Multipactor Suppression in Resonant Cavities via Secondary Modes

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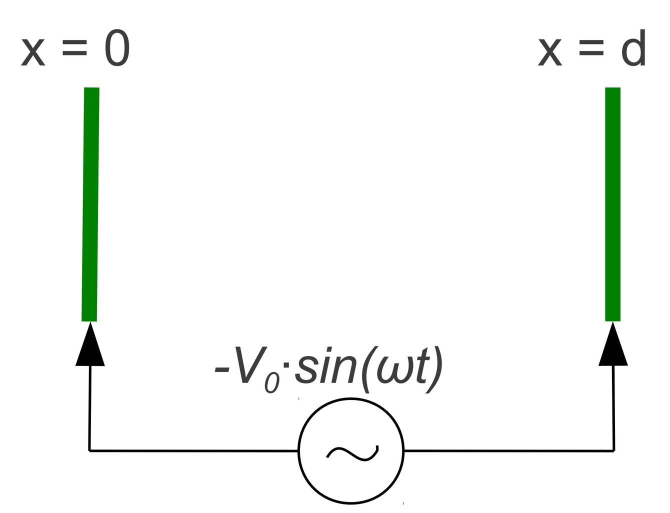
Introduction

Multipactor is a resonant phenomenon in which an electromagnetic field causes a free electron to impact a surface, resulting in the surface emitting one or more secondary electrons. If the surface geometry and electromagnetic fields are appropriately arranged, the secondary electrons can then be accelerated and again impact a surface in the bounding geometry. If the net number of secondary electrons participating in multipactor is non-decreasing, then the process can repeat indefinitely. This phenomenon is of considerable practical interest in the design and operation of radio frequency (RF) resonant structures.

Background

Consider two parallel plate conductors separated by a distance d and driven by an AC voltage $-V_0 \cdot \sin(\omega t)$, as shown below in Figure 1. An electron starting at rest from x=0 at t=0 will have a position x(t) as given below.



$$x(t) = \frac{q \cdot V_o}{m_e \cdot d \cdot \omega^2}(\omega \cdot t - \sin(\omega \cdot t))$$

Figure 1: Conceptual example of basic multipactor geometry.

If the electron arrives at x=d after one-half of the RF period, then its collision with the plate is capable of ejecting secondary electrons. The average secondary electron yield (SEY) is determined by the kinetic energy of the incident electron upon impact, as shown below in Figure 2. Values for SEY curves of specific materials can be found in [1].

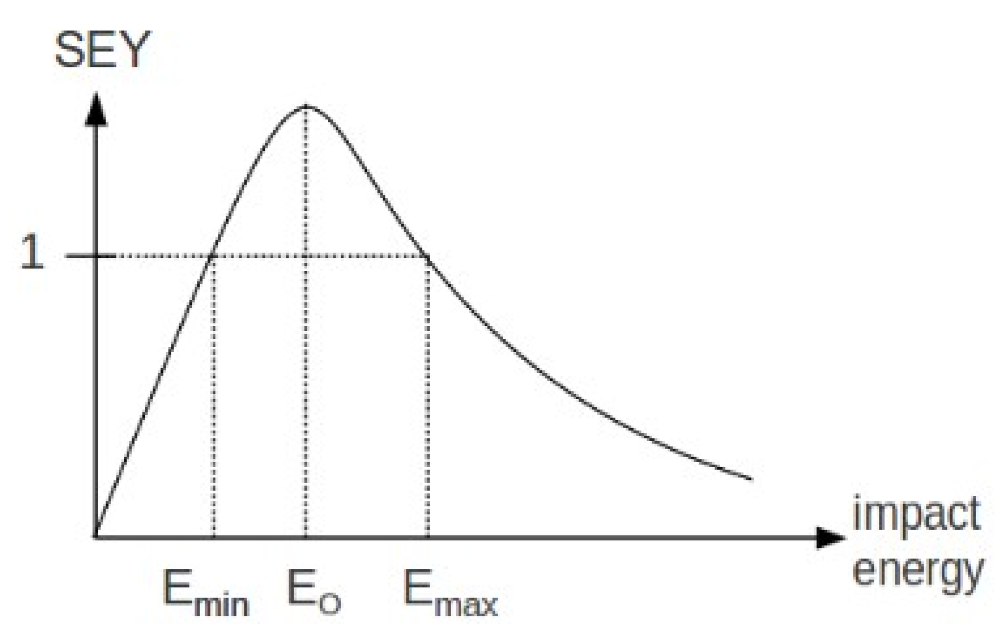


Figure 2: Typical SEY curve showing SEY dependence upon kinetic energy of incident electron.

The previous parallel-plate example serves as a good starting point to understand multipactor, but it is an oversimplification in two significant ways: (1) the electron does not necessarily start at t=0 (ie. arbitrary excitation phase needs to be considered), and (2) multipactor orbits can occur over 1,2,3... impact surfaces and multiple RF cycles as discussed in [2]. Vaughan [3] provides a more general analysis of the geometry and phase conditions necessary to sustain parallel-plate 2-point multipactor, in which the starting phase and initial velocity are arbitrary. For more complicated cases, we resort to numerical particle-tracking simulations.

Multipactor Suppression via Secondary Modes

Multipactor can only be sustained if the average SEY over the multipactor orbits is at least unity. This suggests a novel way to suppress multipactor, via the application of secondary excitation modes which result in the secondary electron impact energy being outside of the range of E_{min} to E_{max} where the SEY exceeds unity.

The plots in Figure 3 below show regions where multipactor occured in numerical simulations of a z-invariant coaxial conducting geometry, as a function of peak voltage V_o and phase θ for a nominal excitation voltage $V_o \cdot \cos(\omega t+\theta)$. The specific dimensions were an an inner radius of 1 cm, an outer radius of 5.6472 cm, and an excitation frequency of 80.5 MHz; these values were chosen to give significant multipactor for an applied peak voltage V_o of 1000 V. The left plot shows the multipactor results for the nominal excitation. The right plot shows the multipactor results when a 3^{rd} harmonic suppression mode of $-3V_o \cdot \cos(3\omega t+3\theta)$ is applied in addition to the nominal excitation. As can be seen, the multipactor is virtually eliminated in this case.

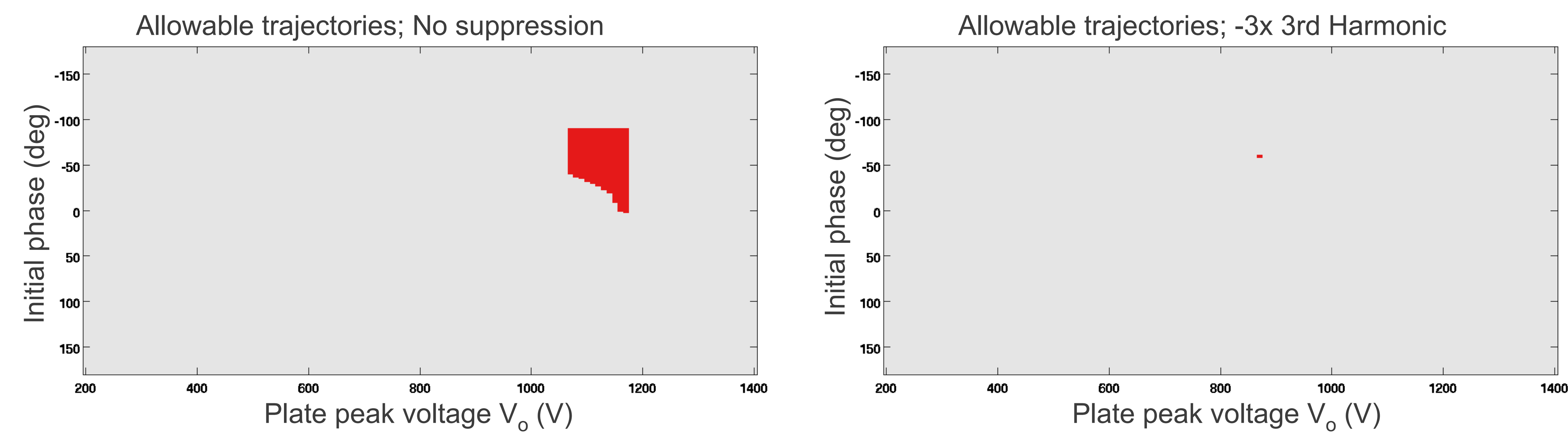


Figure 3: Multipactor sustainability in a notional coaxial geometry, with (right) and without (left) multipactor suppression modes. Areas of red show where multipactor was observed to occur.

Conclusions and Future Work

Proof-of-principle multipactor suppression in a z-invariant coaxial geometry has been demonstrated via an appropriately weighted and phased 3^{rd} harmonic of the fundamental mode excitation. Further possible suppression modes will be explored in future work, as well as more general coaxial structures both with and without z-invariance.

References

[1] CRC Handbook of Chemistry and Physics, 65th Edition, CRC Press, 1994, Section 12, p. 115.
[2] Padamsee et. al, RF Superconductivity for Accelerators, Chapter 10: Multipacting, pp. 182-197
[3] Vaughan, "Multipactor", *IEEE Transactions on Electron Devices*, Vol. 35, No. 7, July 1988, pp. 1172-1180

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