A pedagogical Multiwire Proportional Chamber

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Abstract. The purpose of this laboratory session is to provide the basic ingredients for understanding the construction and operation of Multiwire Proportional Chambers (MWPC). During this session the students constructed and tested a simple position sensitive MWPC. Only measurements requiring rather simple hardware (amplifiers, digital oscilloscope) were made and some of them are presented.

INTRODUCTION

Principles of Operation

The principles underlying modern multiwire chambers were already shown around 1920 (Geiger-Müller counter); the first wire chamber used in high-energy physics was, in fact, a spark chamber, whose electrode plates were replaced by grids of parallel wires in order to reduce multiple scattering, energy loss and secondary interactions, and to allow the localization of particle impact points without using photographic methods. Later, the idea of the Geiger-Müller counter was taken up again and developed into modern MWPC. In 1968 Charpak was able to operate such detector and the first large-size MWPCs were successfully used in the early 1970s by Jack Steinberger and collaborators in an experiment on CP violation.

A MWPC in its simplest form is made of a set of thin parallel anode wires stretched and sandwiched between two cathode plates (figure 1). The chamber is filled with an appropriate mixture of gases depending on the desire mode of operation. On application of a high voltage (HV) between anodes and cathodes, the electric field takes the form shown in figure 2.

If an ionizing process occurs in the gas, the produced electrons (primaries) will drift toward an anode wire. Far away from those wires (~20 times the wire-diameter) the electric field is basically constant, however, near them the electric field becomes inversely proportional to the square of distance (r) to the wire, therefore the primary electrons can gain enough kinetic energy so that inelastic collisions with the gas molecules can lead to new ionizations, with the generation of secondary electrons (figure 3).
The latter can undergo further inelastic collisions, eventually resulting in what is called “an electron avalanche” or “charge multiplication”. If the total collected charge is proportional to the number of primary electrons, then the chamber is said to operate in the “proportional mode”. The proportionality constant is called “multiplication factor” and depends exponential on the applied HV.

The electron avalanche is rapidly (~nsec) collected by the wires, the positive ions leftover (figure 3) in the trail of multiplying electrons move in opposite direction toward the cathode. In their motion, they induce image charges in all surrounding electrodes, and these results in a negative signal on the wire where the avalanche originated. So, in principle, each wire could act as an individual detector.
If it is possible to decode on which of the wires the signal originated, then the MWPC is said to be “position sensitive”. The easiest, but most expensive, way to read those electric signals is to connect each wire to a circuit which includes an amplifier, a discriminator and digitizer (ADC or QDC). However, handling a high number of electronic channels is often not affordable. In those cases, cheaper (interpolation) methods such as delay line, or charge division, are recommended (Ref 1).

**EXPERIMENTAL PROCEDURE**

**Mechanical Construction**

The multiplication factor, efficiency and other operating characteristics of a MWPC depend on both, the mechanical parameters (wires diameter and distances, electrode's gap, etc), and on the gas used. Since our aim here is that the students could build their own position sensitive MWPC, the chambers to be described here have a design and an electronic read out that is easy to assemble, and is sufficient to demonstrate position sensing capabilities. The mechanical parameters here can be considered as typical for a small size MWPC (Ref. 2,3).

Our chamber consists of a central anode wire plane placed between two cathodes. The anode was formed by a 17 Tungsten Au-plated wires (25 microns diameter and 3 cm long) with a 2.5 mm separation between them (the “pitch”). They were soldered to a 1/16"-thick fiberglass printed circuit board (PCB). The cathodes were made from a single 4x4 cm Cu strip laid down on a PCB.

The electrodes were enclosed in a 10x12x2.5 cm³ gas-thigh, high-density, polyurethane container (see fig 4). For pedagogical reason the box had a transparent
Lucite® cover to show the inner parts of the chamber. A 5x3 cm² entrance window made of 1.5 microns thick Mylar was also necessary to allow a calibration using alpha particles from a radioactive source.

In order to obtain the position information, the charge division readout method was implemented in these chambers. In this method the wires are electrically connected by resistors forming a chain. The ratio of the charge collected at one end of the chain to the total charge determines the position (fig 5).

![FIGURE 4. Schematic diagram of the mechanical assembling of the MWPC.](image)

**Assembling**

Each chamber were designed like a ready-made kit, which includes housing, anode and cathode PCBs, anode wires, spacers, plastic screws, resistors, capacitors and soldering equipment. The detector housing was fitted with the appropriate feed-troughs for the HV, signal outputs and gas connectors (fig 2). In order to simplify

![FIGURE 5. Schematic of the anode plane and resistive network implemented in the charge division readout method.](image)
the construction, the students were provided with PCB frames on which the tensed (100 g) Tungsten wires had already been soldered. In this way, the anode plane could be quickly built, by just placing the wired frame directly on top of the PCB anode, and soldering the wires using the anode tracks as guidelines (fig 5).

After soldering the anode wires, it was necessary to cut (very carefully) the wires from the PCB frame. A sharp cuter or single edge knife was found to work just fine. In order to make the resistive chain, a series of resistor (200 ohm each) is placed in the back-side of the PCB anode. Once in place, they were soldered by the students.

The next step was to assemble the anode, and the cathode, planes using the plastic screws and spacers. At this point, it was possible to try different spacers and work with different cathode-anode distances (D), just keeping in mind that for large D’s the chamber needed higher voltages to produce the same charge. The chamber was assembled using only one cathode plane to allow a see-through environment. Finally, the chamber was mounted on the plastic box, and each end of the resistive chain was connected through a 180 pF high voltage capacitor to their respective signal outputs (labeled SL and SR in fig 4). The anode wires were connected to the HV through a 10 Mega-ohm resistor to decrease parasite currents. The cathode was connected to a common electric ground. Final testing of electrical connections was made before placing the Lucite® cover of the detector box, with the corresponding O’ring acting as a gas-tight seal. After this procedure, the MWCP was ready to be filled with gas.

**INITIAL OPERATION**

*Gas Flow*

As with all gaseous detectors, the choice of gas depends on the multiplication factor, among other experimental requirements. It was found that the avalanche process occurs in noble gases at much lower voltages than in complex molecules. Thus, the gas used in a MWPC usually has noble gas as main component. As an example of how much the operational voltage and the avalanche size can vary, in figure 6 we present the pulse-height measured with a chamber (identical to the one built in the School) but filled with two different gases 80%Ar+20%CO$_2$ and 90%Ar+10%CH$_4$. During the laboratory session the gas used was Ar+CO$_2$ mixture which is non explosive.

*Turning on the voltage*

For simplicity, the chamber was operated under a steady gas flow at atmospheric pressure. An $^{241}$Am radioactive source, producing 5.48 MeV alpha-particles, was
used for testing purposes. This source was mounted on a holder with a collimator of 0.5 mm and placed directly on front of the Mylar entrance window of the chamber. The collimator was used to improve the position resolution as well as to control the counting rate. The MWPC output was connected to an ORTEC 142C charge-sensitive preamplifier, followed by a shaping amplifier ORTEC 855 operated with a shaping time of 0.5 microseconds. After flushing the chamber for several minutes with the gas, the HV power supply was switched on, and the bias slowly increased making sure to start from 0 V, and not to exceed 3.5 kV. After reaching 2.3 KV, the signals were clearly visible in the oscilloscope (1 µs/div, 50 mV/div). Figure 7 shows a typical pulse. It is possible to use either the unipolar or bipolar outputs of the amplifier.

MEASUREMENTS

Pulse height

One of the first things to measure in a gas detector is the relationship between operational HV and pulse height (PH). This measurement was carried out by placing the $^{241}$Am source near the center of the chamber and setting the HV to 100 Volts less that the minimum voltage ($\approx 2,200$ V) at which the signal is observed for
first time. In such conditions, the scope’s trigger level is set just above the electronic noise, and kept at the same level from then on. In order to measure the PH, the HV was increased, and our digital oscilloscope was set in an “averaging mode” (64 samples, or higher). Under this condition, a very clean and stable pulse can be observed and measured. The PH was registered for different HV values. Figure 8 shows a log-linear plot of the results obtained while operating one of the chambers. The straight line observed in this plot is the prediction of a simple avalanche growth theory (Ref 4). This exponential growth is also a signature that the chamber is working in the proportional mode. The deviation from linearity at highest HV value indicates the beginning of the Geiger regime, where chamber starts to discharge (sparks).
Position Sensing Capability

The use of digital oscilloscope also helped to illustrated, at least qualitatively, the position sensing capability of the MWPC. Since the charge division method is used, it is expected that the output signals $SL$ and $SR$ (fig 4 and 5) should show a correlation with the position of the source. Placing the source at the middle of the chamber both signals should have approximated the same height. Therefore, when the source is moved closer to the right (left), the $SR$ ($SL$) increases while $SL$ ($SR$) decreases, as shown in Fig. 9. This reveals charge conservation, i.e., the $SR$, $SL$ are proportional to the charge collected at either the end of the resistive chain, so the total signal for a single event has to be proportional to $(SL+SR)$. Thus, $SR/(SR+SL) = (1-SL)/(SR+SL)$, therefore whenever $SR$ ($SL$) increases, $SL$ ($SR$) has to decrease. In fact this ratio is also proportional to the position $X$ of the traversing particle (Ref 5), as measured at the left-end of the chamber, and it is given by

$$X = \frac{L}{SR/(SR+SL)}$$

where $L$ is the total active length of the chamber along $X$ (in our case, 4 cm).

**FIGURE 9.** Position determination using a digital oscilloscope. In (a) the radioactive source is near the center of the MWPC. In (b) the source is closer to the right of the chamber. The signal output order is: right (top), left (middle), ratio right/left (bottom).

**SUMMARY**

In this laboratory session the students built from scratch a MWPC. This MWPC was operated in the proportional mode, and shown to have position-sensing capabilities. Of course, time permitting, once the chamber is ready and working, it is possible to demonstrate to the students other features such as rise time, energy and position resolution etc.
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REFERENCES


