Publ. Astron. Obs. Belgrade No. 99 (2020), 229 - 232 *Contributed Paper*

TRANSITION FROM ELECTRON AVALANCHE NUMBER DISTRIBUTIONS TO FORMATIVE TIME DELAY DISTRIBUTIONS FOR MULTIELECTRON INITIATION AND STREAMER BREAKDOWN MECHANISM (I)

S. N. STAMENKOVIĆ and V. Lj. MARKOVIĆ

Department of Physics, Faculty of Sciences and Mathematics, University of Niš, PO Box 224, 18001 Niš, Serbia
E-mail ssuzana@pmf.ni.ac.rs, vidosav@pmf.ni.ac.rs

Abstract. Transition from number distributions of electron avalanches to formative time delay distributions for streamer breakdown mechanism and multielectron initiation is derived. When the number of initiating electrons k is small, the formative time delay distributions are asymmetric with pronounced right tail, while for $k > 10$ the formative time delay distributions are Gaussians.

1. INTRODUCTION

By studying the fluctuation phenomena in electron avalanches initiated by one particle, Furry 1937 and Wijsman 1949 derived the electron number distribution of an avalanche, which for a large number of electrons can be approximated by the exponential distribution. Numerous experimental distributions of carrier numbers of electron avalanches have been reported by Raether 1964 and coworkers. However, some experimental distributions (Raether 1964) show a deviation from the Furry and Wijsman distribution at higher values of the reduced electric field. The Polya distribution function was therefore introduced (Byrne 1962, Lansiart et al. 1962, Cookson et al. 1966a, Genz 1973) to describe this deviation. The calculation of the carrier number distribution function was presented in Legler 1964 and Cookson et al. 1966b, where the influence of the secondary ionization coefficient was taken into account. A review of avalanche models can be found in Alkazov 1970.

In Jovanović et al. 2019, the experimental results for the single electron initiation were modeled using the Monte Carlo simulation, and the shape of the distribution under different conditions was discussed. A generalization of the electron avalanche statistics for multielectron initiation with fixed and Poissondistributed number of initiating electrons was proposed in Stamenković et al. 2018, Marković et al. 2019. In Stamenković et al. 2020, the statistics of secondary electron avalanches with ion-induced electron emission in air was based on NBD and its mixtures, as well as on their Gaussian continual approximations.

In Devismes et al. 2002, a search for an optimum time response function of spark counters was undertaken, changing voltage, content of noble and quencher gases, pressure and energy-loss. The time response function of a spark counter was then calculated considering that the time delay and its fluctuations originate from the avalanche growth (Mangiarotti et al. 2002). Analytic expressions for the shape of the time response function were derived for the single cluster avalanche without the space charge effect, as well as for the multicluster environment with the effects of space charge. It was found that a peak and a tail of the time response probability density correlate with an increase of the overall time delay (Mangiarotti et al. 2002). Afterwards, in Gobbi et al. 2003, the fluctuation theory developed in Mangiarotti et al. 2002 was applied to measurements of spark counters Devismes et al. 2002 and extended to other counters. In this paper (designated as I), the number distributions of electron avalanches and formative time delay distributions for streamer breakdown mechanism are studied, while in Marković et al. 2020 (designated as II) the formative time delay distributions for Townsend breakdown mechanism are studied.

2. TRANSITION FROM THE ELECTRON AVALANCHE NUMBER DISTRIBUTIONS TO THE FORMATIVE TIME DELAY DISTRIBUTIONS FOR STREAMER BREAKDOWN MECHANISMS AND MULTIELECTRON INITIATION

According to Raether 1949, the formative time delay t_f is approximately equal to the time the avalanche takes to build up to the certain magnitude n (usually to the critical number of electrons $n_c \approx 10^8$). Therefore, the fluctuation in avalanche growth can be described as a fluctuation in avalanche length instead of final number of electrons. For mathematical derivation of probability density form, the multiplication N at fixed length d is transformed into the length L at fixed n_c. During the derivation, the replacement of random variables was carried out and probability $P_N(n) = \int \rho_N(n)dn$ that the multiplication N is less than n is replaced by the probability $P_L(l) = \int \rho_L(l)dl$ that avalanche length is less than l:

$$P_N(n)dn = P_L(l)dl \quad (1)$$

The form of $\rho_L(l)$ is obtained by taking into account probability $P(L > l)$ that the avalanche will grow longer than a length l, which is equal to the probability that over a length l it has not yet reached the critical number of electrons n_c, $P(N < n_c, d = l)$:

$$P_L(l) = 1 - P(L > l) \quad (2)$$

Assuming the probability density $\rho_N(n)$ dependence on avalanche length d into the form:

$$\rho_N(n) \equiv \rho_N(n,d) = \frac{1}{\bar{n}(d)} f\left(\frac{n}{\bar{n}(d)}\right), \tag{3}$$

and introducing the new variable $x = n/\bar{n}$, as well as $\bar{n}(l) = \exp(\alpha l)$, $\rho_L(l)$ follows

$$\rho_L(l) = \alpha\, x(l) f[x(l)] = \frac{\alpha n_c}{\bar{n}(l)} f\left(\frac{n_c}{\bar{n}(l)}\right), \tag{4}$$

In the case of Polya probability density distribution for the electron number in the avalanche at fixed distance d:

$$\rho_N(n) \equiv \rho_N(n,d) = \frac{k}{\Gamma(k)\bar{n}(d)} \left[\frac{kn}{\bar{n}(d)}\right]^k \exp\left(-\frac{kn}{\bar{n}(d)}\right), \tag{5}$$

probability density $\rho_L(l)$ takes the form:

$$\rho_L(l) = \frac{\alpha k n_c}{\Gamma(k)\bar{n}(l)} \left[\frac{k n_c}{\bar{n}(l)}\right]^k \exp\left(-\frac{k n_c}{\bar{n}(l)}\right), \tag{6}$$

The previous relation is further transformed into the formative time delay probability density $\rho_T(t_f)$ by using $\bar{n}(l) = \exp(\alpha l) = \exp(\alpha w_e t_f)$:

$$\rho_T(t_f) = \frac{\alpha w_e}{\Gamma(k)} \left[\frac{k n_c}{\exp(\alpha w_e t_f)}\right]^k \exp\left(-\frac{k n_c}{\exp(\alpha w_e t_f)}\right), \tag{7}$$

where α is the Townsend first electron ionization coefficient, w_e is the electron drift velocity and k is the number of initiating electrons. According to Genz 1973, the formative time distributions for streamer breakdown mechanism at different number of initiating electrons k are presented in Figure 1. When the number of initiating electrons k is small, the formative time delay distributions are asymmetric with pronounced right tail. With increasing k, the formative time distributions shift to the shorter formative times and become narrower and higher, more symmetric and Gauss-like. As statistical tests show, for $k > 10$ the hypothesis that the formative time distributions are Gaussians cannot be rejected (Fig. 1).

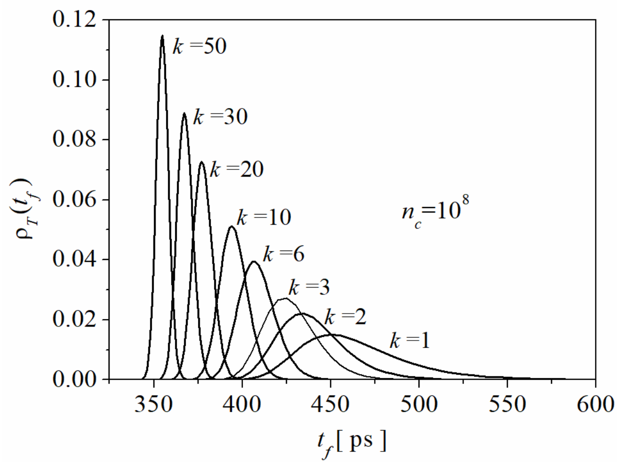

Figure 1: The formative time distributions for streamer breakdown mechanism at different number of initiating electrons k.

Acknowledgments: The authors are grateful to the Ministry of Education, Science, and Technological Development of the Republic of Serbia for partial financial support (contract number 451-03-68/2020-14/200124)

References

Alkazov, G. D. : 1970, *Nucl. Instrum. Meth.*, **89**, 155 (1970).

Byrne, J. : 1962, *Proc. Roy. Soc.* Edinburgh Section A, **66**, 33.

Cookson, A. H., Ward, B. W., Lewis, T. J. : 1966a, *Brit. J. Appl. Phys.*, **17**, 891.

Cookson, A. H., Lewis, T. J. : 1966b, *Brit. J. Appl. Phys.*, **17**, 1473.

Devismes, A., Frank, Ch., Kress, T., Gobbi, A., Eschke, J., Herrmann, N., Hildenbrand, K. D., Koczon, P., Petrovici, M. : 2002, *Nucl. Instr. and Meth.* A, **482**, 179.

Furry, H. : 1937, *Phys. Rev.* **52**, 569.

Genz, H. : 1973, *Nucl. Instr. and Meth.* **112**, 83 and references therein.

Gobbi, A., Mangiarotti, A. : 2003, *Nucl. Instr. and Meth.* A, **508**, 23.

Jovanović, A. P., Stamenković, S. N., Stankov, M. N., Marković, V. Lj. : 2019, *Contrib. Plasma Phys.*, **59**, 272.

Lansiart, L., Morucci, J. P. : 1962, *J. Phys. Phys. Appl.* (Suppl. 6), **23**, 102.

Legler, H. : 1964, *Z. Naturforsch.* **19A**, 481.

Marković, V. Lj., Stamenković, S. N., Jovanović, A. P. : 2019, *JINST*, **14**, P06009.

Marković, V. Lj., Stamenković, S. N., Jovanović, A. P. : 2020, Contributed papers of 30th Summer School and International Symposium on the Physics of Ionized Gases (Šabac, Serbia, 2020) (subsequent paper at this conference, designated as II).

Mangiarotti, A., Gobbi, A. : 2002, *Nucl. Instr. and Meth.* A **482**, 192.

Raether, H. : 1964, *Electron Avalanches and Breakdown in Gases*, Butterworths, London.

Stamenković, S. N., Marković, V. Lj., Jovanović, A. P., Stankov, M. N. : 2018, *JINST*, **13**, P12002.

Stamenković, S. N., Marković, V. Lj., Stankov, M. N., Jovanović, A. P. : 2020, *Eur. Phys. J. Plus*, 135: 51.

Wijsman, R. A. : 1949, *Phys. Rev.*, **75**, 833.