible with Ethernet Network. The Instrument has local display/alarm buzzer and light as well as TCP/IP Ethernet communication. The is provision for a Central data logging server running MySQL database and Data Logging application in PHP that pulls the data from the instrument automatically after given time delay. The time delay can be varied as per user requirement. The network parameters and instrument parameters can be modified using web browser. The instrument has capability of pushing the data over database irrespective of sampling time in case when radiation dose rate is higher than threshold. The central server may also have graph plotting application and report generation of any particular instrument. The entire unit was fabricated by soldering components on printed circuit board and enclosing the same in a general purpose polymer box. The control button panel and display was fixed on the top cover.

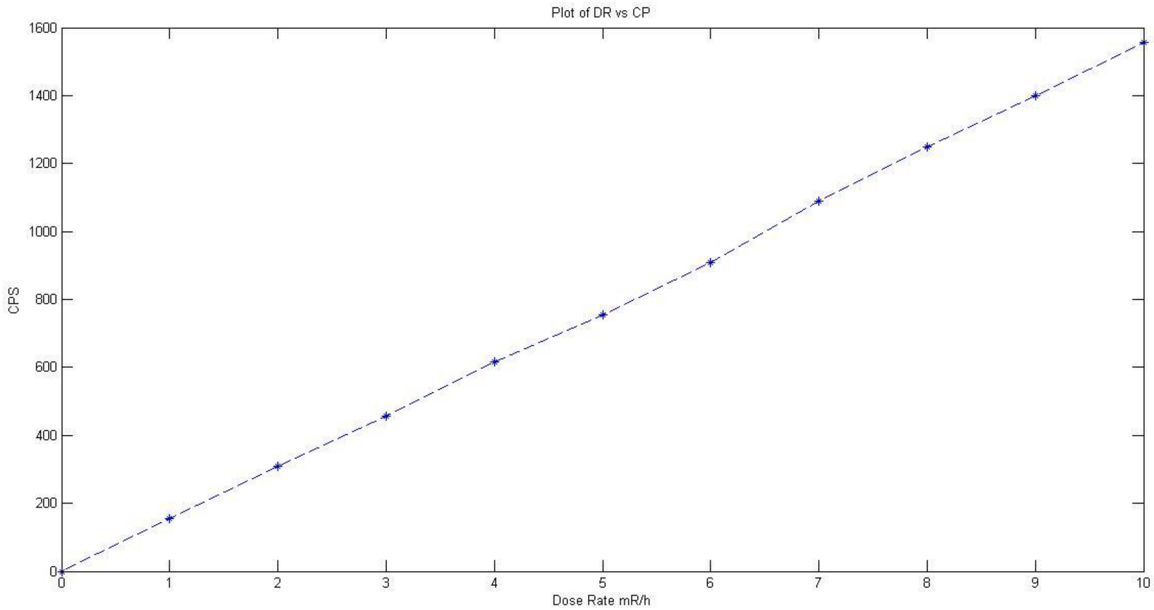

Fig. 13 Plot of CPS vs Dose Rate in mR/hr during calibration of model with Ethernet interface

The Calibration was done for a range of 0 to 10mR/hr and residual errors were adjusted within the software as in Fig. 13, after that instrument prototype was found to be accurate within 5% of Actual reading which is acceptable.

4. Conclusion

The accuracy of the instruments were initially ±10% , which is expected to degrade once the instrument ages. To mitigate this the instruments have to be recalibrated over a period of 6 months to 1 year subject to the accuracy if it is better than acceptable limit. Higher sensitivity GM tube may be used in case of areas where high resolution of Radiation detection is required. Since the instrument fabrication is modular over the printed circuit boards, the features implemented like RS-485, 4-20mA loop, Ethernet, Audio Visual alarm, potential free Relay output etc. maybe kept optional. This implementation adds versatility to further research, fabrication, production and deployment of Geiger Muller tube based radiation detectors in Radiation industries.

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Calibration Services

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