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RESISTIVE CATHODE TRANSPARENCY

G. Battistoni, P. Campana, V. Chiarella, U. Denni, E. Iarocci and G. Nicoletti
INFN - Laboratori Nazionali di Frascati, Frascati, Italy.

ABSTRACT

The basic features of induced pulse detection by strip electrodes outside wire devices with high resistivity cathode will be discussed, making use of the results of tests and calculations. The dependence on the essential parameters fixing cathode transparency is shown.

1. - INTRODUCTION

Transparency to transients of high resistivity cathodes(1) and the use of outside pick-up electrodes, separated from the wire device, widely extends the application possibilities of standard cathode readout. Here the same electrode performs the double function of cathode and pick-up, which in fact restricts the set of possible configurations. For instance, devices with a cathode segmentation parallel to the wires, like drift chambers with field shaping electrodes or multitube devices, are incompatible with a cathode segmentation into orthogonal strips. The splitting of the two functions makes possible a wide range of design of cathode and pick-up electrode geometries. In particular an orthogonal strip readout may be introduced in graded cathode drift chambers or multitube modules, when the cathode is resistive(2).

The resistive cathode method has been applied on a large scale in the Mont Blanc proton decay detector(3): a digital calorimeter containing about 50000 limited streamer tubes, 1 cm^2 in cross section and 3.5 m long. The basic module is a 16-tube plastic (PVC) structure, with 100 μm anode wires and a graphite coating as cathode. Twenty such units are placed one near the other to make a 3.5 x 3.5 m^2 detector plane. Both coordinates of the plane are read out by two sets of pick-up strip planes on the outside of the wire modules, one set parallel to the wires, the other orthogonal.

We want to point out a number of attractive features of this kind of device, due to the specific use of resistive cathode. The most relevant, of course, is the use of orthogonal strips to achieve a bidimensional readout on a multitube detector. The parallel strip readout simply replaces the wire readout, but with a number of simplifying features: no interference between the gas and H.V. systems and the readout (no high voltage capacitors are used). A high degree of modularity of the detector has been achieved, due to their being three independent elements: one active (the 16-tube unit), and two passive (the parallel and orthogonal 16-strip units). This kind of modularity allows the construction of very large area detectors with two dimensional readout by juxtaposition of many tube and strip modular units. The large streamer signals ($\gtrsim$ 1 mA on the wire) and the thick anode wires which must be used, reduce the typical problems of large area detectors. In practice the limit for both tube and strip modules is given by the maximum module length which can be reasonably handled and transported. Due to the physical flexibility of the multistrip elements, such detector configurations may be adapted to cylindrical geometries, with tubes parallel to the axis and strips at an angle, following the cylindrical surface. The use of resistive cathodes involves the use of plastic materials, such as PVC, which gives the possibility of taking advantage of the specific technologies of thermoplastic materials, such as extrusion, thermosetting, injection moulding, welding by heating, and so on. The extensive use of these technologies, together with the modularity of the tube and strip components, make possible in practice a high degree of automatization of construction.

In a preceding paper(1), a detailed study was presented concerning the transparency of resistive cathode pulses with helical delay line readout, while only the essential features of strip and pad readout were described. Here we will discuss in some detail the strip readout, making use of the results of both calculations performed on simulation circuits and systematic experimental tests.

2. - EQUIVALENT CIRCUIT FOR STRIP READOUT

The basic geometry of a resistive cathode device with strip readout is shown in Fig. 1a. The figure actually

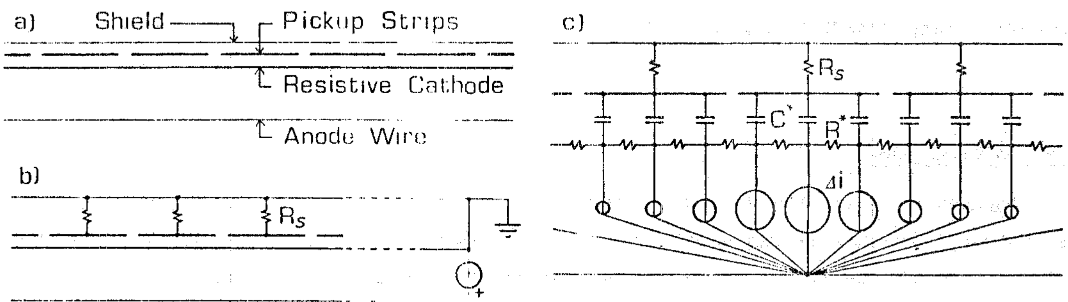


FIG. 1 - a) The schematic cross section of a wire device with resistive cathode and external pick-up strips (only the upper half is shown); b) the electrical connections; c) a lumped parameter equivalent circuit with current generators to simulate the induction from an amplification process near the anode wire.

represents one half the cross section of the device, supposed to be essentially symmetric with respect to the anode wire plane. In this simple scheme, the resistive cathode can represent either the cathode plane of a multiwire chamber, or tube elements parallel to the wires, the side walls being not shown. A set of strips orthogonal to the wire is shown behind the cathode, followed by a ground plane. As already mentioned, in practice it is convenient to make two independent physical units: the wire + cathode unit which is the active part of the device, that is where the detection process (proportional, limited streamer, and so on) is generated, and the strip-shield unit which is the pick-up element of the device. The electrical connections are shown in Fig. 1b. The strips are grounded via the input resistance Rs of the readout circuit. The cathode also is grounded and the wires are connected to the anode voltage (but one can also have grounded wires and the resistive electrode connected to a cathode voltage).

The equivalent circuit with the relevant parameters to simulate pulse generation on wires and strips is shown in a lumped parameter approximation in Fig. 1c. It is drawn as a linear and uniform array of circuit elements according to the projective geometry of the strips. The cathode is simulated by resistance elements R^* coupled to the strips by capacitance elements C^*. Charge induction is simulated by a current generator array irradiating from a point on the wire and connected to the cathode elements. Since charge induction has circular symmetry on the cathode surface, the circuit element array should be bidimensional and the linear and uniform circuit adopted is only a simplifying approximation, which however does not affect the qualitative features of the process we want to point out. The amplitude distribution of the current generators simulating an amplification process in the wire region, can be assumed to equal the projected charge distribution induced by a static charge on two parallel conducting planes, enclosing it symmetrically. Such distribution is plotted in Fig. 2 as a function of position measured in units of the gap between the two planes.

The essential features of pulse transmission through the cathode can be worked out by examining the response of the equivalent circuit for a very short current pulse. That has been calculated with the SPICE program[4], and is shown in Fig. 3a and b for the central and side strip respectively. During the short pulse time,

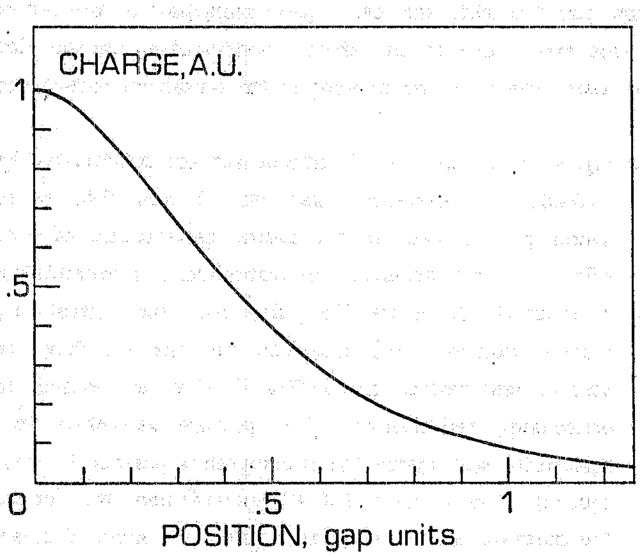


FIG. 2 - The projected charge distribution on one of the two planes induced by a static charge in the middle of the gap (g).

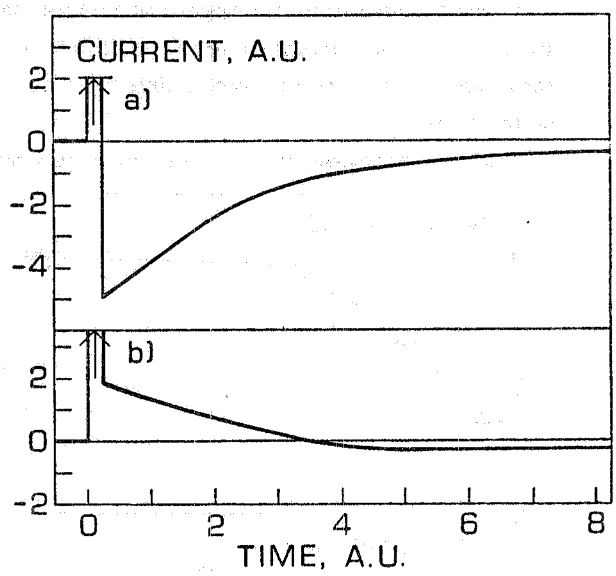


FIG. 3 - Calculated response on the central (a) and side (b) strips for a fast current pulse.

the current charges up the cathode-strip capacitances C^* flowing directly through the strip load Rs. On the central strip (Fig. 3a) the initial positive pulse is followed by an exponential-like negative tail. This corresponds to the discharge of the capacitance elements C^* through the resistances R^*. It is the characteristic behaviour of a capacitive coupling, and also the net area under the pulse waveform is zero. In other words the negative current tail corresponds to the accumulation of the induced charge on the resistive cathode, that is to its shielding action. On the side strip (Fig. 3b), the pulse shape is qualitatively different: the tail following the initial positive pulse starts positive before going eventually negative. In fact any lateral C^* element will at first receive an extra charge from the more central ones through the resistance elements R^*. Undistorted pulse transmission through the cathode occurs if the discharge time of the R^*C^* network (the cathode shielding time) is much longer than pulse duration. It is clear that the cathode shielding time depends symmetrically on R^* and C^*, being a function of their product. But in practice the only effective parameter is the cathode resistivity, since the range of variation of the cathode-strip capacitance is negligible.

3. - TRANPARENCY TESTS

We have performed systematic tests on cathode transparency with a small wire chamber (10x10 cm^2) with the schematic cross section of Fig. 1a which was operated in the limited streamer mode. The anode wires were 100 μm in diameter, with 2 cm spacing and separated by field wires. The two resistive cathode planes, 1 cm apart, were made of a graphite coating on 1 mm thick PVC plates. These could be easily replaced to test different resistivities. A multi-strip electrode was placed on one side of the chamber with the strips orthogonal to the wires. Two outer shield planes enclosed the device. Tests were made with X rays from a ^{55}Fe source collimated into a small region along to the wire and in correspondence of the center of one of the pick-up strips. Both strips and wires were terminated by 50 Ω resistors.

Transparency tests were made varying cathode resistivity, strip width and strip distance from the cathode. As a measure of cathode transparency(1) we have assumed the ratio between the central and side strip peak amplitudes, normalized to the plateau limit for very high resistivity. This choice comes from experience. In fact when the shielding time is comparable to pulse duration, together with the loss in peak amplitude on the central strip, there is an increase in peak amplitude on the side strips, due to the effect mentioned in the previous paragraph. In practice the most visible effect of a low resistivity is the broadening of the amplitude distribution on the strips.

Cathode transparency for 1 cm strips is shown in Fig. 4a as a function of cathode surface resistivity. The cathode-strip dielectric gap was 2 mm PVC corresponding to a specific distributed capacitance of ~ 1.5 pF/cm^2. In this situation the transparency plateau begins at about 10^5 Ω/square. The pulses from the central strip, from an adjacent strip, and from the wire are shown for various test resistivities in Fig. 5. They are ordered for decreasing resistivities. The picture 5a refers to a resistivity well inside the transparency plateau (7 MΩ/square); 5b to a point (180 kΩ/square) near the knee of the plateau. At these two test points the induced pulses, on both central and side strips, have substantially the same shape as the wire pulse, but with a slight differentiation on the central strip in 5b. Going to a lower resistivity (30 kΩ/square) in (c)) the derivation effect on the central strip is larger, with a visible decrease in the peak amplitude. However the most noticeable effect is on the side strip, where the pulse amplitude is visibly larger due to the broadening of the voltage distribution on the graphite. At the small resistivity value (10 kΩ/square) of the last picture (5d), the shielding time of the graphite starts to be so short as to show a visible differentiation effect also on the side strip.

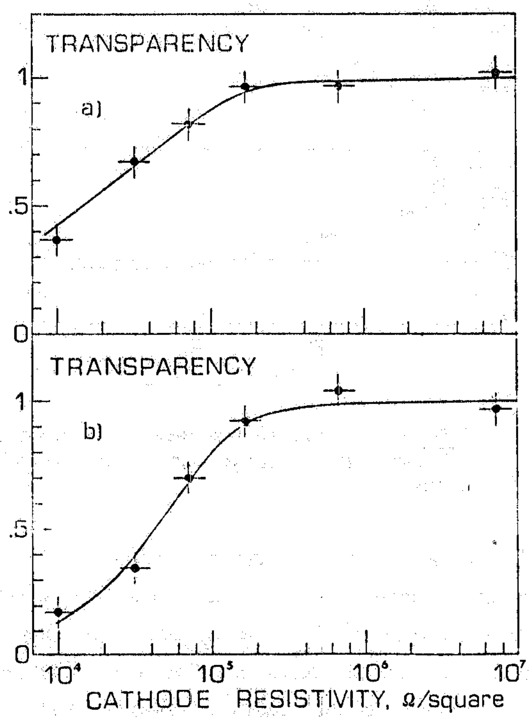
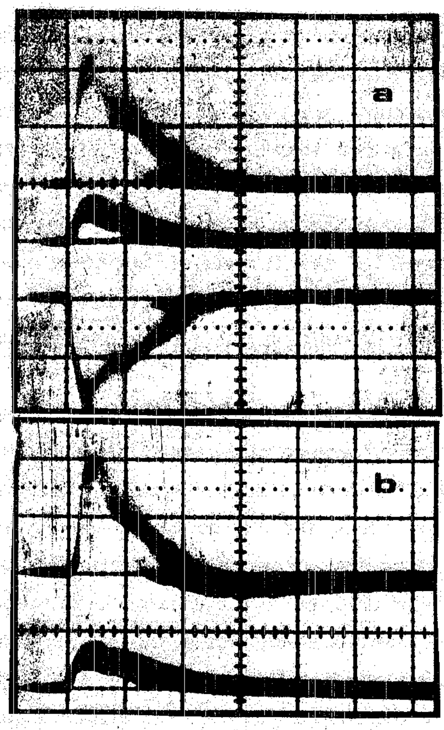


FIG. 4 - Cathode transparency as a function of surface resistivity, for 1 cm strips (a) and 2 cm strips (b). The continuous curves are the results of a calculation.



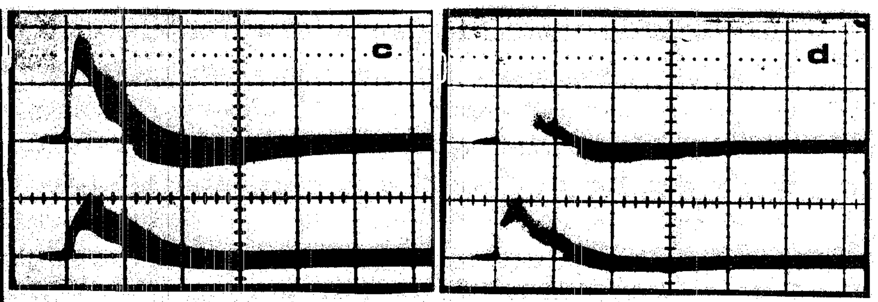


FIG. 5 - a) Pulses on the central strip, side strip and wire, from top to bottom respectively, for a cathode resistivity R=7 MΩ/square. Strips and wire are terminated by 50Ω ; the scales are 10 and 50 mV/cm vertical (strips and wire respectively), 20 ns/cm horizontal. Pulses on central and side strips, for R=200 kΩ/square (b), 30 kΩ/square (c), 10 kΩ/square (d).

The response of the test chamber has been calculated by using the SPICE program. A lumped parameter approximation of 5 R^*C^* elements per strip was used and the current generators were given an amplitude distribution following the charge distribution curve in Fig. 2. The pulse shape was set triangular, with 5 ns rise time and 50 ns duration, to simulate the limited streamer pulse of the test chamber. The continuous curve following the data of Fig. 4a, was obtained simulating 1 cm of cathode in the projected view of the equivalent circuit, with R^* values numerically equal to the surface resistivity of the cathode and a cathode-strip capacitance equivalent to that for an area of 2 cm^2. The program, for given values of the parameters, generated the pulse shape on the strip load (50 Ω), simulating the test described before. The pulse shape on the central and side strip corresponding to a resistivity value of 2×10^6 Ω/square, i.e. in the transparency plateau, are shown in Fig. 6a and b respectively. The corresponding pulses for resistivity values of 5×10^4 Ω/square are shown in Fig. 6c and d: they exhibit the effects already described for the test chamber, being directly comparable to the pulses in Fig. 5c, which referred to a resistivity of 3×10^4 Ω/square. There is a noticeable quantitative agreement between the simulated and experimental data.

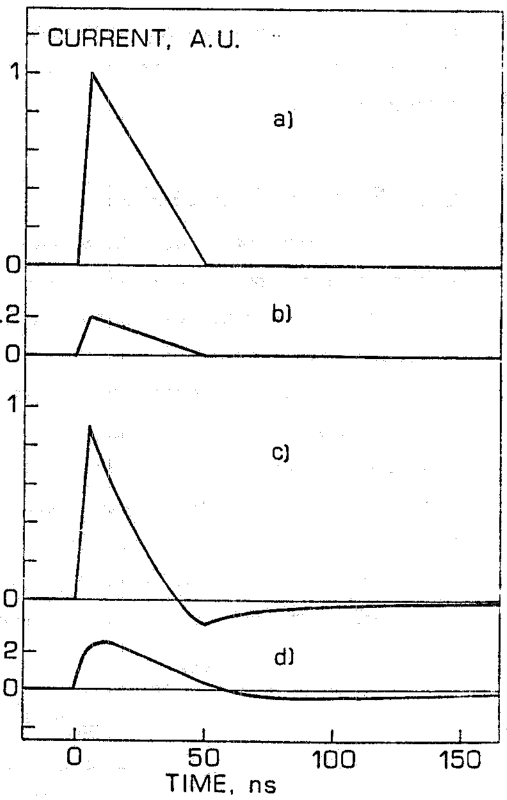


FIG. 6 - Pulse shapes on the strip as simulated with the SPICE program, for full transparency (a,b), and for a transparency equal to 0.75 (c,d).

We have increased by a factor of two the cathode-strip capacitance in the test chamber, by replacing the 2 mm PVC dielectric gap with 1 mm PVC. As expected we have found the same transparency characteristics but shifted to resistivity values lower by a factor of 2. Again with a 2 mm PVC cathode to strip gap, but with 2 cm strips, we obtained the dependence on resistivity shown in Fig. 4b. The transparency region starts again around 10^5 Ω/square. The continuous curve was calculated as before. The simulation circuit contained again 5 R^*C^* elements for strip. To match the new situation where the strips are twice as large, both the R^* and C^* values where changed by a factor of two. The current generator distribution was arranged to follow again the curve in Fig. 2. It may appear surprising that the transparency limit does not vary when there is a change by a factor of four in the time constant of the R^*C^* circuit element. But this comes from the fact that now the side strip works on the tail of the current distribution, the plateau ratio between central and side strip amplitude being around 20; so it is very sensitive to a broadening of the voltage distribution on the resistive cathode.

All the preceding discussion applies as well to resistive cathodes made of independent tube elements, with a similar transparency dependence on resistivity. There is only one noticeable difference to be taken into account. For strips behind a plane cathode there is no relevant effect if the angle between strips and wires is changed. This is not true for tubes: when, in the limit, the strips are parallel to the tubes, there is no direct connection between the cathode regions facing different wires, and the broadening of the strip amplitude distribution due to partial cathode shielding is absent. So, for parallel strips the resistivity limit is lower. In practice we have found advantageous[2] to construct tube devices by joining together two independent profiles: an open multicell profile and a top cover, both coated with graphite. The open structure simplifies both cathode varnishing and wire assembly. Also this geometry of the cathode is not symmetric respect to the strip angle. We have placed strips parallel to the tube elements on the back of the multicell profile, for which a resistivity of about 30 kΩ/square is sufficient for full transparency, while a minimum of about 200 kΩ/square is needed on the top cover for orthogonal strips.

4. - LONG PICK-UP ELEMENTS

In the preceding paragraphs we have described the condition for induced pulses to be detected undistorted on a strip electrode out of a resistive cathode. The effect involved are all local, concerning a small region around the detection process, and independent of cathode and pick-up electrode extension. We have seen that for resistivity values below the minimum for full transparency, the most evident effect due to cathode shielding is a broadening in the peak amplitude distribution over the strip.

A similar effect[1] but of different origin, arises when very long strips are considered. Study of the equivalent circuit in Fig. 1c is enough to show this: any two adjacent strips are coupled via the series C^*-R^*-C^*. Now as far as induced pulse detection is concerned, those elements refer to a small portion of the cathode, and therefore the impedance is high. But when a pulse is detected on a strip and propagates along it, the coupling is active throughout the total strip length, and clearly the cross-talk impedance becomes smaller.

In Fig. 7 the equivalent circuit is presented in the simplest lumped parameter approximation, that is with a

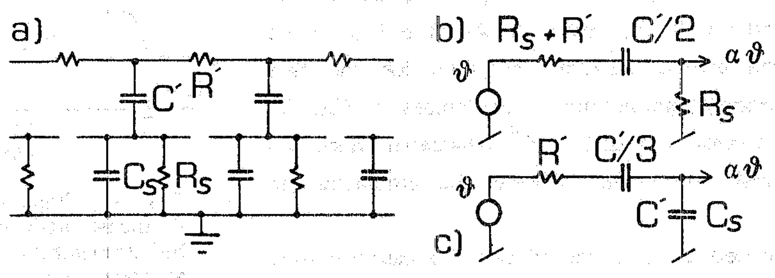


FIG. 7 - Equivalent circuit to evaluate cross-talk due to resistive cathode (a), together with the limit cross-talk networks (b,c).

single element per strip. Neglecting also in first approximation the influence of the other strips, the fraction of voltage signal A transferred from one strip to its neighbour can be written as

$$A = \frac{Z_S}{2Z_S + Z_{CT}} \tag{1}$$

where Z_s is the strip impedance to ground, and Z_{CT} the cross-talk impedance. To simplify the numerical expression in the following we will consider 1 cm wide strips, which is in any case rather typical. Z_s may be written as the parallel impedance of the input resistance Rs of the readout circuit and the total strip capacitance to ground, which is the strip length 1 in cm times the distributed strips to ground capacitance Cs per cm^2:

$$Z_s = \frac{R_s/j\omega C_s l}{R_s + \frac{2}{j\omega C_s l}} \tag{2}$$

Z_{CT} in the adopted lumped parameter approximation is the series impedance of the cathode cross-talk resistance R' (the cathode resistivity in Ω/square divided by the strip lenght in cm), and of twice the cross-talk capacitance C' (the distributed strip to cathode capacitance per cm^2 times the lenght 1 in cm)

$$Z_{CT} = \frac{1}{l} \left(R' + \frac{1}{j\omega C'}\right) \tag{3}$$

Let us consider two limit situations

$$R_s \ll \left|\frac{1}{j\omega C_s l}\right| \tag{4}$$

$$R_s \gg \left|\frac{1}{j\omega C_s l}\right| \tag{5}$$

The hypothesis (4) means either short strips or small strip load. In this case the expression (1) becomes:

$$A = \frac{R_s}{2R_s + Z_{CT}} \tag{6}$$

which corresponds to the simple network of Fig. 7b. The hypothesis (5) corresponds to long strips, and assuming Cs=C which is rather natural in practice, the expression (1) takes the simple form:

$$A = \frac{0.25}{1 + \frac{j\omega R'C'}{4}} \tag{8}$$

(see Fig. 7c) which is independent of length, and composed of an attenuation times an integration term.

In practice, by selecting cathode resistivity, its distributed capacitance and the strip load somewhere in the ranges $10^5 \div 10^6$ Ω/square, $1 \div 10$ pF/cm^2, $\leq 10^3$ Ω respectively it is always possible to make small the cross-talk. For the quoted[2,3] streamer tube system (R$\gtrsim 10^5$ Ω/square), 1 cm strips, 1 mm apart, have been tested up to 10 m length showing a cross-talk of no more than a few percent.

A different effect which could become important for very long cathode elements is the limitation in the maximum operation rate it can introduce, due to the voltage drop caused by the discharge process current. Let us consider the limited streamer mode, which is the worst case due to the large currents involved, which are about 0.5×10^{-9} A/particle/s[1]. For the typical situation of 1 m long wires, with 1 cm spacing, and cathode resistivity of 2×10^5 Ω/square, the total minimum resistance R_{tot} associated to a wire is 10^7 Ω if a chamber structure is considered. If the cathode is grounded in correspondence of both wire ends it is easy to verify that for uniform particle rate distribution along the wires, the maximum voltage drop on the cathode is

$$\Delta V_{max} = \frac{R_{tot} \times I_{tot}}{8} \qquad (9)$$

where I_{tot} is the total current associated to a wire. Now the maximum streamer rate for a 1 m wire is $\sim 10^4$/s, to which corresponds an inefficiency of ~ 1%. Substituting in (9) the corresponding d.c. current, a maximum voltage drop of ~ 5 V is obtained which is negligible.

ACKNOWLEDGEMENTS

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