Modeling and simulation of polarization potential in a planar gamma-ray detector

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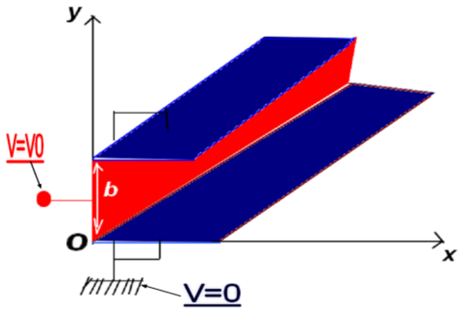
1. Background and Goal of the present work

Radioactivity is a natural phenomenon that manifests by the emission of radiation. This radiation can be used in several fields of application. It is imperceptible to the human senses and one can use detectors to identify it. In medicine, gamma cameras are used for medical imaging through gamma radiation from a radioactive source. When radiation interacts within the gamma detector, it causes the release of charge carriers which are accelerated by an applied polarization potential. This facilitates the collection of charges and the formation of the image by processing the obtained signal. The polarization potential is an important factor for the image formation and its distribution along a planar detector will allow us to identify the region of the detector where the collection of charges is optimal. The aim of this work is to determine this distribution in order to evaluate the influence of the position of electrodes on the collection of charge carriers.

2. Materials and methods

2.1. Analytical Method

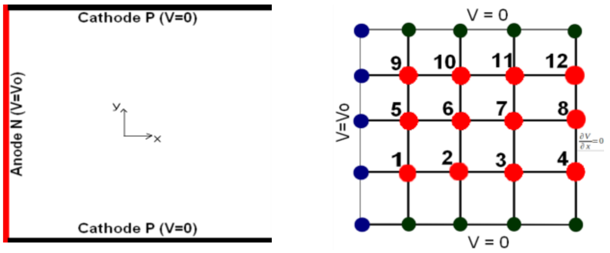
– Two semi-infinite electrodes connected to a potential V=0 (cathodes), located at the positions y=0 and y=b respectively.
– One electrode maintained at constant potential V_0 (anode), placed at position x=0.



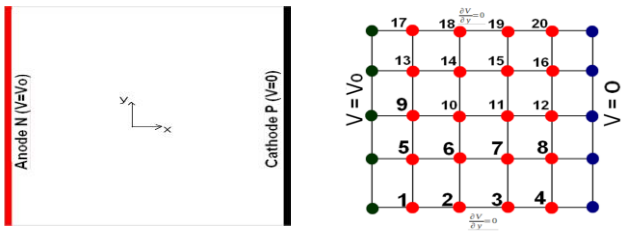
Description of a region of space delimited by electrodes which configuration is used for an analytical calculation.

$$\Delta \cdot \left(\varepsilon \vec{E}\right) = \rho \Rightarrow \Delta V = 0$$

2.2. Numerical Method



Detector model defined respecting the same configuration of the electrodes as that of the region described above for the use of analytical calculation. This model of detector is used to develop and validate a numerical calculation method.



Standard detector model: This model is used to evaluate the influence of the position of electrodes on the distribution of the polarization potential.

$$\frac{\partial^2}{\partial x^2} V(x,y) + \frac{\partial^2}{\partial y^2} V(x,y) = 0$$

$$V_{i-1,j} + V_{i,j-1} - 4V_{i,j} + V_{i+1,j} + V_{i,j+1} = 0$$

$$A = \begin{pmatrix}
-4 & 1 & 0 & 0 & 2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & -4 & 1 & 0 & 0 & 2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & -4 & 1 & 0 & 0 & 2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & -4 & 0 & 0 & 0 & 2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & -4 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 1 & -4 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 1 & -4 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 1 & -4 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & -4 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & -4 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & -4 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & -4 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & -4 & 1 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & -4 & 1 & 0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & -4 & 1 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & -4 & 0 & 0 & 0 & 1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2 & 0 & 0 & 0 & -4 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2 & 0 & 0 & 1 & -4 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2 & 0 & 0 & 1 & -4 & 1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2 & 0 & 0 & 1 & -4
\end{pmatrix}$$

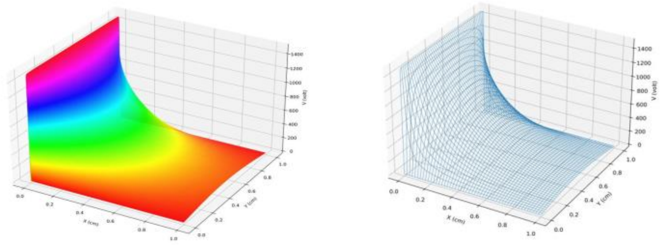
$$X = {}^t\left(V_1 \quad V_2 \quad V_3 \quad V_4 \quad V_5 \quad V_6 \quad V_7 \quad V_8 \quad V_9 \quad V_{10} \quad V_{11} \quad V_{12} \quad V_{13} \quad V_{14} \quad V_{15} \quad V_{16} \quad V_{17} \quad V_{18} \quad V_{19} \quad V_{20}\right)$$

$$B = {}^t\left(-V_0 \quad 0 \quad 0 \quad 0 \quad -V_0 \quad 0 \quad 0 \quad 0 \quad -V_0 \quad 0 \quad 0 \quad 0 \quad -V_0 \quad 0 \quad 0 \quad 0 \quad -V_0 \quad 0 \quad 0 \quad 0\right)$$

$$\mathrm{A} \cdot \mathrm{X} = \mathrm{B} \Rightarrow \mathrm{X} = ?$$

3. Results and discussion

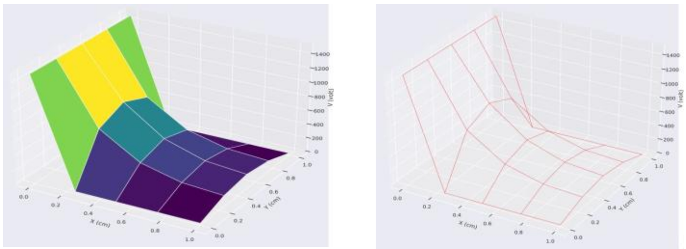
3.1. Analytical Solution



Analytical solution showing the distribution of the polarization potential inside the region of space bounded by the three electrodes.

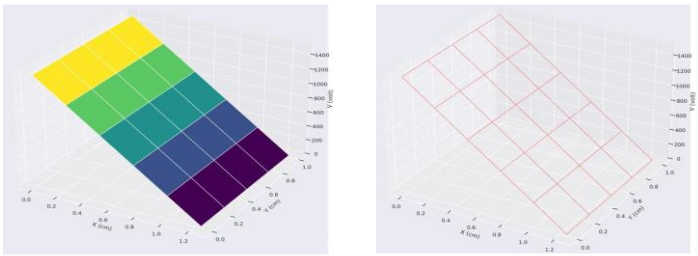
$$V(x,y) = \frac{4 \cdot V_0}{\pi} \sum_{n=1,3,5,\ldots}^{\infty} \frac{1}{n} \sin\left(\frac{n\pi y}{b}\right) \exp\left(-\frac{n\pi x}{b}\right)$$

3.2. Numerical method validation



Numerical solution: The distribution of the polarization potential is similar to that of the analytical solution. This validates the numerical method. The potential decreases exponentially according to the values of x

3.3. Influence of electrodes on the polarization potential



Distribution of the polarization potential in a standard planar detector. The potential decreases linearly according to the values of x

4. Conclusions

- ➢ First configuration model of electrodes position is used to simulate potential distribution and to validate numerical method.
- ➢ Second configuration model shows the influence of electrodes position on the polarization potential distribution
- ➢ The standard model of planar detector (where potential decrease linearly) is better than the first one (where potential decrease exponentially)

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