Study of the multipactor avalanche in two-wire transmission line

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Currently the multipactor discharge presents important limiting factor for space born communications. Therefore any design of novel rf components has to include a study of the multipactor threshold. An important example in space applications is helix antenna consisting of helically wound metallic wires (see Fig. 1). Up to recently the multipactor threshold was estimated in these structures using the existing ESA standard [1] which is based mainly on a resonance theory and plane-parallel model. A number of recent papers demonstrated that the ESA standard is not quite applicable to predict the multipactor threshold inside many systems with non-uniform rf field (such as hollow [2] and coaxial [3] waveguides, waveguide iris [4], micro-strip lines [5]). However very little attention has so far been given to multipactor breakdown in open antenna structures and the purpose of this paper is to analyze the limits set by multipactor such antennas by considering simplified model consisting of parallel cylindrical wires.

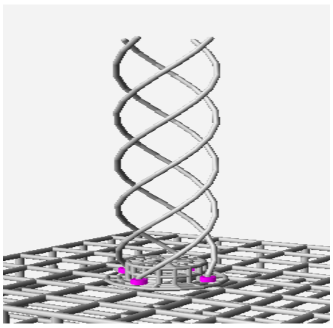

Fig. 1. Configuration of the helix antenna.

Under the realistic conditions a distance between the wires exceeds considerably the wire radius and amplitude of electron oscillations driven by rf field which is excited in the system. This makes it possible (i) to separate drift and oscillatory parts in electron motion, (ii) to estimate the average impact velocity of electron using the polyphase multipactor theory [6]. Specifically, the drift motion is determined mainly by initial acceleration of the secondary electron in a direction perpendicular to the wire surface. Evidently, a curvature of these surfaces results in a spread of electron bunch during its passage between two wires. The spread is accompanied by a decrease of electron density and a growth of the multipactor avalanche is possible only when this decrease is balanced by the secondary emission yield. An estimate of the necessary threshold value of the secondary emission yield (SEY), σ_{th}, is very simple for narrow bunch around straight line connecting the wire axes in the plane perpendicular to these axes [7]:

$$\sigma_{th} = 1 + d/R \,, \qquad (1)$$

where d and R denote a distance between the wire surfaces and wire radius respectively. Correspondingly, the multipactor threshold can be expressed as equality between the averaged (over electron impacts) value of the SEY $\langle\sigma\rangle$ and its threshold value, σ_{th}. In Ref. [7] it was suggested to estimate $\langle\sigma\rangle$ using the average value of electron impact velocity, $\langle v\rangle$:

$$\langle\sigma\rangle \approx \sigma(\langle v\rangle)\,,\ \langle v\rangle = \frac{\int v^2 dt}{\int v dt}\,,$$

$$v = v_d + v_\omega \cos(\omega t),$$

where v_d stands for the drift velocity, $v_\omega = eE/m\omega$ stands for amplitude of electron oscillatory velocity, E is maximum electric field amplitude attained at the wire surface, e, m stand for electron charge and mass, ω is the angular field frequency. Taking maximum possible value of the drift velocity $v_d = v_\omega$ one can get the following average approximation

$$\langle\sigma\rangle \approx \sigma(3v_\omega/2)\,, \qquad (2)$$

instead of the equality

$$\langle\sigma\rangle \approx \sigma(2v_\omega)\,, \qquad (3)$$

accepted within the resonance theory. To verify the above simple theory the multipactor avalanche between two parallel wires was simulated numerically using the Monte-Carlo algorithm and Vaughan's approximation for dependence of the secondary emission yield on impact electron velocity [8]. The simulation results are shown on Figs 2-4 where the multipactor threshold in terms of the rf voltage amplitude, V, (applied between the wires) is given depending on the wire radius for different distances between the wires and different parameters of the secondary emission.

When a distance between the wires is small a spread in electron initial velocity is not important and the resonance theory is quite applicable to estimate the average SEY, as can be seen from Fig. 2. This figure demonstrates also that the above threshold value of SEY (1) is quite good. Nevertheless on the Fig. 3 one can see considerable discrepancy between the simple estimate of the multipactor threshold and simulation results. This discrepancy is mainly related to incorrectness of the approximation $\langle \sigma \rangle \approx \sigma(\langle v \rangle)$ which is caused by nonlinear dependence of the SEY on impact electron velocity.

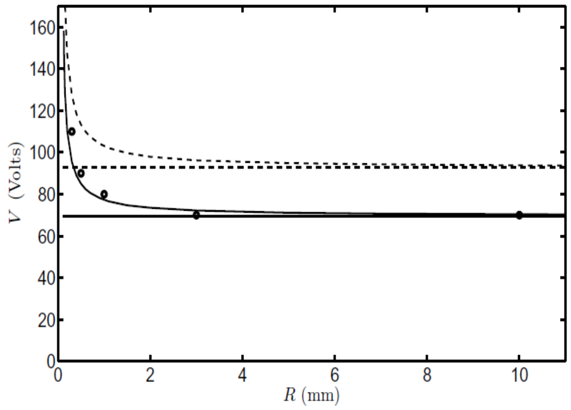

Fig. 2. The threshold voltage, *V*, vs. wire radius, *R*, in case of small distance, *d*=0.15 mm. Simulation results (circles) are obtained taking ESA standard [1] for the secondary emission yield from silver (maximum SEY=2.22, the first cross-over point, W_1=30 eV) and initial energy of secondary electron, W_0=3eV. The solid line shows results of simple estimate ($\langle \sigma \rangle = \sigma_{th}$) taking average approximation (2). The dashed line presents the similar estimate taking resonance approximation (3). The straight solid and dashed lines represent results (resonance and average) of the plane-parallel model.

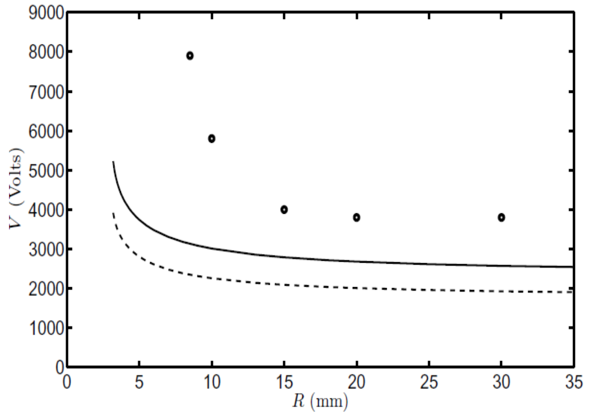

Fig. 3. The threshold voltage, *V*, vs. wire radius, *R*, in case of typical distance, *d*=3.8 mm. The same SEY parameters and the same notations are used as in Fig. 1.

The latter assumption was confirmed in additional series of simulations where all parameters were taken the same as in Fig. 3 with the exception of maximum value of SEY taken to be 10. In this case a dependence of the SEY on the impact velocity is closer to linear one around the threshold value, $\sigma \approx \sigma_{th}$. Correspondingly a discrepancy between the simple estimate and the simulation data becomes considerably smaller (see Fig. 4).

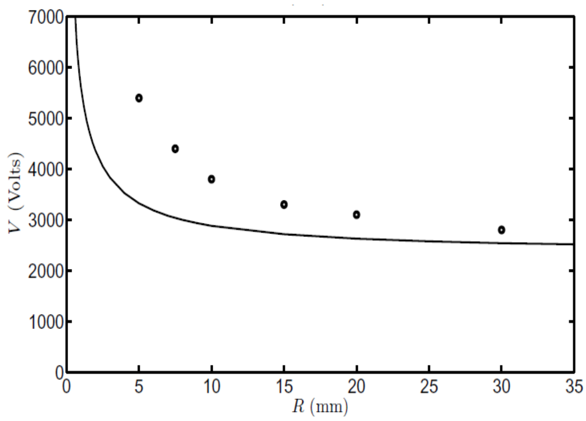

Fig. 4. The threshold voltage, *V*, vs. wire radius, *R*, in case of typical distance, *d*=3.8 mm. The maximum SEY is taken to be 10 whereas all other parameters and notations are the same as in Fig. 2.

References

1. ESA for ECSS, “Space engineering, multipactor design, and test,” ESA Publications Division, Noordwijk, The Netherlands, ECSS-E-20-01-01A, 5 May (2003).
2. *Kossyi I.A., Lukyanchikov G.S., Semenov V.E., Rakova E.I., Anderson D., Lisak M., and Puech J.* Polyphase (non-resonant) multipactor in rectangular waveguides // Journal Of Physics D: Applied Physics (J. Phys. D: Appl. Phys.) **41** 065203 (pp 1-8) (2008)
3. *Perez A.M., Tienda C., Vicente C., Anza S., Gil J., Gimeno B., Boria V.E., and Raboso D.* Prediction of Multipactor Breakdown Thresholds in Coaxial Transmission Lines for Travelling, Standing, and Mixed Waves // IEEE transactions on Plasma Science, V. 37, No. 10, pp. 2031-2040 (2009).
4. *Semenov V.E., Rakova E., Udiljak R., Anderson D., Lisak M., and Puech J.* Conformal mapping analysis of multipactor breakdown in waveguide irises // Phys. Plasmas V. 15, 033501, pp. 1-8 (2008)
5. *Semenov V.E., Rakova E.I., Sazontov A.G., Nefedov I.M., Pozdnyakova V.I., Shereshevskii I.A., Anderson D., Lisak M. and Puech J.* Simulations of multipactor thresholds in shielded microstrip lines // J. Phys. D: Appl. Phys. V.42 (2009) 205204 (7pp).
6. *Grishin L.V., Dorofeyuk A.A., Kossyi I.A., Luk'yanchikov G.S., Savchenko M.M.* A study of secondary-emission microwave discharges with large electron transit angles // Lebedev Physics Institute Series (Consultants Bureau, New York, London, 1977), V. 92, pp. 63-101.
7. *Rasch J., Anderson D., Johansson J., Lisak M., Puech J., Rakova E., Semenov V.* Microwave multipactor breakdown between two cylinders // IEEE Trans. Plasma Science, V. 38, No. 8, (2010), pp. 1997-2005.
8. *Vaughan J. R. M.*, A New Formula for Secondary Emission Yield // IEEE Trans. Electron Devices, V. 36, No. 9, pp. 1963-1967, (1989)