Gains, Uniformity and Signal Sharing in XY Readouts of the 10 cm × 10 cm Gas Electron Multiplier (GEM) Detector

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ABSTRACT: *The gas electron multiplier (GEM) detector is a promising particle and radiation detector which has been greatly improved from previous gas detectors. In particular, the 10 cm × 10 cm GEM detector is utilised in applications including high-resolution tracking devices in nuclear and particle physics. With its operational and design simplicity, while still maintaining high quality, the GEM detector is suitable for both start-up and advanced research. This article reports simple procedures and results of an investigation of important properties of this detector, using current measurement and signal counting. Results show that gains of the GEM detector increase exponentially as voltages supplied to the detector increase and that the detector reaches full efficiency when the voltages are greater than −4100 V. In terms of signal sharing between X and Y strips of the read-out, the X strips, on the top layer of the read-out, collect larger signals. For the uniformity test, the GEM detector has slightly higher efficiencies at the centre of the detector. These results can be used for future reference and for better understanding of the GEM detector's characteristics.*

Keywords: Particle detector, radiation detector, gas electron multiplier detector, GEM, gas detectors

1. INTRODUCTION

The gas electron multiplier (GEM) detector was invented by Sauli in 1997.[1] Since its invention, it has gained attention amongst international scientists and researchers. Some of its successes stem from its improved properties compared with previous gas detectors. Examples of the improvements include the ability to

operate in most gases, the ability to vary gains of the detector (up to 10^5), excellent spatial resolution (50 µm or better), high rate capability, flexibility in design and its relatively low cost.[2,3] GEM detectors are now utilised in varied scientific research, including tracking devices in nuclear and particle physics, medical imaging, astronomy and neutron detection.[4–7]

The 10 cm × 10 cm GEM detector was designed, developed and supplied by the Gas Detectors Development Group at the European Organization for Nuclear Research (CERN). The triple GEM detector consists of three GEM foils, which are 50 µm thick insulating foils made of polyimide (Kapton). Each foil is sandwiched by two thin copper plates. The GEM foil is perforated with arrays of 70 µm holes (GEM holes) with a 140 µm pitch between two adjacent holes. A voltage difference of 250–400 V is supplied between the two copper plates, such that a strong electric field is formed inside the GEM holes. In addition to GEM foils, the drift cathode is usually made of a thin sheet of aluminised Kapton, where the aluminium side is supplied with the most negative voltage. All GEM foils and the drift cathode are enclosed in a gas-tight box with one gas inlet and one gas outlet. The read-out of the GEM detector has an XY configuration in which two sets of 512 thin conducting wires run perpendicular to each other. A schematic drawing of the GEM detector and the read-out strips are shown in Figure 1 and Figure 2, respectively. The widths of the X and Y strips are 50 µm and 150 µm, respectively. The difference in strip widths is designed to improve signal sharing between the X and Y strips.[8]
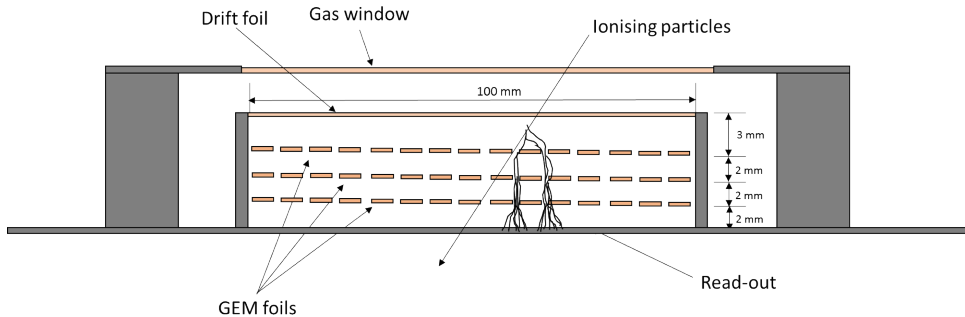

Figure 1:   Schematic drawing of 10 cm × 10 cm GEM detector. GEM foils and drift cathode are stacked at the centre of the gas-tight box with read-out serving as the base of the detector.

To operate the GEM detector, an appropriate gas filling must flow through the detector. In principle, a pure noble gas such as argon can be used. However, in order to improve the stability of the detector (lower discharge probability between GEM foils and lower propagating discharge probability between the last GEM foil to the readout), a gas mixture is usually used; a standard gas mixture is Ar/CO_2 with

a ratio of 70:30. Although other gas mixture ratios are possible for operating the GEM detector, the ratio of 70:30 provides high stability and suitable gains for most applications.[9] Ionising particles and radiation passing through the GEM detector ionise gas molecules inside the detector and create groups of primary electrons, which drift down to the GEM foils and gain enough energy from the strong electric fields inside the GEM holes to further ionise gas molecules. The amplified signal is detected by the XY read-out strips and transferred to an appropriate data acquisition system for data processing.[10]
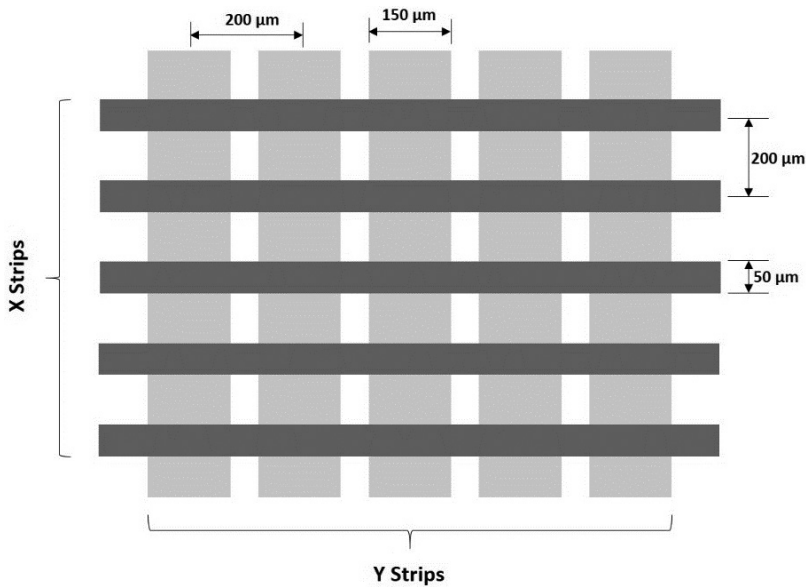

Figure 2: Schematic drawing of the read-out of the 10 cm × 10 cm GEM detector in XY configuration. The X strips are wires which are on top, with a width of 50 μm and a distance between strips of 200 μm. The Y strips are bottom wires with a width of 150 μm and a distance between strips of 200 μm.

The GEM technology has been much developed in recent years. Sophisticated designs and large-sized detectors have been manufactured to be used in much advanced research. In particular, the 10 cm × 10 cm GEM detector plays important roles in many studies, particularly in start-up research and preliminary studies. However, information about and simple procedures for the detector's performance are still inadequate. Thus, this study aims to report thorough details about the procedures and results of the investigation of important properties of the detector, viz. the count rate behaviour of the detector, its gains as a function of power supply voltages, signal sharing between the X and Y strips and the uniformity of the detector.

2.   EXPERIMENTAL

2.1   Count Rate Investigation

To investigate the count rates, which implied relative efficiencies as a function of voltage supplied, the emitting rate of 5.9 keV X-rays from Fe-55 was measured as the power supply voltage was varied from −3900 to −4300 V in 50 V increments. The set-up schematic diagram of the rate measurement is shown in Figure 3. The preamplifier used for this purpose was a charge-sensitive amplifier (Cremat-110) with the gain of 1.4 V/pC.[11] The threshold at the discriminator was set at 65 mV to eliminate all electronic noises. The power was supplied to the GEM detector through a voltage divider, as shown in Figure 4.
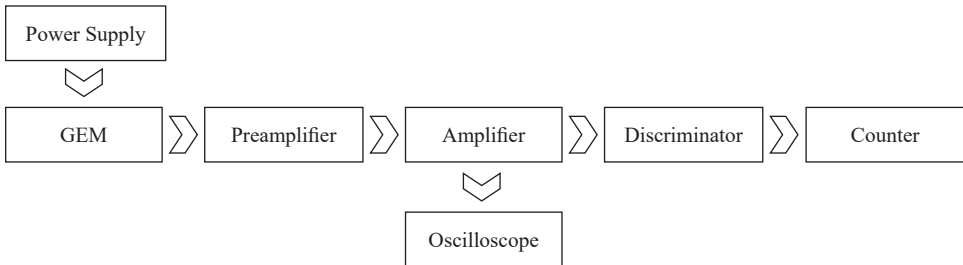

Figure 3:   Schematic drawing of the set-up for the emitting rate of 5.9 keV X-rays from Fe-55 in the count rate investigation.
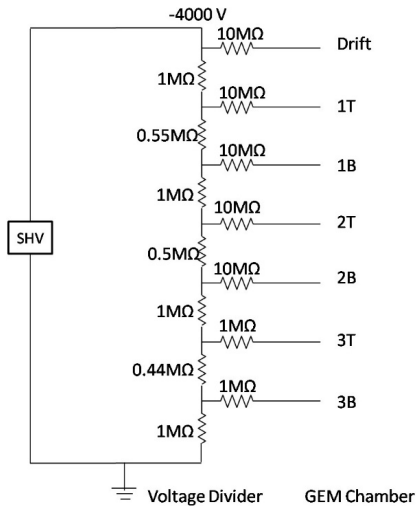

Figure 4:   Schematic drawing of the voltage divider used for supplying voltages to the GEM detector.

2.2   Gain Measurement

To measure the gains of the GEM detector, currents passing through the read-out from the detection of 5.9 keV X-rays were measured as power supply voltages were varied from 3900 to 4300 V in 50 V increments. The possible leakage or background currents were automatically subtracted during the gain measurement using current values from background runs. In the equation:

$$I = R \times N \times G \times e \tag{1}$$

I is the measured current, R is the emitting rate of 5.9 keV X-rays from Fe-55 at the maximum count rate, N is the number of primary electrons, G is the gain of the detector, and e is the charge of an electron ($e = 1.6 \times 10^{-19}$ C). In order to obtain G, values of I, R and N must be carefully measured and evaluated. To measure I, a pico-ammeter with a 20 fm current resolution was used for the current measurement. The set-up for the current measurement is shown in Figure 5. N could be estimated using the average work function (W) of the gas mixture (Ar/CO_2) in the ratio of 70:30, which was calculated using Equation 2:

$$\frac{1}{W} = \frac{\% \text{ of } Ar}{W_{Ar}} + \frac{\% \text{ of } CO_2}{W_{CO_2}} \tag{2}$$

where $W_{Ar} = 25$ eV, $W_{CO_2} = 34$ eV, % of $Ar = 0.7$ and % of $CO_2 = 0.3$. Using these values in Equation 2 gave $W = 27.8$ eV.[12] Assuming that only a photoelectric effect occurred during the interaction between the X-rays ($E = 5.9$ keV) and gas molecules ($W = 27.8$ eV), N could be calculated by dividing E by W, hence, N was approximately 212 electrons.
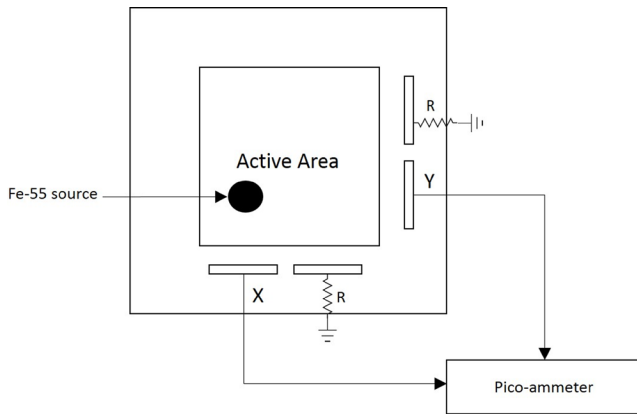

Figure 5:   Schematic drawing of the current measurement using a pico-ammeter and a Fe-55 source. Two scenarios, viz. only X strips and a combination of X and Y strips, were used for current measurement.

2.3   Signal Sharing Between X and Y Strips

Although the purpose of different widths in the XY read-out strips was to improve signal sharing between the X and Y strips such that signals were shared equally between them, inequality in the signal sharing could still occur. To investigate the signal sharing, currents were measured in three scenarios, viz. only X strips (I_X), only Y strips (I_Y), and a combination of X and Y strips (I_{XY}). The ratio of I_X/I_{XY} and I_Y/I_{XY} indicates the percentages of the signal collected by the X strips and Y strips, respectively.

2.4   Uniformity Test

Since the efficiencies of the GEM detector at areas near the edges of the active area was expected to be lower than the efficiencies at the centre, an investigation of the uniformity of the GEM detector was needed to better understand these differences. To test the uniformity, the 10 cm × 10 cm GEM active area was divided into 36 positions (6 columns and 6 rows). Am-241, which emits primary alpha particles and 59 keV secondary gamma, was placed 0.5 cm above the GEM gas window on each divided position. In order to correctly compare the efficiencies at different positions, the gas flow rate ($3.0\,l\,h^{-1}$), the detection duration (3 min) and the power supply voltage (−4100 V) were set to be the same throughout the measurement. For each position, the numbers of counts detected using the set-up in Figure 3 were collected and averaged. After completing all 36 positions, the numbers of counts were plotted using the OriginPro software to produce a contour of uniformity.

3.   RESULTS AND DISCUSSION

3.1   Count Rate Investigation

The results of the count rates of emitting 5.9 keV X-rays from Fe-55 as a function of power supply voltages are shown in Figure 6.

As shown in Figure 6, the maximum and constant efficiency of the GEM detector occurred when the power supply voltages were higher than −4100 V. This implied that although the amplitudes of signals became larger as voltages increased, the maximum efficiency of the GEM detector was already achieved at V = −4100 V.
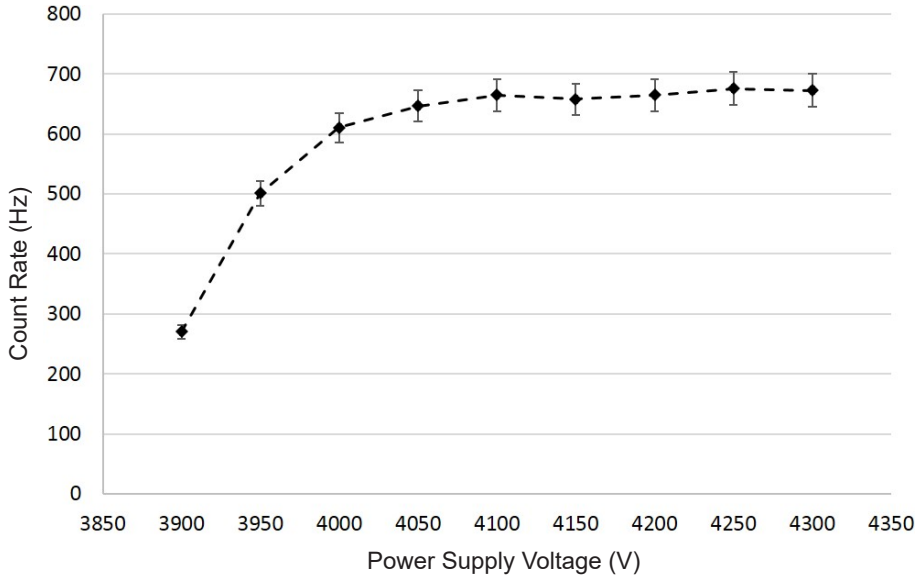
Figure 6:   Count rates of 5.9 keV X-rays from Fe-55 measured by the GEM detector as a function of power supply voltages. The GEM detector reached the constant region after 4100 V.

3.2   Gain Measurement

From calculations and measurements in previous sections, $R = 670$ Hz, $N = 212$ electrons and $e = 1.6 \times 10^{-19}$ C. The currents from the detection of the 5.9 keV X-rays measured with a combination of X and Y strips as a function of power supply voltages are shown in Table 1.

Table 1:   Currents from the detection of 5.9 keV X-rays of the GEM detector as the power supply voltages were varied from −3900 V to −4300 V.

Power supply voltage (V)	Current (nA)
3900	0.05
3950	0.07
4000	0.10
4050	0.15
4100	0.20
4150	0.29
4200	0.42
4250	0.60
4300	0.90

With the values of *I, N, e* and *R* indicated in previous sections, the gains of the GEM detector for different voltages were calculated and are shown in Figure 7.
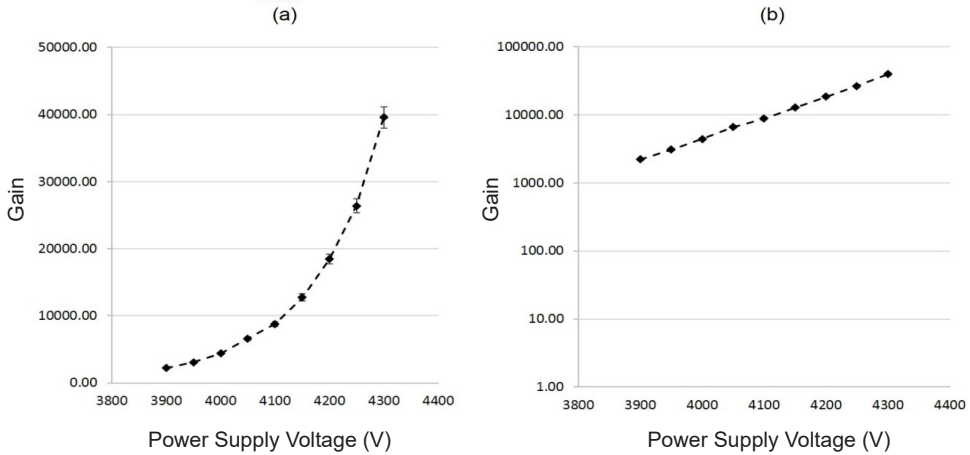

Figure 7:   Gains of the GEM detector (a) as a function of power supply voltages, in which (b) was plotted in logarithm scale.

As shown in Figure 7(a) and 7(b), the gains of the GEM detector increased exponentially as the power supply voltages increased. This was due to the increases in power supply voltages causing electric field inside GEM holes to increase, thus primary electrons were accelerated with greater electric forces, causing higher numbers of electron avalanches and higher signal amplitudes.
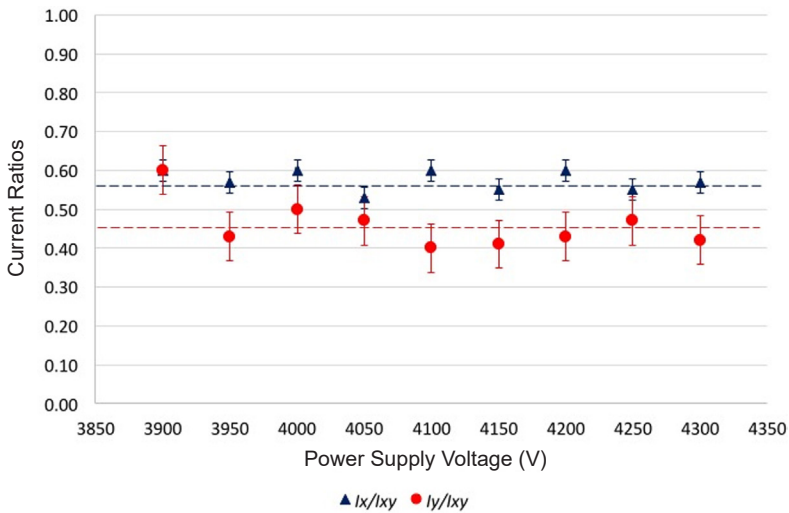
3.3   Signal Sharing Between X and Y Strips

To determine the ratio of signal sharing between the X and Y strips, the currents from the detection of 5.9 keV X-rays measured in the X strips only (I_X) and Y strips only (I_Y) were compared with the currents measured in a combination of X and Y strips (I_{XY}). Values of I_X, I_Y, I_{XY} and I_X/I_{XY} are shown in Table 2.

Figure 8 shows that the average $I_X/I_{XY} = 0.57 \pm 0.03$ and $I_X/I_{XY} = 0.46 \pm 0.06$. Thus, the X strips, which were narrower and located on the top layer of the read-out, collected larger signals compared to the Y strips. To improve signal sharing, a new design and better manufacture of the read-out are required.[4]

Table 2: Current measurement from the detection of 5.9 keV X-ray in X strips only and in a combination of X and Y strips.

Power supply voltage (V)	Current from X strips (nA) I_X	Current from Y strips (nA) I_Y	Current from a combination of X and Y strips (nA) I_{XY}	I_X/I_{XY}	I_Y/I_{XY}
3900	0.03	0.03	0.05	0.60	0.60
3950	0.04	0.03	0.07	0.57	0.43
4000	0.06	0.05	0.10	0.60	0.50
4050	0.08	0.07	0.15	0.53	0.47
4100	0.12	0.08	0.20	0.60	0.40
4150	0.16	0.12	0.29	0.55	0.41
4200	0.25	0.18	0.42	0.60	0.43
4250	0.33	0.28	0.60	0.55	0.47
4300	0.51	0.38	0.90	0.57	0.42

Figure 8: Plots of I_X/I_{XY} and I_Y/I_{XY}, in which the blue and red dotted lines represent the average of I_X/I_{XY} and I_Y/I_{XY}, respectively.

3.4   Uniformity Test

Figure 9 shows the uniformity of the GEM detector using Am-241 as a gamma emitter. Areas near the centre of the active area had higher efficiencies compared to areas near edges of the detector. This behaviour was expected, since ionising particles or ionised electrons occurring near the edges had the possibility of travelling or drifting out of the active area, thus lowering the detector's overall

efficiencies and signal amplitudes. However, if considering areas at least 1 cm away from the edges, the efficiency was within 20% of each position. Slight differences in efficiencies between vertical and horizontal orientations might be due to gas distributions and the characteristics of the gas flow from the gas inlet to the gas outlet.
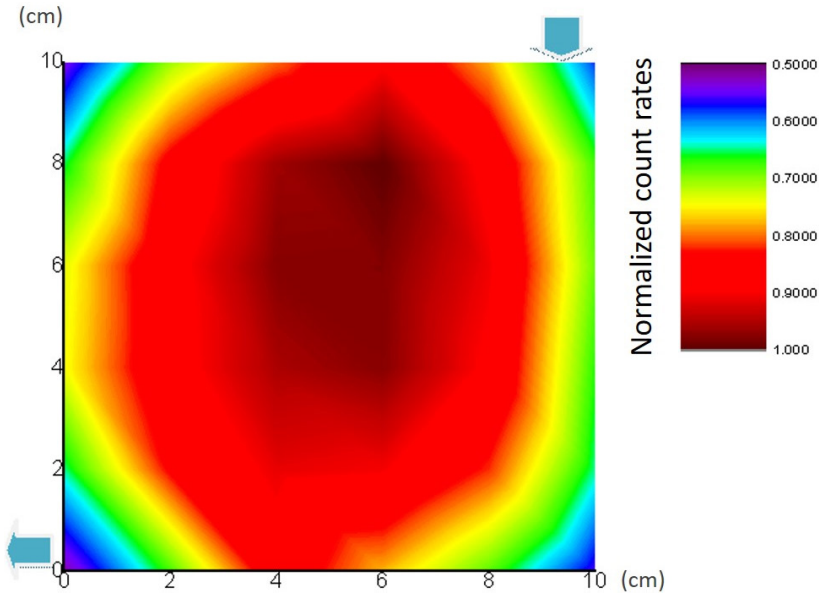

Figure 9:   Uniformity of the GEM detectors showing higher efficiencies at the centre of the detector.

4.   CONCLUSION

The GEM detector has recently become one of the most promising particle and radiation detectors. It has been utilised in varied scientific research, including particle and nuclear physics, medical applications, astronomy and national security. Since the 10 cm × 10 cm GEM detector has a simple design and excellent properties, it is suitable for both start-up and advanced research. Many researchers have relied on the excellent properties of the GEM detector in their research. This study investigated the main properties of the GEM detector. The results showed that the GEM detector reached full efficiency when the power supply voltages reached −4100 V and became relatively constant when the voltages were greater than −4100 V. The recommended voltages to run the GEM detector were between −4100 V and −4150 V. It was found that the gains of the GEM detector increased exponentially with increases in power supply voltages and that the X strips, which

are narrower and located on the top layer of the read-out, collected larger signals than the Y strips. In terms of uniformity, the GEM detector demonstrated higher efficiencies at the centre of the active area, while areas near the edges showed lower efficiencies. The outcomes of these investigations will be very useful for future reference and for a better understanding of the GEM detector. Further studies on the GEM detector should follow in order to improve it and to widen its possible applications.

5.   ACKNOWLEDGEMENTS

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