Development of an electrical model of a resistive micromegas

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May 10, 2014

1 Model description

We have developed a model to simulate the behavior of micromegas (MICROMesh GAseous Structure) [1] geometry to a discharge using an electronic software (Virtuoso [2]).

The principle of operation of a micromegas detector is presented in figure 1.

![Figure 1: Principle of operation of a micromegas detector](image)

When a charged particle crosses the sensitive volume, it creates primary electrons in the conversion gap whose drift toward the mesh under the influence of a low electric field (few kV/cm). Due to high field ratio between the conversion gap and the amplification gap, most of them enter the amplification gap and are multiplicated under a high electric field, $E \sim 30 \text{ kV/cm}$, due to the avalanche.
mechanism. The motion of the charges in the amplification gap induces a signal on the anode plane made of strips of 120 mm length.

In our simulations, we have described the detector by its electrical parameters as presented in figure 2. The simulation has been done for different values of resistivity ($10\,k\Omega/\square$, $100\,k\Omega/\square$, $1\,M\Omega/\square$ and $10\,M\Omega/\square$) and for 3 different widths of strips (100, 200 and 300$\mu m$). For practical reasons, we have segmented the strips according to its width in order to keep a square elementary cell ($100 \times 100\mu m^2$, $200 \times 200\mu m^2$ and $300 \times 300\mu m^2$) to match the unit of resistivity.

The mesh and the strip are described by a pattern of inductances ($L_{\text{mesh}}$ and $L_{\text{strip}}$) and resistors, and the resistive layer and the ground plane are described by a serie of resistance. We have introduced three capacitances to modelise the capacitance of the gas gap ($C_{\text{gas}}$), the capacitance of the insulating layer ($C_{\text{dielectric}}$) between the resistive strip and the read out one and the capacitance of the insulating layer between the read out strip and the ground plane ($C_{\text{gnd}}$). The values of those parameters are presented in table 1.

| Strip width | $C_{\text{gas}}$ (fF) | $C_{\text{dielectric}}$ (fF) | $C_{\text{gnd}}$ (fF) | $L_{\text{mesh}}$ (pH) | $L_{\text{strip}}$ (pH) |
|-------------|----------------------|-----------------------------|----------------------|------------------------|------------------------|
| 100$\mu m$  | 0.7                  | 8.32                        | 0.26                 | 60                     | 48.5                   |
| 200$\mu m$  | 2.8                  | 33                          | 1                    | 120                    | 83                     |
| 300$\mu m$  | 6.3                  | 75                          | 2.3                  | 180                    | 112.5                  |

Figure 2: Elementary cell for a 100$\mu m$ width strip

Table 1: Computed parameters used in the model for the three widths of strip
In case of the mesh, the resistive layer and the strip, we add an output point in order to extract the useful parameters (voltage and current).

The elementary cells are connected to their neighbors through two directions (right and left) to modelise a complete strip of 120 mm length. It is important to notice that in our model, we have segmented the strip with a pitch of $900\,\mu m$ for a strip of $100\,\mu m$ and $300\,\mu m$ (121 elements which represents a total length of 108.9 mm) and with a pitch of 1 mm with a strip width of $200\,\mu m$ (121 elements which represents a total length of 121 mm). We have decided to have an odd number of elementary cells in our pitch (9 for $100\,\mu m$, 5 for $200\,\mu m$ and 3 for $300\,\mu m$) and also in our total number of pitch (121) in order to have a discharge located in the center of the strip, to avoid any asymmetry that could play a role in the results. An example for a cell of $100\,\mu m$ is shown in figure 3.

![Figure 3: Full strip made of 121 elements of 9 elementary cells of $100\,\mu m$](image)

We have done the simulation for a single strip geometry as it shown on figure 4.

The discharge is produced by a switch that connect the mesh and the resistive layer with the following parameters (opening time = closing time = 100 ps and the pulse duration = 1 ns). One can notice on the diagram that the resistive strip
is connected to ground with a $10M\Omega$ resistor and the read out strip is connected to a $50\Omega$ resistor to modelise the input of the charge preamplifier. The voltage applied on the mesh is -400 V to simulate the difference of potential applied between the mesh and the resistive strip in the real case.

2 Results

As it has been previously mentioned, we have simulated 3 different sizes of strip widths. We will present the results obtained for each configurations using the model presented before.

2.1 Strip width of 100\(\mu\)m

We present the results obtained with a width of strip of 100\(\mu\)m. We have 9 elementary cells per element (to get a longitudinal size of the element close to 1 mm) and 121 elements to modelise the complete length of the strip. The elements are numbered from 1 to 121 and the discharge is located on the middle of the strip (element \#60).

We have performed the simulations with 4 different values of resistivity ($10k\Omega/\square, 100k\Omega/\square, 1M\Omega/\square$ and $10M\Omega/\square$) to observe the effect of the resistivity.

2.1.1 Signal on the readout strip

The figure shows the maximum voltage drop reached for the 121 elements of the readout strip.

We can notice that the element containing the discharge has the higher voltage drop (-120 V) for the 4 different values of resistivity. We observed a decrease of this drop for the elements placed away of the central one. At the
Figure 5: Maximum voltage drop reached for each of the 121 elements of the readout strip for the four values of resistivity

end of the strip, the curve shows alternatively positive and negative values. One possible explanation of those oscillations at the beginning and the end of the strip could be due to the inductances introduced in our model. This plot shows that the value of the resistivity does not seem to have an important effect on the value of the maximum voltage drop reached by the elements of the strips, we observe a similar shape and a similar order of magnitude of the values of the drop for the different values of resistivity.

2.1.2 Signal on the resistive strip

The figure 6 shows the typical signal observed on different elements of the resistive strips. We see the voltage drops for the discharge element (#60) and its ten following neighbors (#62 to #72) versus time as provided by the simulator at its output.

The plot with the lowest value of resistivity ($10k\Omega/\square$) shows a higher spread of the discharge signal on the neighbors elements (#62 to #72) with a higher voltage drop of these elements (few tens of volts) but with a time propagation of $\sim 1\mu s$. This is not the case with the higher value of resistivity ($10M\Omega/\square$) where we observe a spread of the discharge signal of only few volts on the neighbouring elements but with a longer time propagation (few hundreds of $\mu s$).

The figure 7 presents the maximum voltage drop observed on the resistive layer.

On this figure, we can observe the effect of the resistivity on the signal spread on the resistive layer, the higher the resistivity, the smaller is the spread. For the
Figure 6: The top plots represent the discharge element (left) and its 10 neighbors (right) for a $10k\Omega/\Box$ resistivity and the bottom plots represent the discharge element (left) and its 10 neighbors (right) for a $10M\Omega/\Box$ resistivity.

Figure 7: Maximum voltage drop reached for each of the 121 elements of the resistive layer (on the left, the full resistive strip and on the right a zoom on the central area around the discharge).

Higher value of the resistivity ($10M\Omega/\Box$), we see that 3 elements have a voltage drop, the element that contains the discharge (voltage drop = -400 V) and its 2 closest neighbors (voltage drop ~ 10 V). For the lowest value of resistivity ($10k\Omega/\Box$), we observe an area of 23 elements that have a non negligible voltage drop, the central element that contains the discharge (voltage drop = -370 V) and the 11 closest neighbors (voltage drop from -80 V for the 2 closest ones and -5 V for the 2 farest ones).

2.2 Strip width of $200\mu m$

In this section, we present the results obtained with a width of strip of $200\mu m$. As previously mentioned before, an element is composed by 5 elementary cells.
to get a 1mm element length for a total length of 121 mm. The location of the discharging element is the same as before (element ≠ 60).

The simulations were done for 4 different values of resistivity ($10k\Omega/\square, 100k\Omega/\square, 1M\Omega/\square$ and $10M\Omega/\square$) to observe the effect of the resistivity.

### 2.2.1 Signal on the readout strip

The figure 8 shows the maximum voltage drop of the 121 elements composing the readout strip.

![Figure 8: Maximum voltage drop reached for each of the 121 elements of the readout strip for the four values of resistivity](image)

The element containing the discharge has the higher voltage drop (-130 V) for the 4 different values of resistivity. We observed a decrease of this drop for the elements placed away of the central one. We also observe the same effect of oscillations at the ends of the strips. One can notice that the values of the voltage drop reached by the elements of the $200\mu m$ are higher than those reached with the $100\mu m$ one. The value of the resistivity does not seem to have an important effect on the value of the maximum voltage drop reached by the elements of the strips, we observe a similar shape and a similar order of magnitude of the values of the drop for the different values of resistivity.

### 2.2.2 Signal on the resistive strip

We observe the results of the voltage drop reached by the 121 elements of the resistive strip on figure 9.
This figure shows the effect of the value resistivity on the signal spread on the resistive layer. For the higher value (10$\,\text{M}\Omega/\square$) of the resistivity, the spread is smaller. We observe 10 elements (except the one containing the discharge) that have a noticeable voltage drop (5V), the element that contains the discharge (voltage drop = -410 V). For the lowest value of resistivity (10$\,\text{k}\Omega/\square$), we observe an area of 22 elements (except the discharging one) that have a non negligible voltage drop (10 V or more), the central element that contains the discharge (voltage drop = -370 V).

2.3 Strip width of 300$\mu$m

In this section, we present the results obtained with a width of strip of 300$\mu$m. We have 3 elementary cells per element (to get a longitudinal size of the element close to 1 mm) and the others parameters are the same as the ones used for the two widths of strips simulated before (number of elements for one strip, element that contains the discharge and number and value of resistivity simulated).

2.3.1 Signal on the readout strip

The maximum voltage drop of elements of the strip is showed on figure 10.

The element that contains the discharge (#60) shows the higher voltage drop (-170V) for all the values of resistivity. The voltage drop decreases for the elements along the strips (−120V for the close neighbors to ±50V for the elements at the ends of the strip). We still observe oscillations at the ends of the strip. One can also notice that the value of the resistivity does not play a role on the voltage drop of the elements, the shape and the magnitude remaining similar for the 4 values of resistivity.

2.3.2 Signal on the resistive strip

The results concerning the resistive elements are presented on figure 11.
Figure 10: Maximum voltage drop reached for each of the 121 elements of the readout strip for the four values of resistivity

Figure 11: Maximum voltage drop reached for each of the 121 elements of the resistive layer (on the left, the full resistive strip and on the right a zoom on the central area around the discharge)

This figure shows the effect of the value of the resistivity on the signal spread on the resistive layer. For the higher value (10MΩ/□) of the resistivity, the voltage drop of the discharging element is higher (-410V) where with the lowest value of resistivity (10kΩ/□), we observe a smaller voltage drop of the same element (-370V). Concerning the spread of the discharge, in case of the lowest value of resistivity, the area involved in the discharge is 7 elements around the discharging one with a maximum voltage drop value from -100V to -20V. For the highest value of resistivity, the area involved in the discharge is smaller (4 elements around the discharging one) with value of maximum voltage drop of -10V, the other elements have a maximum voltage drop of +10V.
2.4 Effect of the inductance values for the mesh electrode and the readout strip

In this section, we have tested the effect of the inductance value for the mesh and the read strip for a 200µm strip width keeping constant all the other parameters of the configuration.

2.4.1 Effect of the pad inductance value

We present in this part, the effect of the pad inductance value used in our model of simulation. We have simulated the single strip geometry presented in fig. 4 with 4 different values of pad inductance (0 pH, 10 pH, 41.5 pH and 83 pH) and a constant value of the mesh inductance (120 pH). The result is presented in figure 12.

Figure 12: Maximum voltage drop reached by the 121 elements of the readout strip for four values of pad inductance

The plot shows the effect of the inductance value. The value previously used in our model for a 200µm strip width is 83 pH. Table 2 presents the value of the maximum voltage drop reach by the central element (#60) and lowest voltage drop reach by elements located at both ends of the strip.

One can notice that the pad inductance plays an important role in the voltage drop reach by each of the 121 elements composing the strip. Without any inductance of the strip (0 pF), the voltage drop reaches a value of few mV. As soon as this value increases to 10 pF, the voltage drop increases to -18 V for the element #60 and ± 5V for the elements located at the ends of the strip. If this value still increase to 41.5 pF, we observe high value of voltage drop for
Table 2: Maximum value of voltage drop for the central element (#60) (voltage drop 1) and at the ends of strip (voltage drop 2) as a function of the pad inductance value

| $L_{pad}$ (pH) | Voltage drop 1 (V) | Voltage drop 2 (V) |
|----------------|--------------------|--------------------|
| 0              | $-3.8 \times 10^{-3}$ | $-2 \times 10^{-3}$ |
| 10             | -18                | $\pm 5$            |
| 41.5           | -130               | $\pm 25$           |
| 83             | -130               | $\pm 25$           |

We can also notice that we do not observe any difference in the value of the voltage drop obtained with 41.5 pH and 83 pH and also in the shape of the plot.

### 2.4.2 Effect of the mesh inductance value

In this part, we present the value of the maximum voltage drop reached by the 121 elements of the readout strip for different values of the mesh inductance (0, 60, 120 and 240 pH). Those simulations have been realised for a width of strips of 200µm and the results are presented in figure 13.

![Figure 13: Maximum voltage drop reached by the 121 elements of the readout strip for four values of mesh inductance](image)

We can observe that the higher is the value of the mesh inductance, the lower is the voltage drop of the elements composing the readout strip. The value of the voltage drop are summarized in table 3.
Table 3: Maximum value of voltage drop for the central element (\#60) (voltage drop 1) and at the ends of strip (voltage drop 2) as a function of the mesh inductance value

| $L_{\text{mesh}}$ (pH) | Voltage drop 1 (V) | Voltage drop 2 (V) |
|------------------------|--------------------|--------------------|
| 0                      | -221               | ±27                |
| 60                     | -124               | ±20                |
| 120                    | -127               | ±20                |
| 240                    | -38                | ±10                |

The results presented in table 3 show clearly see the importance of the value of the mesh inductance. There is more than a factor five between the voltage drop reaches without any inductance for the central element and with the highest value of mesh inductance for the same element (-221 V for 0 pH and -38 V for 240 pH). We observe the same trend for the ends of the strip with a lower magnitude (±27 for 0 pH and ±10 V for 240 pH). The last point that one can notice is that with a value of $L_{\text{mesh}}$ of 0 pH, the rebounds, present with all the others values of inductance, are suppressed.

2.4.3 Results without any inductance in the model

In this section, we present the results of the simulation obtained with a model without any inductance ($L_{\text{mesh}} = L_{\text{pad}} = 0$ pH). The results of the maximum voltage drop of the elements composing the readout strip are presented in figure 14.

Figure 14: Maximum voltage drop reached by the 121 elements of the readout strip without any inductance
Without any inductances, the maximum voltage drop reached by the pads is very low (-36 mV for the central element and +2 mV for the elements located at both ends of the strip). One can notice that the results obtained without any inductance is 3 orders of magnitude lower than those obtained with the computed inductance values ($L_{mesh} = 120 \text{ pH}$ and $L_{pads} = 83 \text{ pH}$). We also observed a smooth curve without rebounds but with two discontinuities for pad #40 and #80.

3 Conclusion

3.1 Readout strip

Comparing the 3 strip widths, we observe a similar shape of curve for the 4 different values of resistivity, nevertheless, the value of the maximum voltage of the element of the strip increases with the width of the strips as it is shown in table 4.

| Width ($\mu m$) | Voltage drop 1 (V) | Voltage drop 2 (V) |
|----------------|-------------------|-------------------|
| 100            | -120              | $\sim \pm 15$     |
| 200            | -130              | $\sim \pm 25$     |
| 300            | -170              | $\sim \pm 50$     |

Table 4: Maximum value of voltage drop for the central element (#60) (voltage drop 1) and at the end of strip (voltage drop 2) function the width of the strip

One can also notice that the larger is the strip, the larger is the number of elements involved in the discharge (spread of the discharge signal). This can be explained by the fact that for the 100$\mu m$ width strip, an element is composed by 9 elementary cell of size $100 \times 100 \mu m^2$ of a given resistivity. For the same resistivity, a 300$\mu m$ width strip will be composed by only 3 elementary cells of size $300 \times 300 \mu m^2$. The resistivity will be 9 times lower in the latter case and this will lead to a higher number of elements involved in the discharge area.

Another important point is the value of the inductance of the pad used in our model. Table 2 shows that there is a clear trade off between the case with no inductance and the presence of, even, a small inductance (few pH), the value of the maximum voltage drop varying by 3 orders of magnitude from few mV to -20 V for the central element. If the value of the inductance increases to 41.5 pH, we observe an increase of the maximum voltage drop from -20 V to -130 V for the central element. After that, it seems that the curve reaches a plateau, we do not observe any increase between 41.5 pH and 83 pH.
3.2 Resistive strip

For each width of the strip, we have simulated 4 different values of resistivity. We observe that the higher is the value of the resistivity, the higher is the value of the maximum voltage drop of the central element (#60) and this observation is the same for the other 120 elements of the strip. The results of the maximum voltage drop for the element containing the discharge and the spread of the discharge signal are presented in table 5.

| Width (µm) | ρ (Ω/□) | Voltage drop 1 (V) | Spread | Voltage drop 2 (V) |
|------------|---------|--------------------|--------|--------------------|
| 100        | 10k     | -370               | ± 10   | 0                  |
|            | 100k    | -390               | ± 7    | 0                  |
|            | 1M      | -400               | ± 3    | 0                  |
|            | 10M     | -400               | ± 1    | 0                  |
| 200        | 10k     | -370               | ± 11   | 5                  |
|            | 100k    | -400               | ± 7    | 5                  |
|            | 1M      | -410               | ± 3    | 5                  |
|            | 10M     | -410               | ± 3    | 5                  |
| 300        | 10k     | -370               | ± 7    | 10-15              |
|            | 100k    | -400               | ± 3    | 10-15              |
|            | 1M      | -410               | ± 3    | 10-15              |
|            | 10M     | -410               | ± 3    | 10-15              |

Table 5: Maximum value of voltage drop for the central element (#60) (voltage drop 1), the spread of the discharge around the central element (in number of elements) and the maximum voltage drop at the end of the strip (voltage drop 2) for the different strip widths and resistivity (ρ)

One can notice on figure 7 that for a 100µm width strip there is a signal peak centered on the element #60 and the elements not involved in the discharge have a voltage drop of 0V. This pattern is very well defined. In the case of larger strip (200µm and 300µm), we still have a peak due to the discharge but we also have a tail of this peak that includes elements far away from the discharge (figures 9 and 11). The amplitude of the voltage drop of the elements included in this tail increases with the width of the strip. We observe for a 200µm width, a maximum voltage drop at the end of the strip of ~5V.

For a 300µm width, the amplitude of the voltage drop at the end of the strip is ~ 10 - 15V. We also can see on the figures 9 and 11 the apparition of oscillations between close elements that do not have similar voltage drop as we could expect.

References

[1] I. Giomataris et al., Nucl. Instr. and Meth. A 376 (2002) 29.
[2] www.cadence.com