Development and Characterization of 2m×2m Glass Resistive Plate Chambers (RPC)

Maulik Nariya

Research Scholar, INO(DHEP), Tata Institute of Fundamental Research

Introduction:

Resistive Plate Chambers (RPC's) are gas detectors used in a large number of High Energy Physics and Astroparticle Physics experiments. The main advantages of RPC's are high gain, good spatial and time resolution, good efficiency, long term stability, simple design, and low cost. In principle, RPC's can detect any charged particle, but are primarily used to detect high energy muons and are capable of handling extremely high count rates (~1KHz/cm^2 in avalanche mode). The following report describes development and characterization of 2m×2m glass RPC's which are used in the detector RND for India-based Neutrino Observatory

Basic construction and principle of operation of RPC:

RPC's consist of two planar electrodes, made out high resistive material (glass in our case) with bulk resistivity of 10^{10}-10^{12} Ω-cm, separated by a few mm by means a polycarbonate spacer having bulk resistivity great than 10^{13} Ω-cm. The electrodes are connected to high voltage power supply to create a uniform electric field (typically about 5kV/mm) in the gap between them. A thin layer of Graphite is coated on the external surface (thickness of the layer~15-20μm) of the electrode to provide the uniform electric field. A thick layer of gas mixture of Freon (134A), isobutene and SF_6 at normal pressure is flown between the gap. This gas mixture forms the sensitive element of the detector. A set pick-up strips, made of copper, are mounted on either sides of the external surface of the RPC. The two sets of strips are oriented in orthogonal directions on both sides. The strips behave like a transmission line with characteristic impedance of 50Ω

When a charged particle passed through the gap of the RPC, it ionizes the gas and produces electron ion pair. The electrons are accelerated towards the positive electrode, further ionizing the gas leading to avalanche formation. High resistivity of the electrodes prevents high voltage supply from providing the electric charge that would be necessary to maintain the discharge between the electrodes. Therefore the electric field drops drastically in the region of the discharge causing it to extinguish. The time duration discharge is ~1ns. The relaxation time of the resistive electrode plate is ~2s. This ensures that during the discharge, the electrode plates behave like insulators and only a limited area of ~0.1cm^2 remains inactive for the dead time of the detector. The surface resistivity of the graphite layer is high enough to render it transparent to the electric pulses generated.

Fig.1 shows a schematic of an RPC

Cons

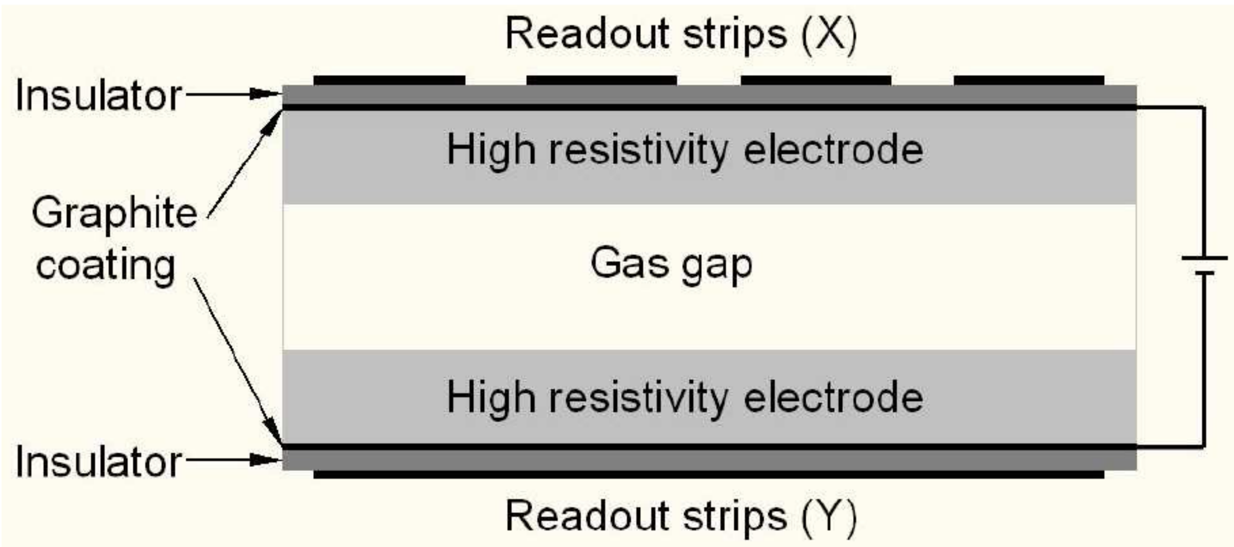


Fig.1: Constructional schematic of an RPC
(transverse view)

Some details about the RPC used:

1. Glass: 2m×2m×3mm Asahi float glass,
2. Spacer thickness: 2mm
3. Gas mixture: 95.15% Freon, 4.51% Isobutane, 0.34% SF_6
4. Graphite coating: conductive paint about 15-20μm thick
5. Pick-up strips: 2.8cm wide.
6. Insulating material between the graphite coating and the pick-up strip: Mylar sheet.

Operating modes:

(1)Avalanche Mode: In avalanche mode, the charged particles passing through the gas produce primary ionization which in turn produce secondary ionization. The avalanche stops after sometime because the external electric field is opposite to that of the internal field created due to ionization. The avalanche mode operates at a lower voltage (<10kV). The charge produced in the gas in avalanche mode is ~1pC, and the pulse produced in this mode is a few mV. Hence, it requires sophisticated electronic to record the data. However is possible to handle high count rates and ensure slower aging of the detector in avalanche mode.

(2)Streamer mode: For steamer mode, the detector is operated at extremely high voltages. At such high voltages, the secondary ionization continues till there is a gas breakdown and a continuous discharge takes place. A conductive channel is formed between the electrodes and a weak spark may be created. The charge produced in streamer mode is ~100pC and the pulse produced in this mode quite large (about 100-200mV). Hence, no amplification is needed and the signal can be discriminated directly against the detection threshold.

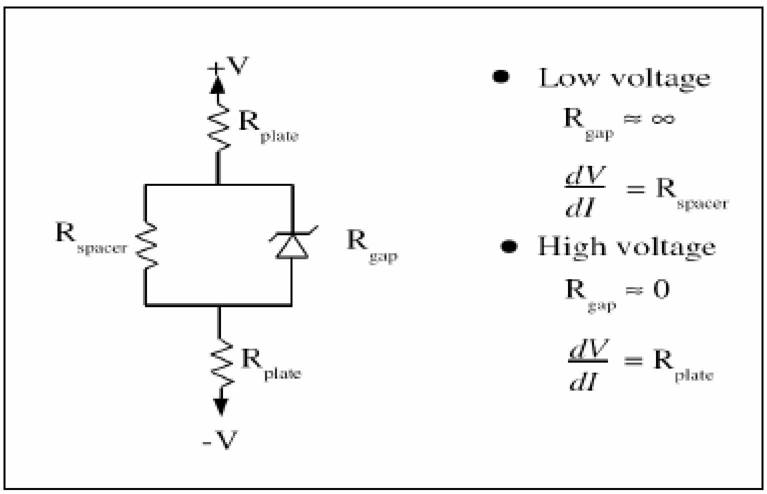


Fig.2: Electrical representation of an RPC

Stages involved in fabrication of RPC:

1.) **Glass cleaning and cutting**: The 3mm thick float glass is first cut, by means of diamond cutter, to exact dimension of 2m×2m. The corners are chamfered by a jig of correct dimensions to make it exactly 45^{o}. The glass is the thoroughly cleaned by alcohol followed by distilled water. The polycarbonate spacers and the button spacers are also cleaned with alcohol. The edges of the glass are taped over using a masking tape to prevent the graphite coating to go right till the edges.

2.) **Conductive coating**: The glass is coated (on one side) with a mixture of dry colloidal graphite and industrial lacquer (with the ratio 1:8). The coating is conductive enough to act as electrode and resistive enough to prevent the signal to conduct away from the pick-up planes.

3.) **Glass gluing:** One of the glass plates is kept on a plastic sheet and the button spacers (2mm thick) are glued to form an array, with 3M Scotch-weld epoxy adhesive (DP 190) in a duo pack cartridge. The other glass placed over the array of the spacer to have a uniform gas gap of 2mm. The straight spacer and the side nozzles are also of the same thickness and fit in between the gas gap. To put a uniform pressure the whole surface, the whole set up is wrapped with plastic sheet and the air inside is sucked slowly to create a partial vacuum and a pressure equivalent to 5cm of water. The set-up is left for about 6 hours to fix the button spacers to the gap. The spacers are glued to the glass using a syringe.

4.) **Gas leak test:** To ensure that there is no gas leak (especially at the glued corners), leak test is performed using a gas leak checker RIKEN GH-202F, which is sensitive to Freon gas at atmospheric pressure.

5.) **High voltage cables:** The high voltage is applied to the graphite layer by sticking on a copper tape and leads are then soldered on to the copper. Positive voltage is applied to one side and qual and negative voltage to the other side, using a bi-polar high voltage DC supply, so that both see a common ground.

6.) **Pick-up strips:** The RPC is now sandwiched between two honeycomb pickup panels placed orthogonal to each other and then packed in an aluminum case. The pickup panel consists of 64 copper strips on one side and a layer of 5mm of plastic and aluminum on the other side. Each strip is machined to a width 2.8 cm and the gap between two adjacent strips is 0.2cm. Honeycomb panels are lightweight and provide adequate mechanical strength. Each strip is terminated with a 50Ω impedance to match the characteristic impedance of the preamplifier. A mylar sheet of thickness 100μm is placed between the graphite layer and the pickup panel to provide insulation.

Gas composition:

The choice of fill gas largely depends on the following factors:

- Low working voltage
- High gain
- High rate capability

Noble gases like Freon, Argon require minimum ionization energy and hence are the ones usually used.

If n_0 primary electrons are created by the passage of the charged particle, then the number of electrons reaching the anode is given by

$$n = n_0 e^{\eta x}$$

$$\eta = \alpha - \beta$$

α: first Townsend co-efficient.(represents number of ionizations per unit length)

β: attachment co-efficient (represents number of electrons captured per unit length)

The parameter β becomes particularly important for electronegative gases.

In our case, for operating in avalanche mode, Freon (R134A) is used. We also need some gas for absorbing the ultraviolet photons produced in electron-ion recombination. Generally, polyatomic gases, often hydrocarbons are used. In our cse we use Isobutane for quenching. Finally, we need some gas to absorb the excess electrons. SF_6 (Sulphur-hexafluoride), is used for this purpose.

Gas mixing unit and gas flow system:

The above gases are mixed the proper proportion (95.15% Freon, 4.51% Isobutane, 0.34% SF_6) by the gas mixing unit. The mixing unit consists of the following components:

1. Purifier Column: consists of molecular sieves used to absorb moisture and purify the gas.

2. Mixing Unit: is based on Mass Flow Controllers (MFC) and the flow of the gas is displayed in Standard Cubic Centimetre per Minute (SCCM).

3. Distribution Panel: 16 RPC's can be connected in parallel, which is achieved by "Flow resistors" viz. capillaries, which are 2m long and 200μ in diameter. These offers a resistance of 1/14th of a bar to the gas flow when the flow is about 6sccm.

4. Safety Bubblers: To protect the RPC's from over pressurizing.

5. Isolation Bubblers: It prevents back diffusion of air into the RPC and also indicates the flow of the gas.

6. Exhaust Manifold: All the gas to be vented is collected in this manifold and a single output is provided to vent the used gas into the atmosphere. This manifold has a pressure sensor to indicate the pressure with respect to the room pressure.

7. Moisture Meter: Microprocessor based SHAW sensor meter to monitor the moisture content in the mixed gas.

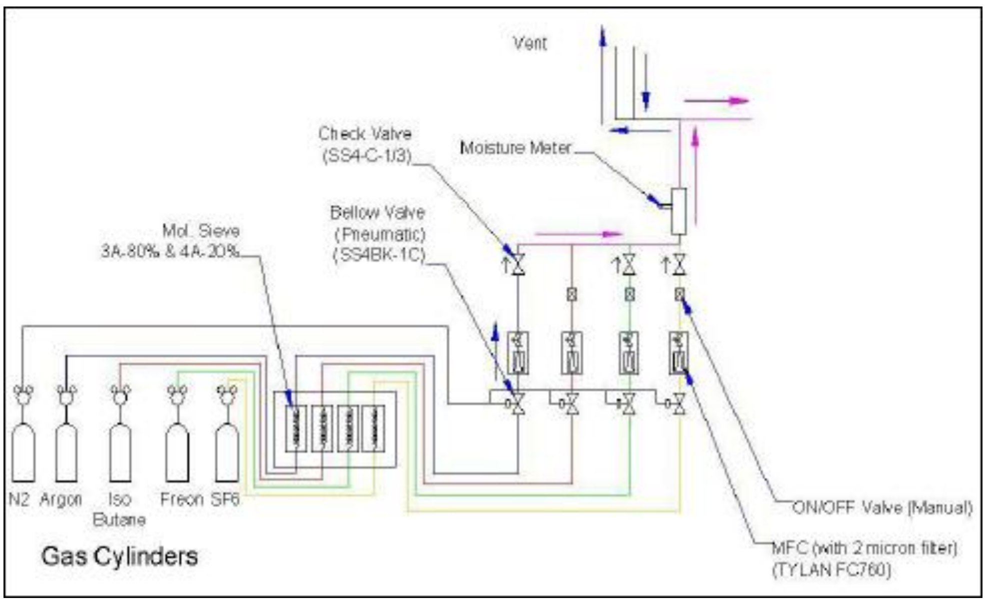


Fig.3: Block diagram of the Gas flow system

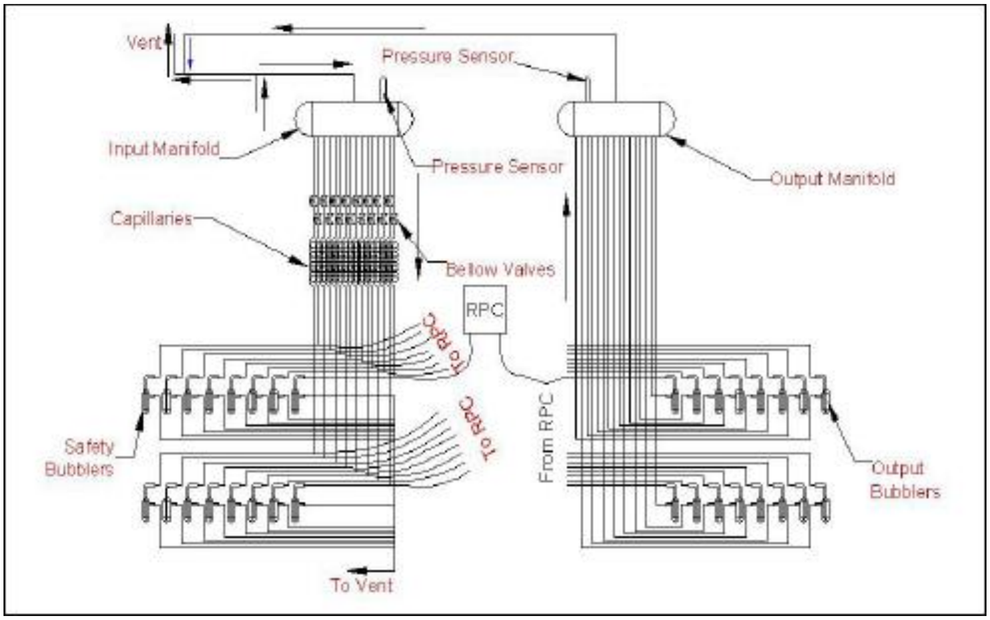


Fig.4: Block diagram of the Gas flow system

Signal processing and data acquisition system:

In order to do the analysis of the data, we need to store the signals generated by the RPC's. A sophisticated electronics system has to be used for this purpose. The whole of the system can be broadly divided in to two major components, viz. Signal processing and Data acquisition system. The Signal processing unit can be further classified into:

1. Front-end electronics. (16 channel Analog front-end and 32 channel Digital front end)
2. Trigger module,
3. Signal routers. (Trigger and TDC Router & Control and Data Router)

Fig.5 shows the block diagram for electronics set-up for the x-plane.

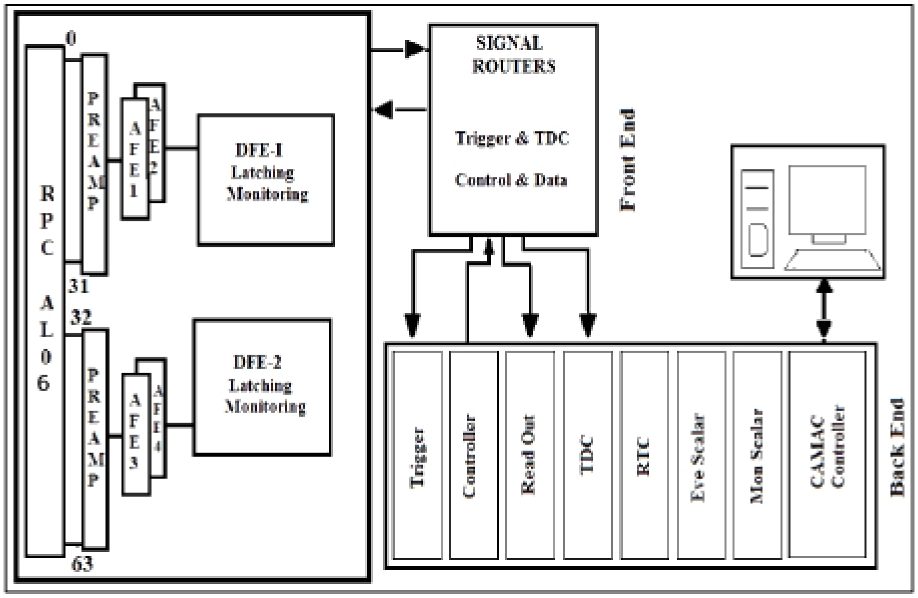


Fig.5:Block diagram for electronic set up for x-plane of RPC

Trigger logic for calculating the RPC efficiency and time resolution:

In order to record the signal that we are getting is from the cosmic muons, we have to employ an appropriate trigger logic. For this scintillator paddles are arranged in such a fashion that if a muon passes through all of them, it produces a trigger signal. Four scintillator paddles P_1 (40cm×20cm), P_2 (40cm×20cm), P_3 (30cm×2cm), P_4 (30cm×3cm) were used and together are called as cosmic ray telescope. The passage of muon through the cosmic ray telescope a trigger signal is generated and the signal is recorded by RPC under test. The RPC trigger logic set up is shown if Fig.6

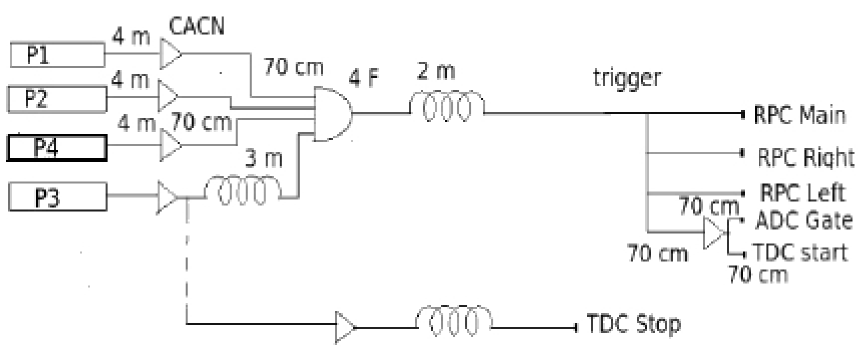


Fig.6: Trigger logic circuit diagram

The analog pulses that come from the pre-amplifiers and the PMT's are converted into digital pulses using discriminator with a threshold voltage of 20mV. The paddles P_1, P_2, P_3, P_4 are ANDed to give 4-fold signal. Scalers are employed at different stages to monitor the count rates of these signals. The P_3 signal is delayed by a 3m cable (approximately 15ns) to take care of the jitter from the scintillation paddles. The pick-up strips of the RPC's are connected to the discriminators and the output is taken to different TDC channels with some delay. RPC trigger is taken from the main strip of RPC (main strip in our case was strip#20) and is ANDed with the 4-fold signal to get a 4-fold×RPC signal. So the efficiency of RPC becomes

$$E = 4\text{-fold} \times \text{RPC} / 4\text{-fold}$$

Fig.7 shows the circuit diagram for calculating RPC efficiency.

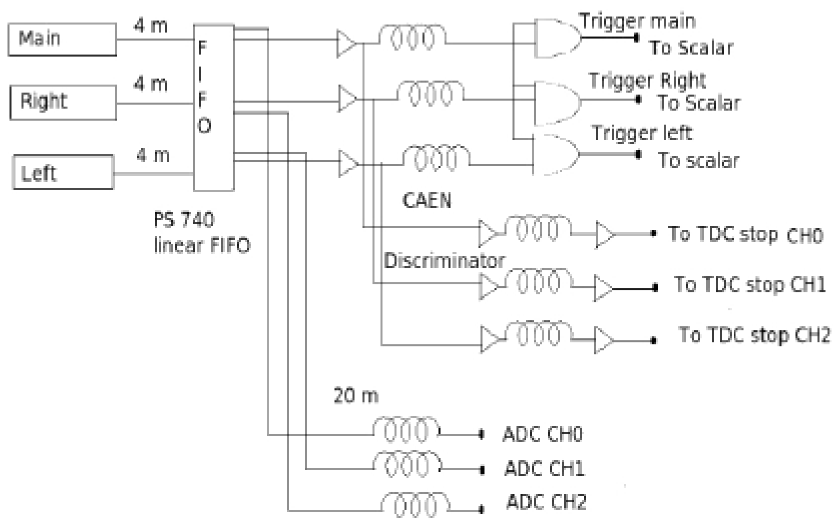
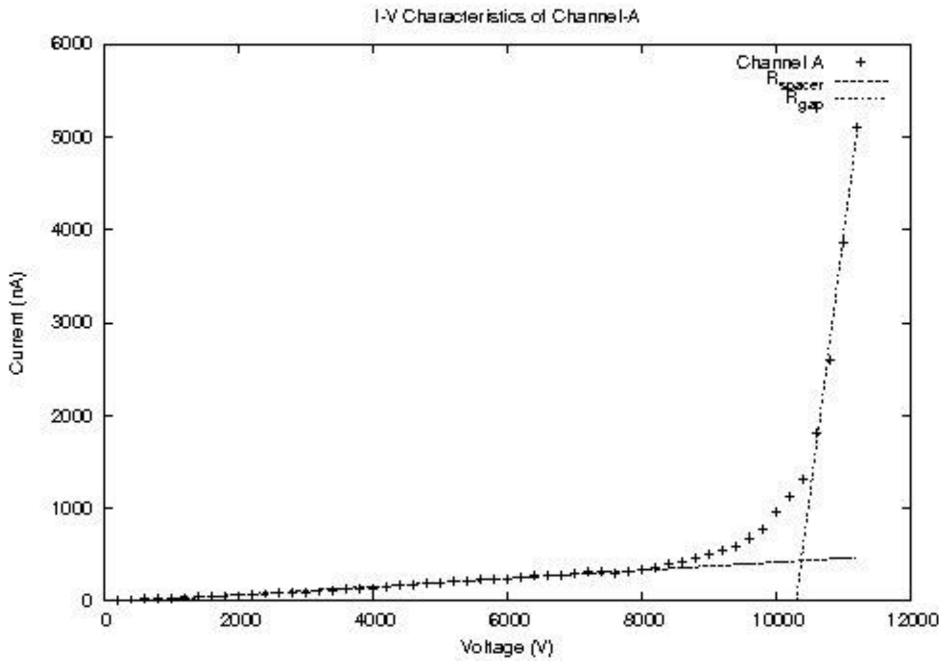
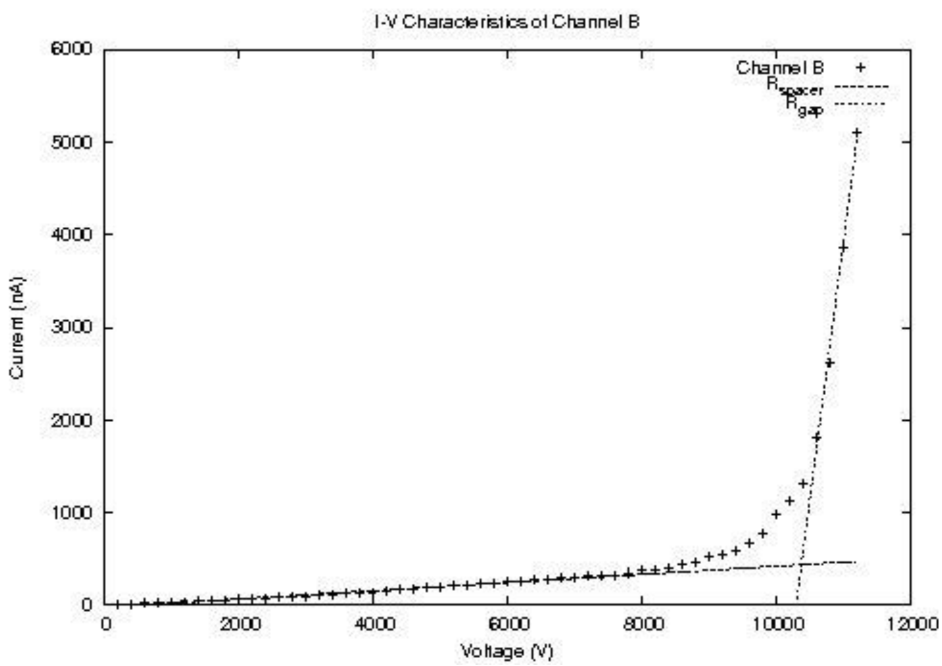


Fig.7: Circuit diagram for efficiency measurement of RPC

Results and Analysis:





From the above plots the slope in the low voltage would give the resistance of the spacer and the slope at high voltage would give the resistance of the gas gap:

Channel A

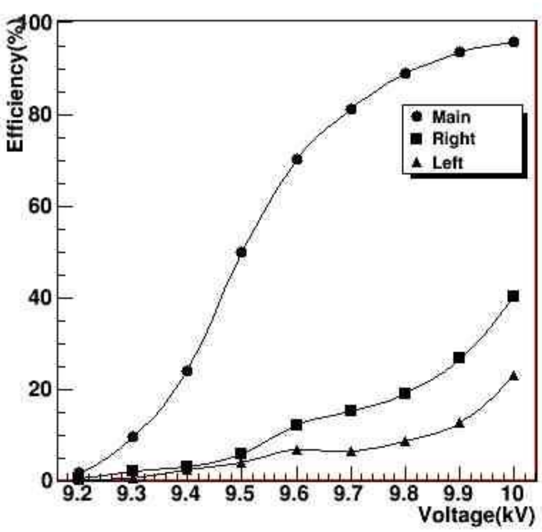
R_{spacer} = 22±3.25 GΩ

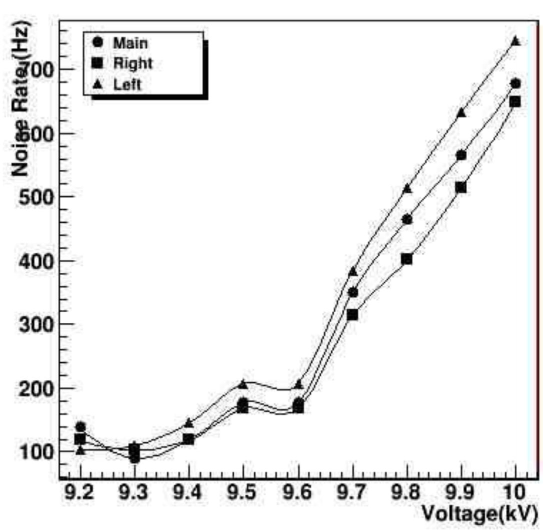
R_{gap} = 0.17±0.05 GΩ

Channel B

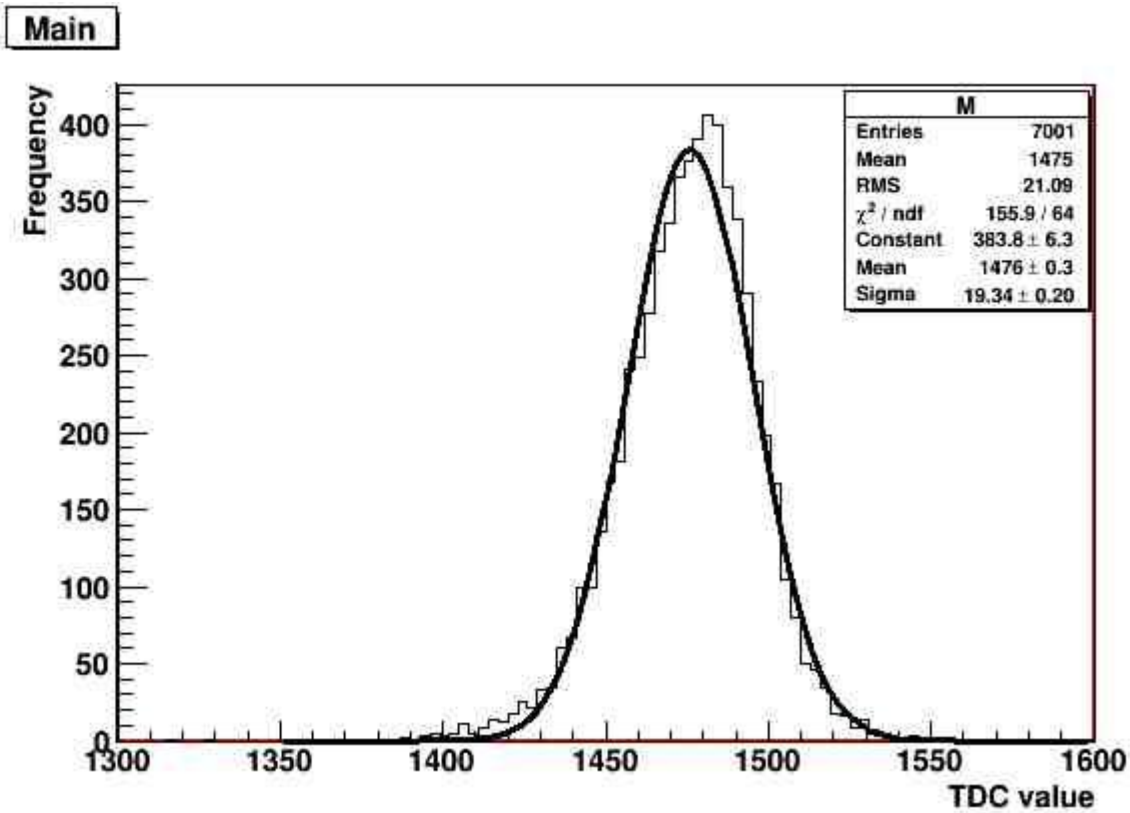
R_{spacer} = 22±3.19 GΩ

R_{gap} = 0.17±0.05 GΩ





From the plots for efficiency and noise rate, we can see that the operating voltage for the RPC is 9.7 kV and the noise rate at this value is 349±19 Hz.



The standard deviation of the above graph is σ =19.3±0.2 The time resolution of TDC is 0.1ns. Hence the time resolution of the RPC is 1.93±0.02 ns.

Conclusion:

- The resistance of the spacer and the gap for channel A and channel B are:

Channel A	Channel B
R_{spacer} = 22±3.25 GΩ	R_{spacer} = 22±3.19 GΩ
R_{gap} = 0.17±0.05 GΩ	R_{gap} = 0.17±0.05 GΩ

- The operating voltage of the RPC is 9.7kV and then noise rate at this voltage is 349±19 Hz.
- The time resolution of RPC is 1.93±0.02 ns.

References:

1. Design and Characterization of Resistive Plate Chambers, B Satyanarayana.
2. Resistive Plate Chambers for experiments at India -based Neutrino Observatory, S.Biswas
3. Development of Glass Resistive Plate Chambers, V.M.Datar, S.Jena, S.D.Kalmani, N.K.Mondal, P.Nagaraj, L.V.Reddy, M.Saraf, B.Satyanarayana, R.R.Shinde, P.Verma,
4. Radiation and detection and measurement, Glenn F. Knoll.
5. Techniques for Nuclear and Particle Physics Experiments, W.R.Leo