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DEALING WITH HIGH VOLTAGE BREAKDOWN IN WIRE CHAMBERS

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Abstract

Two lines of action are described concerning the problem of high voltage breakdown in wire chambers and in particular multiwire proportional chambers. The first one is preventative in nature using as means the gas mixture and strict control over mechanical tolerances and experimental conditions. The second one is dealing with tolerating sparks by minimizing damages, particularly wire breaking. Some of the means available are: reduction of the capacitance discharged, insertion of a limiting resistance in series with the discharge, elimination of multiple sparks and the use of heavier wire.

1. Introduction

Multiwire proportional chambers (MWPC's) together with drift chambers can account for most of today's fundamental particle detectors in high energy physics. Looking at the trends of continuously higher energies and intensities at the accelerators, one can see that MWPC's in particular will play a central role in many future experiments. Fixed target machines need increasingly a device that can provide at the same time good spatial and time resolutions. It is this requirement which dictates the crowding together of the small diameter signal wires forcing the operational high voltage higher and/or the diameter of the wires lower thus aggravating the breakdown problem. High voltage breakdown can damage the preamplifier electronics, or more seriously, break the fine signal wires and render a whole chamber inoperable. The replacement of a chamber in a large often compact apparatus is more than a mere inconvenience. It may result in unacceptable loss of experimental time.

For more than ten years now physicists have been battling the breakdown problem in various ways. They can be summarized in two basic approaches. First, to try and prevent sparking from occuring. Second, to tolerate sparks without suffering damaging consequences. Obviously, most of the time efforts are invested in both directions. However, sometimes specific conditions dictate the emphasis on one or the other of the two approaches. Each approach is described in detail below and reference is made whenever applicable to an experiment involved.

2. Prevention of high voltage breakdown

2.1 General techniques

In order to prevent sparking from occuring in the final experimental set up the conditions for discharge must be studied extensively ahead of time in a test set up for the chosen chamber geometry and gas mixture. This is done with the sense wires held at ground potential through a high resistance e.g. 1 MΩ via "dummy" preamplifier cards. The resistance limits the current in a given discharge and together with a low dischargable capacitance (see section 3.2 below) permits a study of the breakdown conditions through repeated sparking on the sense wires with virtually no damage. Once the breakdown high voltage has been established reproducibly, care must be taken in the final set up to always stay well below - at least 100 volts - the breakdown voltage keeping all other parameters the same, including the humidity present inside the chamber. It must be noted here that mylar traditionally used in chamber windows is permeable while aclar is not. A convenient double foil available (25 μm mylar glued on 25 μm of aclar)[1] provides both tensile strength and water-vapor thightness.

Spark propagation is known to proceed along the surfaces of dielectrics easier than in mid-air. For this reason the profile of the dielectric frame between high voltage and signal planes must provide additional path length for surface discharges. Figure 1 shows two types of profiles[2,3].

Attention must also be paid so that the high voltage rises slowly on the chamber. Most high voltage power supplies made today especially for wire chambers have this as a built-in feature[4].

Finally the usefullness of sensitivity in the electronic amplification cannot be overemphasized. Electronic sensitivity lowers the "knee" of the plateau which for a fixed plateau length implies a lowering of the maximum voltage setting. Thus an increase in sensitivity translates directly into a safety margin away from breakdown conditions. In the Geneva MWPC's[5] a sensitivity of about 10^{-12} Coulomb was necessary for the chambers to function with a 300-400 volt plateau.

2.2 Mechanical aspects

In general a deformation of 0.1 mm in the cathode to anode gap (typically at 6 mm) will result in a 20 % variation of the gain in the chamber[6]. Gain variations cut into the lower end of the overall-chamber plateau thus forcing an increase in the operational high voltage and accentuating the risk of breakdown. Mechanical tolerances must be kept to the 1 % level. The choice of aluminium for the frames facilitates the machining. What is more difficult is limiting the electrostatic deflection of the cathode planes at the center. When the cathode is made out of mylar (coated with graphite or aluminium) prestretching before gluing on the frames can be followed by heating to increase the tension further. The tension which proved sufficient at the University of Geneva[5)] was such that a maximum deflection of 0.1 mm was observed for a distributed weight of 30 g in the center of a 45 x 45 cm^2 stretched mylar window.

For the case of wire plane cathodes tightly stretched nylon support lines are traditionally used. It must be pointed out here that for wire plane cathodes there is a double advantage in keeping the wire diameter big. Using wire smaller than 100 μm in diameter can cause significant dark current in the chamber by field emission. Furthermore, one can increase the mechanical tension with the square of the radius thus limiting the electrostatic deflections.

For the signal plane an insulated steel wire with a mechanical tension up to several kg is stretched on each side of the wire plane causing some inconveniences (see section 3.1 below). It must be noted that an alloy of tungsten and 3 % rhenium instead of the usual tungsten alone can be stretched to higher tensions as it has a breaking point of 130 g instead of 90 g for a diameter of 20 μm. Once again with increased mechanical tension one can decrease the frequency of support lines and in the case of medium size chambers to completely eliminate them[5)].

The choice of gas mixture can play a crucial role in the prevention of sparks. The introduction of an electronegative gas pushes the breakdown voltage higher. At the same time, however, it hinders gas multiplication thus requiring a higher operating voltage for the same gain. The two competing processes have as a net effect the increase as well as the displacement of the plateau to higher voltages. A small amount of freon (~ 1/2 %) has been traditionally used with success in the so-called magic gas mixture argon : isobutane : freon 13B1 (CF_3Br) 75 % : 25 % : 0.5 %. The concentration of freon can be raised up to 1 % which is just about the maximum tolerable for proper operation of MWPC's[7]. Such an abundance of freon has been used in chambers operating at very high voltages of 6000[5] or 8000[8] volts. In the former case ethane was replacing isobutane in order to minimize aging effects. Ethane has a simpler molecular structure and has been proven more resilient against decomposition under radiation when compared to isobutane even at the presence of the non-polymerizing quenching agent methylal[9]. The presence of methylal itself pushes the break-down voltage higher. At some set-ups a high concentration of methylal is maintained for this reason rather than the protection against radiation damage[10]. Finally, isopropyl alcohol can be used instead of methylal[5,11] with similar, if less pronounced results, for those cases where the strong chemical activity of the latter can be a nuisance (e.g. methylal is a powerfull solvent for graphite). An abundance of ~ 1 % isopropyl alcohol will displace the breakdown voltage by 100 to 150 volt while the knee of the plateau will move only by 50 volt.

3. Tolerance of high voltage breakdown

3.1 General

The damage caused by a spark is proportional to the energy dissipated in it. Consequently, in a effort to tolerate dis-charges one must keep down to the extent possible the following: (a) the high voltage from which the breakdown originates; (b) the current in the discharge through a limiting series resistor and/or a reduced capacitance; (c) the overall number of discharges.

In the light of this approach - of tolerating sparks rather than avoiding them - the Columbia team eliminated the cumbersome support lines[3]. The usual insulated steel wire support lines shich keep the signal wires from deflecting introduce a significant inefficiency around them which can be recovered to a large extent by applying on them an intermediate high voltage, figure 2. The recovery of the efficiency this way has to be paid for by an increase in the noise of the chamber. If sparks can be tolerated, one can abandon the idea of confining the signal wires with tightly stretched wires on each side in favor of a much finer support system which will prevent only the relative displacement of the signal wires with respect to each other under repulsive electrostatic forces, figure 3(a). A nylon monofilament[12] of 10-12 μm diameter is weaved through the signal wires twice with opposite polarity thus forming a figure 8 around adjacent wires, figure 3(b). There still remains a measurable inefficiency around this monofilament of the general form shown in figure 3 but with an overall magnitude corresponding to a strip of width 0.5 mm and zero efficiency around this support. It is evident that sufficient mechanical tension in the wires is necessary to prevent excessive deflections of the plane as a whole. For wire lengths of ~ 1.5 m (2 mm wire spacing and 6 mm gap) a minimum of ~ 70 g is recommended.

3.2 Capacitance reduction of the cathode planes

Cathodes made up of wires render themselves to easy reduction of the capacitance discharged in a given spark. Figure 4 shows one way of subdividing a wire plane cathode in which breakdown at 4.3 kilovolts discharged only 10-20 pads on the average on each side of the sparking wire. This represents about 30 cm in a 3 m long chamber[3] that is ~ 10 % of the capacitance corresponding to the full plane.

Large cathode planes made out of aluminized mylar or coated graphite can have similar subdivisions by etching strips into the metal coating. The case of a thin graphite coat, however, provides the additional advantage of the built in series current limiting resistance for sparks. A few μm of graphite represent ~ 30 kΩ/square. A similar resistance would be impossible to incorporate on the other electrode - the signal plane - because the sensitive fast preamplifiers present as a rule a very low input impedance.

It is also advisable to decouple the two high voltage planes with a high resistance R so that sparks occuring on one side of the sandwich do not discharge simultaneously the other cathode plane in the same spark, figure 5. The value of this resistance R must not be exaggerated because of voltage sagging with the current drawn upon the passage of intense beams. One megaohm seems to be a good compromise.

3.3 Wire breaking

The predominant annoyance of high voltage breakdown is breaking the fine signal wire usually made out of tungsten and a diameter $\leqslant$ 20 μm. The condition for wire breaking depends on three parameters: the mechanical tension on the wire, the energy available to the discharge and the fraction dissipated in the wire. The last two depend on the operating high voltage, the capacitance discharged and the resistance in series with the signal wire. Clearly the tension, the high voltage and the capacitance discharged must be kept to a minimum while the resistance in series as big as possible. A study was made for typical wire breaking conditions in the Columbia chambers[3]. Table I shows the results of sparking a total of about 100 times on several 20 μm wire in an isobutane atmosphere. It must be added that repeated sparking on the same wire accelerates breaking through metal fatigue. It is for this reason that the results of table I have a rather qualitative character.

3.4 High voltage cut out devices

Discharges are rarely simple. Usually multiple discharges take place with a period of a few milliseconds on the average. A fast electronic tripping device can protect the chamber from all but the first spark[13]. This can prolong the life time of the wires which otherwise get unnecessarily weakened by metal fatigue. A crytron often used in these protective circuits fires within microseconds and is triggered by sensing the current drawn beyond a preset minimum value. The desired action is not one of cutting out the high voltage supply but rather cross circuiting the high voltage planes to ground so that the remaining charge is deviated away from the discharge. This should be done as close to the chambers as possible so that the cable capacitance - often comparable to the chamber one at large distances - does not get added to the capacitance of the chamber in the first discharge. High voltage power supplies often provide a voltage limiting or cut out mode; however, it is of little use first because they usually are far away from the chambers and secondly because they do not react fast enough.

3.5 Protection for the preamplifiers

The preamplifier channel at the end of a sensing wire must be protected against the large bipolar pulse produced in a discharge. Two diodes (e.g. 1N4151) are recommended back to back clamping the amplifier input to ground for both polarities. Such protection proved effective with the integrated circuits MC 1035[14] and the ALCATEL charge amplifier hybrid 1372, but inadequate with the MOS-FILAS integrated circuits. In the latter case and with a capacitance in the range of 2000 to 3000 pF, channels would either die completely or at best would have their characteristics altered.

4. Summary

The problem of high voltage breakdown in wire chambers can be approached from two different points of view. In the first one, the goal is to prevent discharges and the means available are strict mechanical tolerances and experimental conditions such that the breakdown point is reliably reproducible and can be safely approached. Another means is the gas mixture where one can add electronegative gases (freons) up to 1 % and non-polymerizing quenching agents (alcohol/methylal). In the second point of view, the effort is directed in minimizing the damage caused by discharges mostly by decreasing the energy dissipated in the discharge. Here the reduction of the capacitance and the limitation of the current drawn play an important role. Wire breaking can also be helped by the use of heavier wire and protective devices which provide a quick bypass to ground for multiple sparks.

Frequently effort is, and should be, invested in both approaches. An example is the development of increasingly more sensitive preamplifier electronics which lower the onset of the efficiency plateau and consequently the operational high voltage. This helps both in keeping away from the breakdown point and in reducing the energy dissipated in an eventual discharge. There are cases, however, where either because of particules experimental requirements as for example extremely uniform efficiency implying no support lines, or because of practical and geometrical constraints (e.g. already existing electronics or chambers etc.) one of the two above mentioned approaches may be deployed more than the other.

Table I - Occurence of wire breaking in a total of 100 sparks on several 20 μm wires

mechanical tension g	high voltage kV	capacitance pF	resistance Ω	NEVER	SOMETIMES	OFTEN	ALWAYS
60	4.5	10 000	0				x
60	4.5	3 000	0			x	
60	4.5	2 000	300		x		
60	4.5	1 000	300		x		
60	4.0	1 000	39 000	x			

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1) Laminated polyester KEL-EF consisting of 25 μm polyterephtalate of ethylene (mylar) and 25 μm polychlorotrifluoroethylene (PCTFE) - aclar 3C-KEL-F.

2) P. Schilly, P. Steffen, J. Steinberger, T. Trippe, F. Vannucci and H. Wahl
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3) A Columbia - New York University collaboration experiment described partially in W.S. Carithers, J.H. Christenson, T. Modis, D.R. Nygren, T.P. Pun, E.L. Schwartz, J. Steinberger and P. Weilhammer
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4) For example, NOVELEC 8174, DANPHYSIK 140, LeCroy model HV 4032A, etc.

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6) F. Sauli
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7) M. Breidenbach, F. Sauli and R. Tirler
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10) D.P. Stickland, Ph.D. Thesis HEP/T/77 University of Bristol; also R.J. Gray, Nucl. Instr. and Meth. 176 (1980) 133

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12) The nylon monofilament was found in nylon stockings industry, complements of Du Pont de Nemours International SA.

13) M. Bozzo, A. Buzzo, S. Ferroni, V. Gracco, A. Santroni, R. Kiesler, K. Kirsebom, M. Macri, B. Mouellic, Nucl. Instr. and Meth. 178 (1980) 77;

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14) H. Cunitz, W. Sippach and J.H. Dieperink Nucl. Instr. and Meth. 91 (1971) 211.

FIGURE CAPTIONS

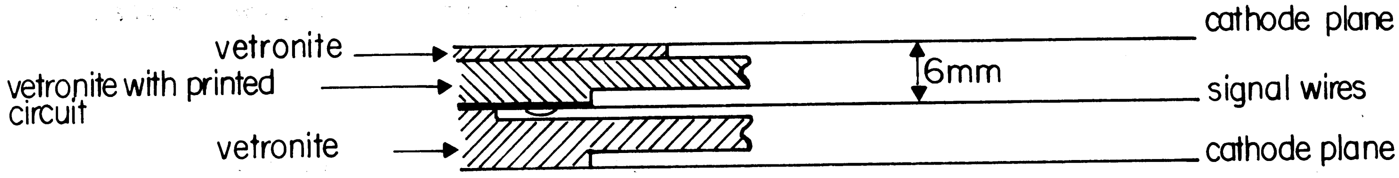
Figure 1 Cross sections showing the frame profile between high voltage and signal planes for the Columbia[3)](a) and the Geneva[5)] (b) MWPC's.

Figure 2 Full dots, the detection efficiency as a function of the distance of the particle track from the support line. Open circles indicate the recovered efficiency by applying 1440 volts on the support line increasing the chamber noise at the same time from 10 to 290 kHz.

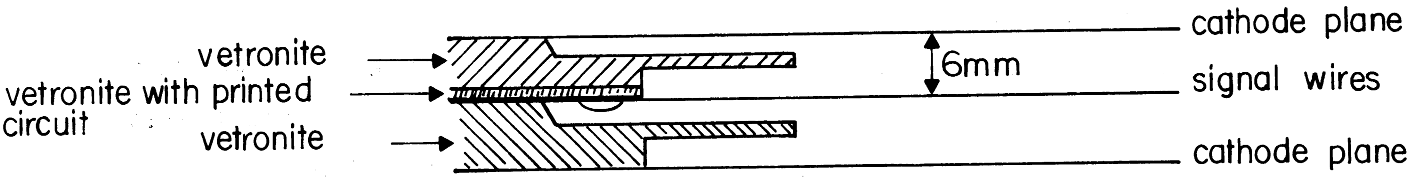
Figure 3 (a) Displacement of signal wires under electrostatic forces. (b) A nylon monofilament woven in figure 8 around signal wires to avoid electrostatic deflections.

Figure 4 Detail of high voltage connection to wire plane cathode[3)]. The zig-zag pattern of the soldering pads is enabling soldering of wires which are 1 mm apart to pads which are more than 1 mm apart so as not to aggravate the spark propagation along the high voltage plane.

Figure 5 Configuration showing the high voltage distribution to the cathode planes. A discharge from one plane to the signal wires is isolated from the other plane through the resistors R. The value of the decoupling resistance R must not exceed ~ 1 MΩ for high intensity beams. The 1GΩ resistance helps discharge the chamber in a reasonable time upon cutting off of the high voltage.


vetronite
vetronite with printed circuit
vetronite
cathode plane
6mm
signal wires
cathode plane

(a)


vetronite
vetronite with printed circuit
vetronite
cathode plane
6mm
signal wires
cathode plane

(b)

Figure 1

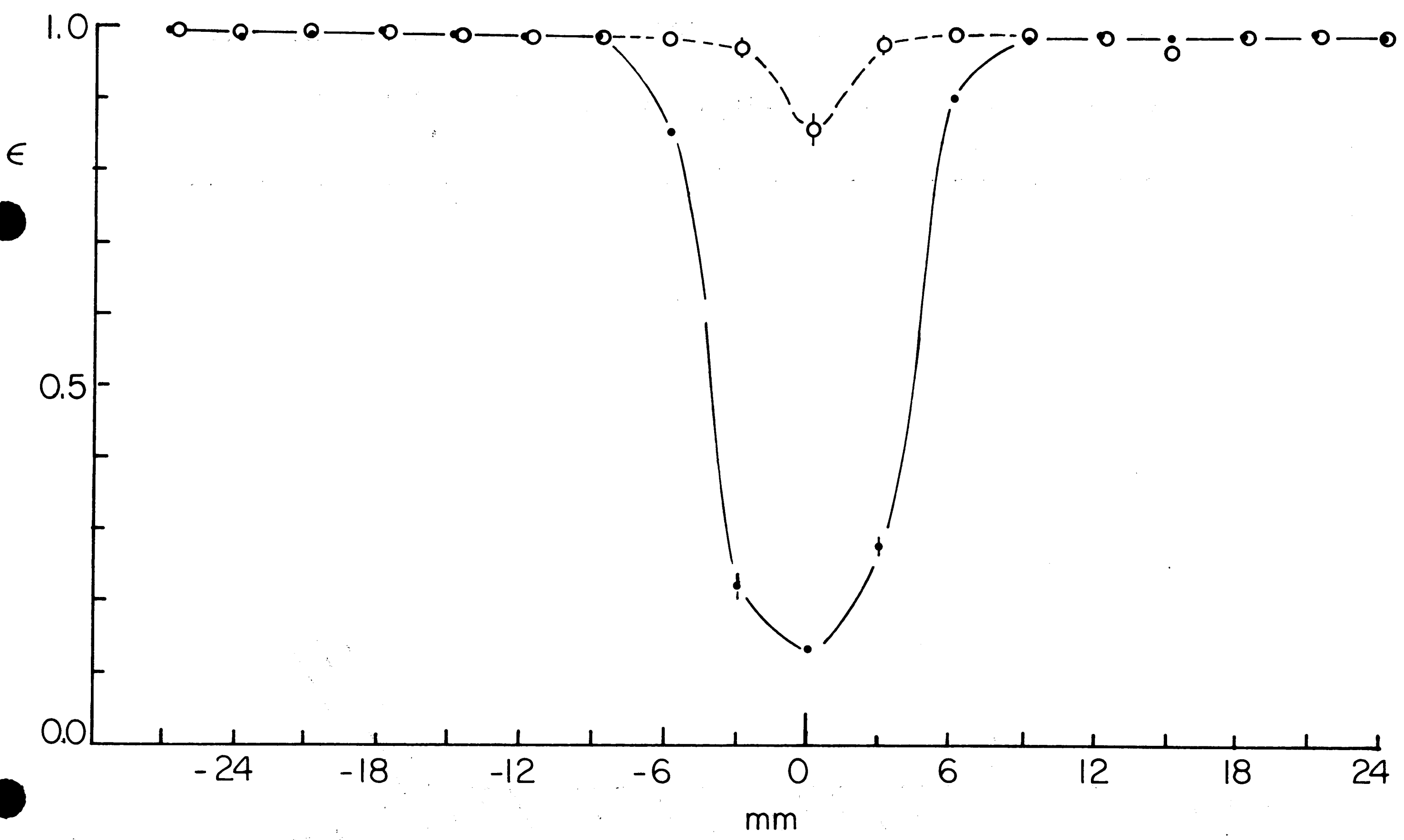
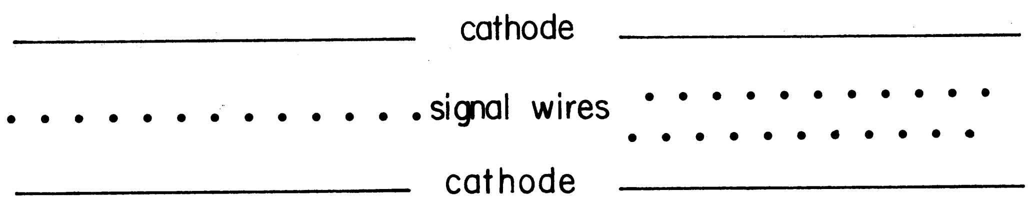
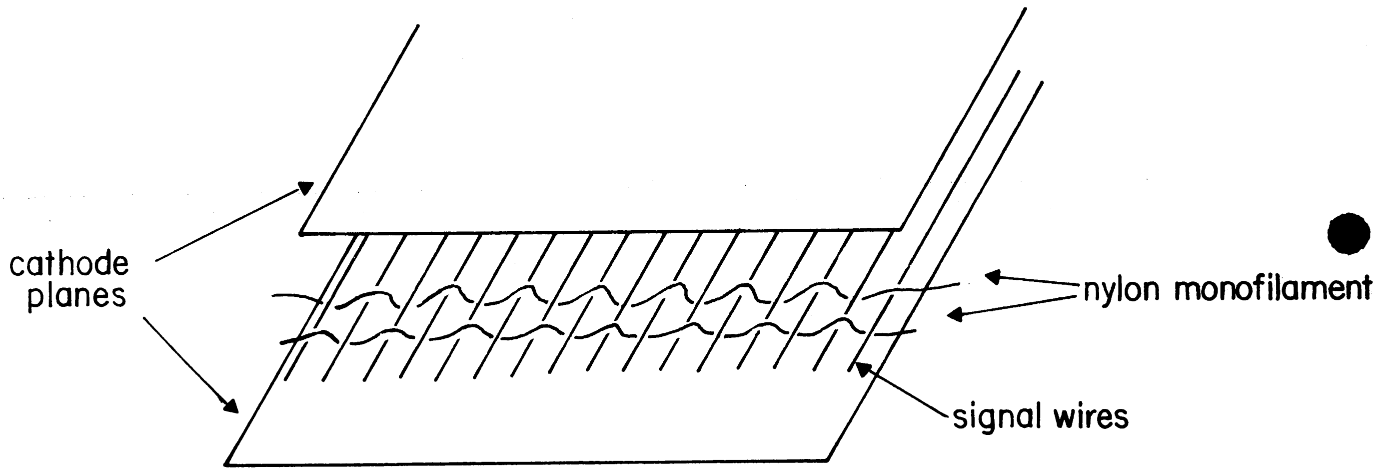


Figure 2

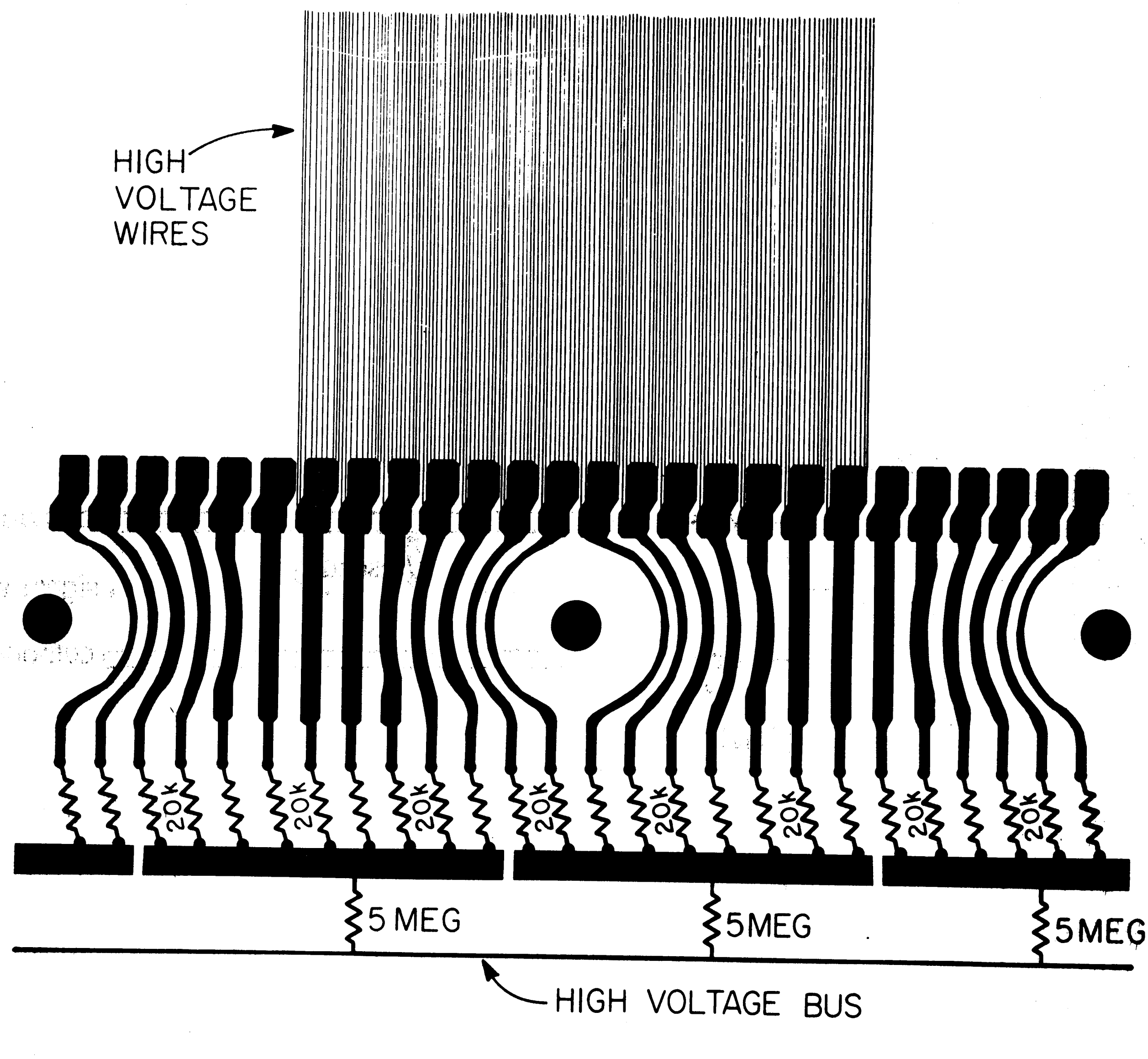

cathode
signal wires
cathode

(a)


cathode planes
nylon monofilament
signal wires

(b)

Figure 3



A SECTION OF A HIGH VOLTAGE FRAME

Figure 4

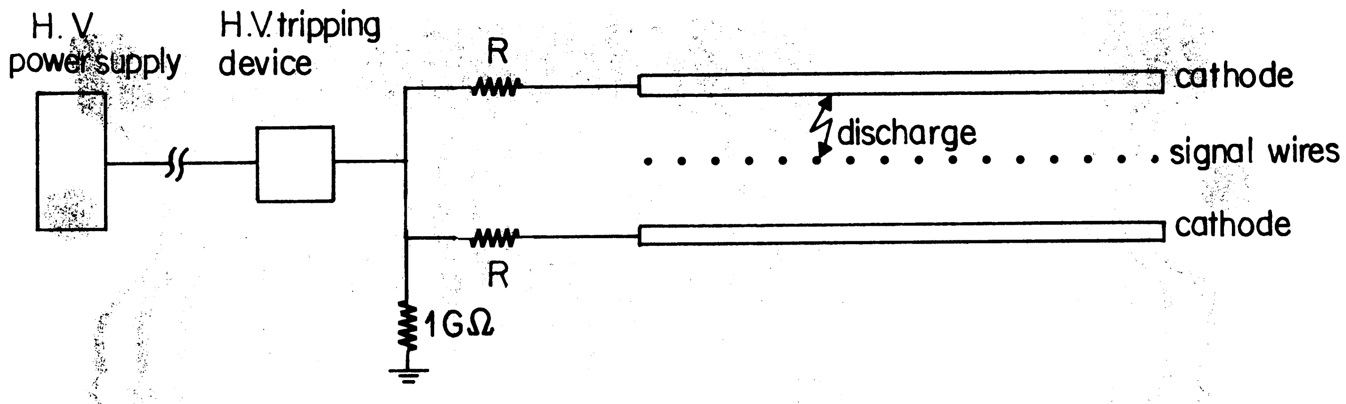

H. V.
power supply
H.V. tripping
device
R
R
1GΩ
cathode
discharge
signal wires
cathode

Figure 5