Multipactor Modelling Using an Averaged Version of Furman's SEY Model

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Introduction

Multipactor [1, 2] 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, windows, and supporting structures.

The formation of multipactor is strongly dependent upon the secondary electron yield (SEY) of a surface, and the emission velocities of the emitted electrons. A typical SEY curve is shown in Figure 1 below, illustrating a low SEY at low and high impact energies, and a high SEY at an intermediate impact energy. Two SEY models are popular within different technical communities:

Vaughan's model [3]
- Popular in the radio frequency (RF) and microwave source industry.
- More computationally simple.
- Does not include SEY contribution from low-impact energy electrons.
- Does not specify emission process (energy, angle, number of electrons, etc.).

Furman's model [4]
- Popular in the particle accelerator community.
- More computationally complex.
- Includes SEY contribution from low-impact energy electrons.
- Stochastically specifies the emission process.
- Requires a Monte Carlo simulation approach in practice.

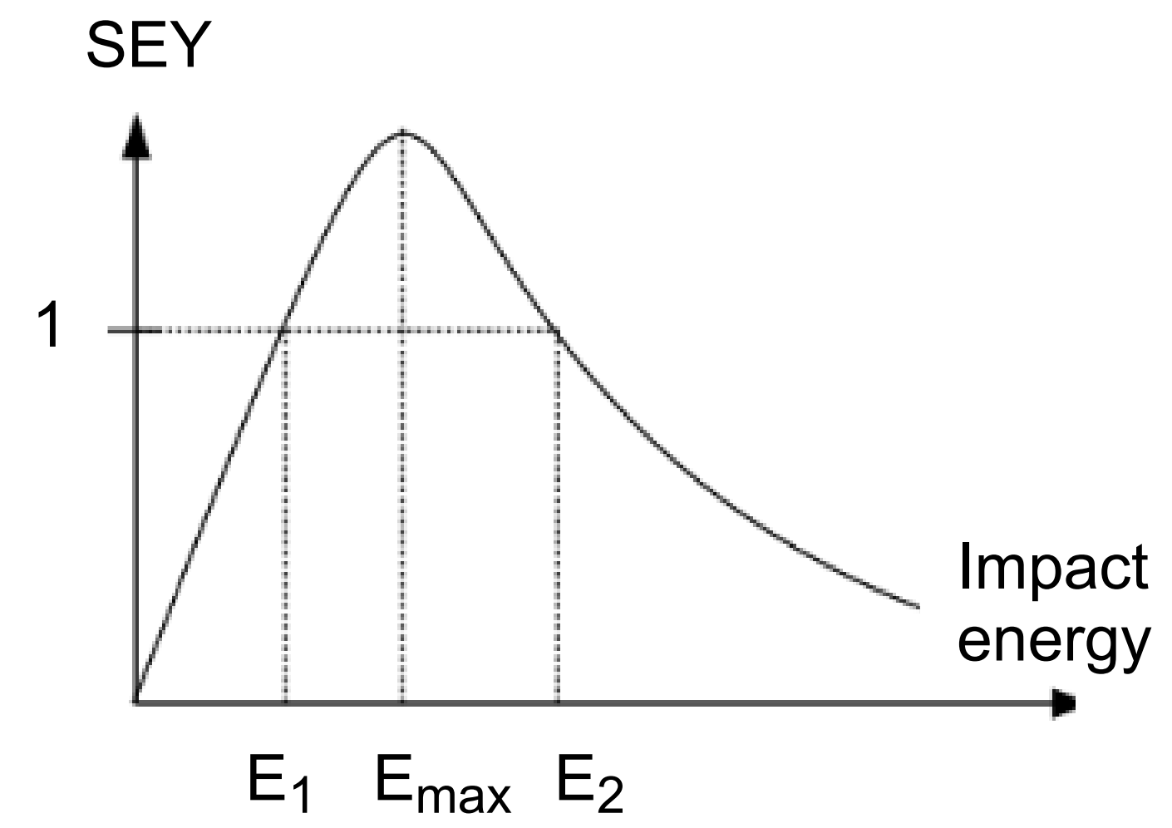

Figure 1: Typical SEY curve.

Numerical Multipactor Simulations

A coaxial cavity shorted at both ends (Figure 2) was excited by a TEM mode specified by $V_o \cdot \cos(\omega t+\theta) \cdot \sin(\pi z/L)$.
- V_o is the peak instantaneous voltage.
- θ is the phase.
- ω is the cavity-dependent resonant angular frequency.
- z is the position along the axial direction, measured from the cavity end.
- Cavity length L = 1.86 m.
- Cavity inner radius a = 1 cm.
- Cavity outer radius b = 5.65 cm.
- Mode resonant frequency is 80.5 MHz.
- Cavity dimensions chosen to yield maximum SEY at $V_o \approx 1000$ V.

For each voltage V_o and phase θ to be simulated, single-particle simulations were performed for 10 cycles: either a boundary strike a a complete RF period, whichever occurs first:
(1) Allow an electron starts from rest at the outer wall.
(2) Electron is accelerated by the cavity fields until it strikes a boundary.
(3) Record SEY for the impact.
(4) Generate secondary electron from emission energy and angle distributions.
(5) Repeat from step #2.

The net SEY is computed as the product of all the single-impact SEY values.
- Gives a proxy measure of the presence of multipactor.
- Net SEY < 1 would indicate that multipactor is not sustainable.
- Nonzero SEY required at least two boundary impacts over the 10 simulation cycles.
- Otherwise, net SEY was defined to be 0.

Furman's SEY model requires Monte Carlo simulations.
- Secondary electrons have random scattering energies and angles.
- 100 independent trials were run for each test point in voltage V_o and phase θ
- Net SEY is averaged over the trials to determine the predicted multipactor.

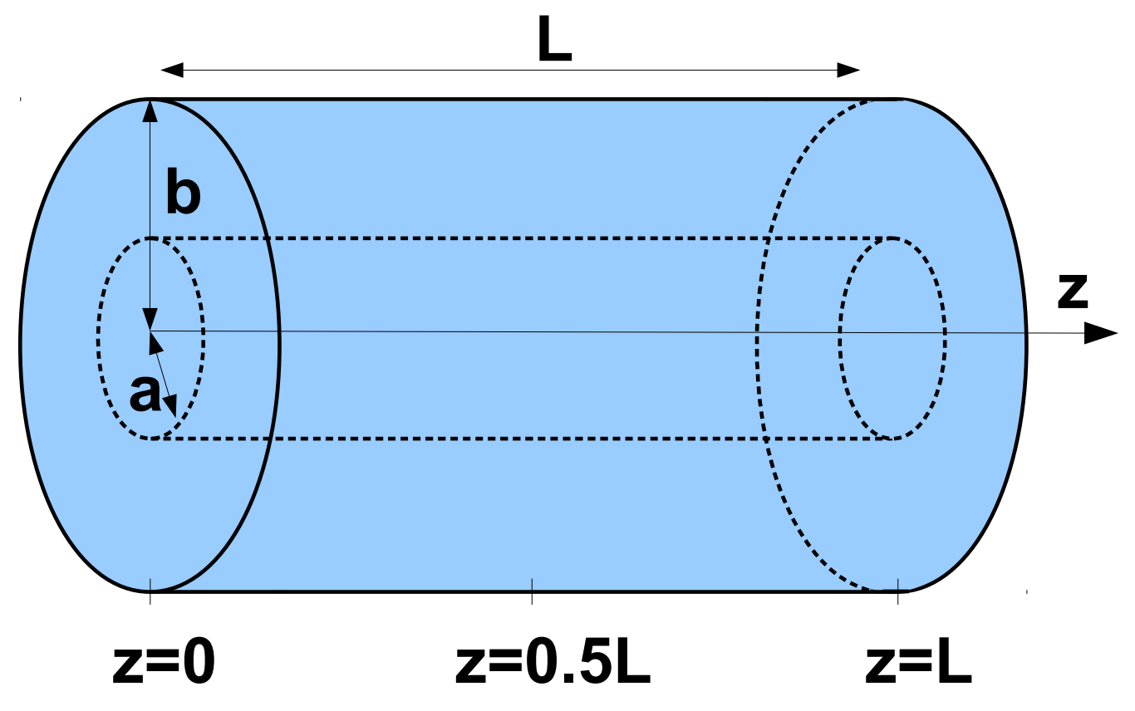

Figure 2: Notional coaxial cavity.

Medianized Variant of Furman's Model

- Recent work has suggested that multipactor formation can be very sensitive to low impact energy electrons [5], as shown in Figure 3. This makes Furman's model particularly appealing.

- However, Furman's SEY model necessitates computationaly costly Monte Carlo simulations to characterize multipactor susceptibility.

- Instead, consider using the (incident energy and angle dependent) median emission energy and emission angle, and running only one simulation.

- This medianized SEY model will not explore the entire phase space: multipactor sustainability will be underestimated, but by how much?

- Respectable multipactor prediction agreement between SEY models is show in Figure 4.

- We next examined a more complicated coaxial field environment.
  - Previous work [6] explored multipactor in the presence of additive perturbative 3rd harmonic TEM mode, we will use this again.
  - Perturbative mode expressed mathematically as $-3V_o \cdot \cos(3\omega t+3\theta) \cdot \sin(3\pi z/L)$.
  - Predicted multipactor is shown for particles at z=0.5L (Figure 5) and z=0.2L (Figure 6).

- Both SEY models are in agreement over much of the search space.
  - Medianized model underestimates the multipactor susceptibility to some degree.
  - But medianized model requires only one simulation, not a Monte Carlo run.

Conclusions and Future Work

- For the cases we have examined, multipactor simulations based upon Furman's fully stochastic SEY model can be well-approximated by a medianized SEY simplification.

- This will allow for considerable computational savings, for example a 100:1 speed increase over simulating 100 independent trials using Furman's full model.

- Applications would include optimizing resonant structures for multipactor performance.

- Future work will assess the accuracy of the medianized Furman model in different geometries and field excitations.

- Future work will also explore the relative accuracy of the medianized Furman model when generalized to other median percentiles besides the 50th percentile median.

References

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[6] Rice and Verboncoeur, "Multipactor Suppression in Resonant Cavities via Higher Order Modes", *IEEE Conference on Pulsed Power & Plasma Science (PPPS 2013)*, San Francisco, CA., June 16-21, 2013

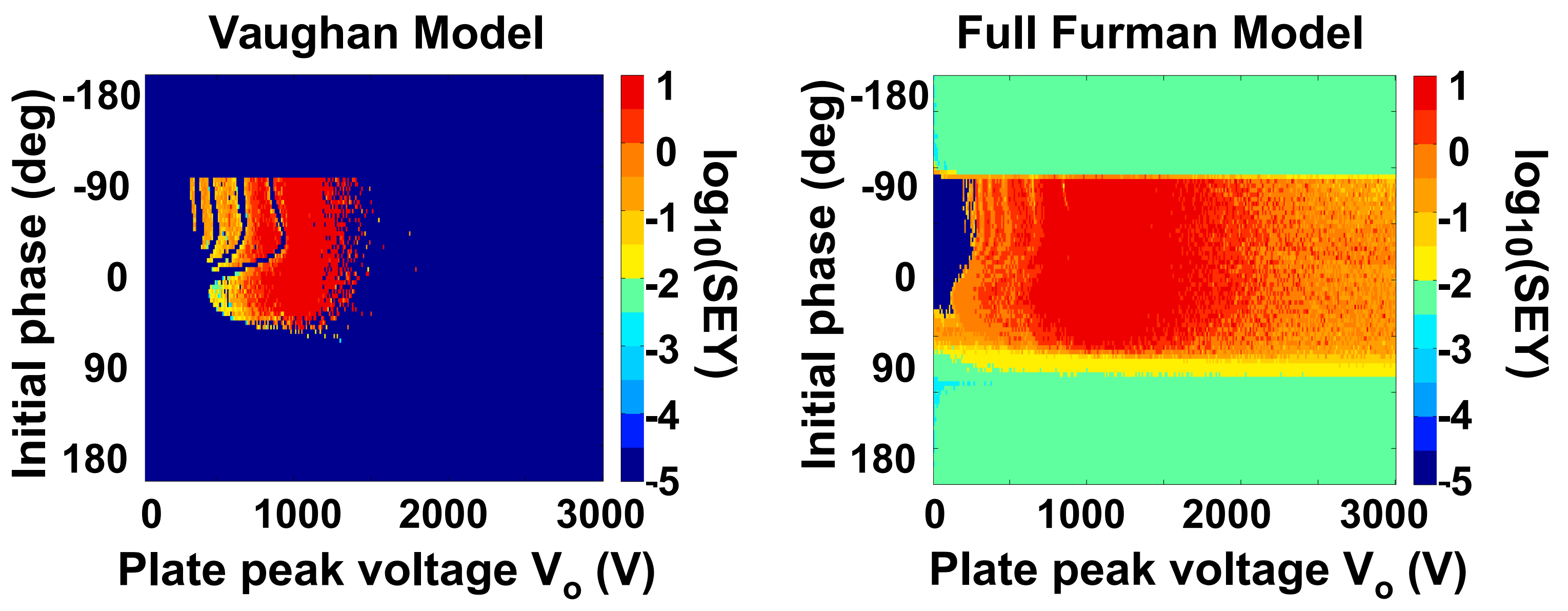

Figure 3: Multipactor sustainability in a notional coaxial geometry, based upon Vaughan's model (left) and Furman's full model averaged over 10 trials (right).

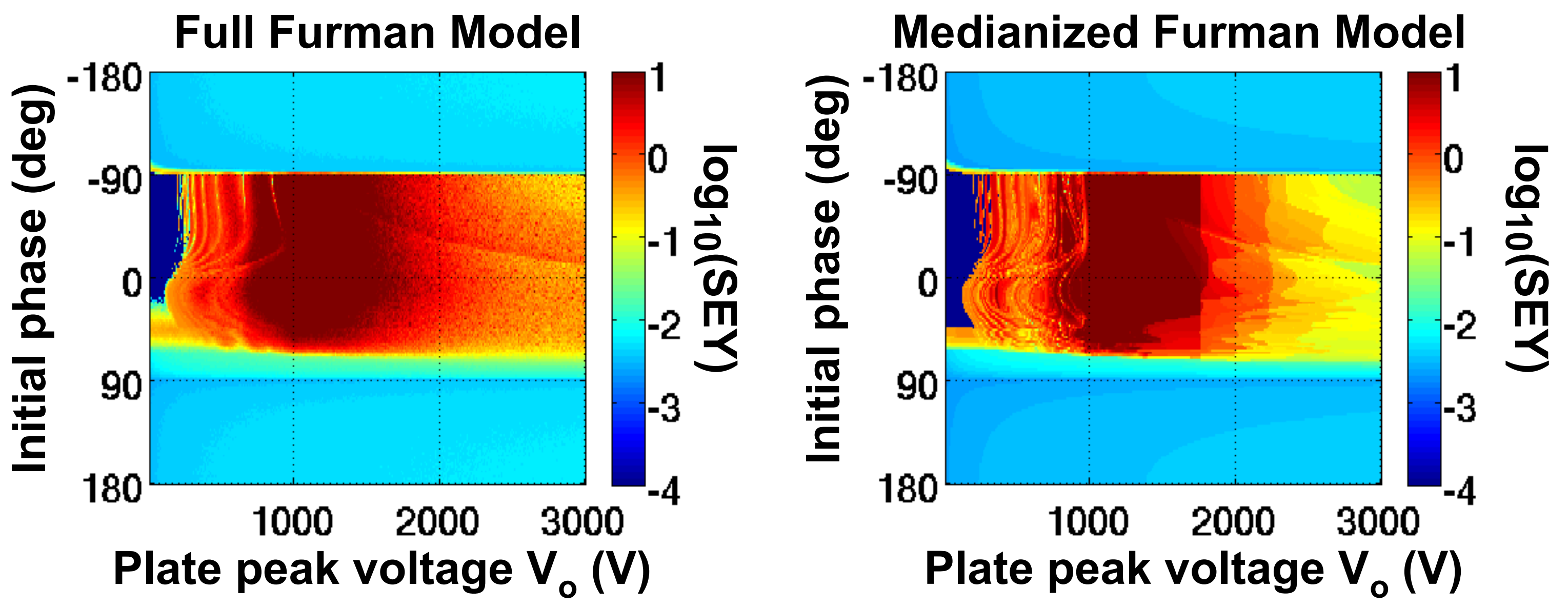

Figure 4: Multipactor sustainability in a notional coaxial geometry, based upon Furman's full model averaged over 100 trials (left) and a single run using medianized model (right).

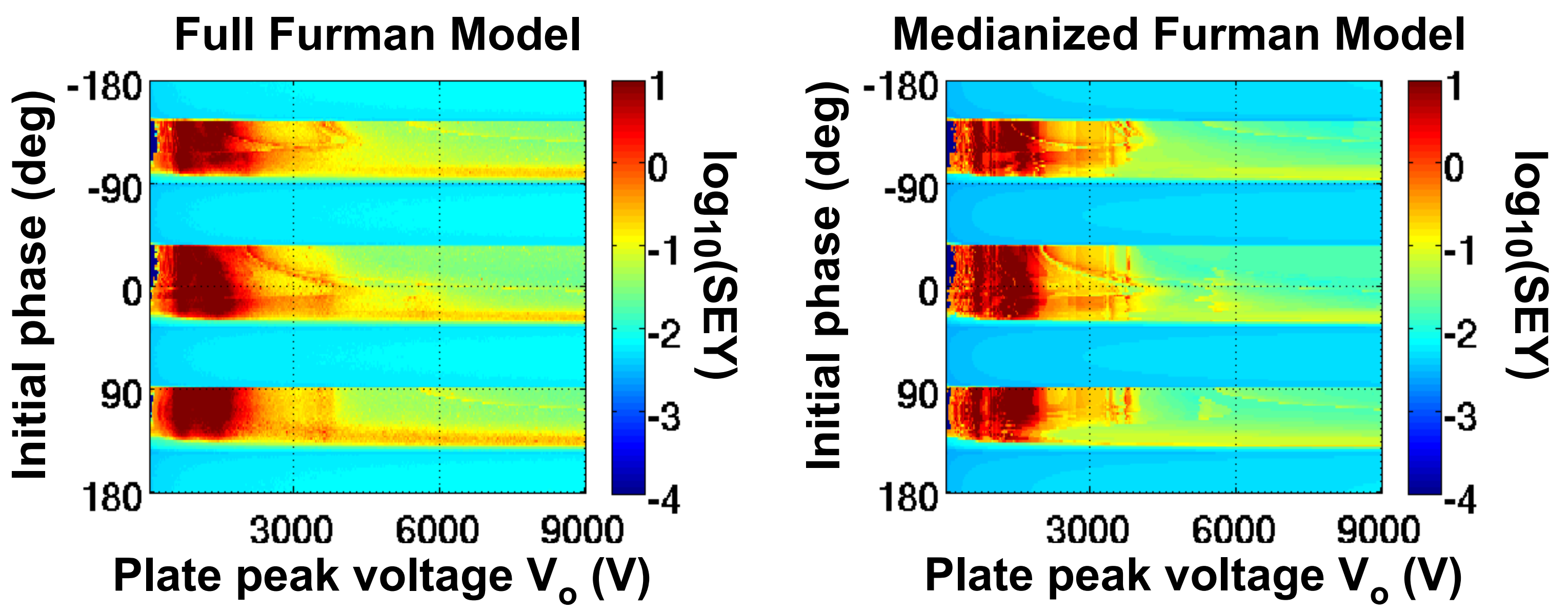

Figure 5: Multipactor sustainability in a notional coaxial geometry at z=0.5L with a perturbative TEM3 mode present, based upon Furman's full model averaged over 100 trials (left) and a single run using medianized model (right).

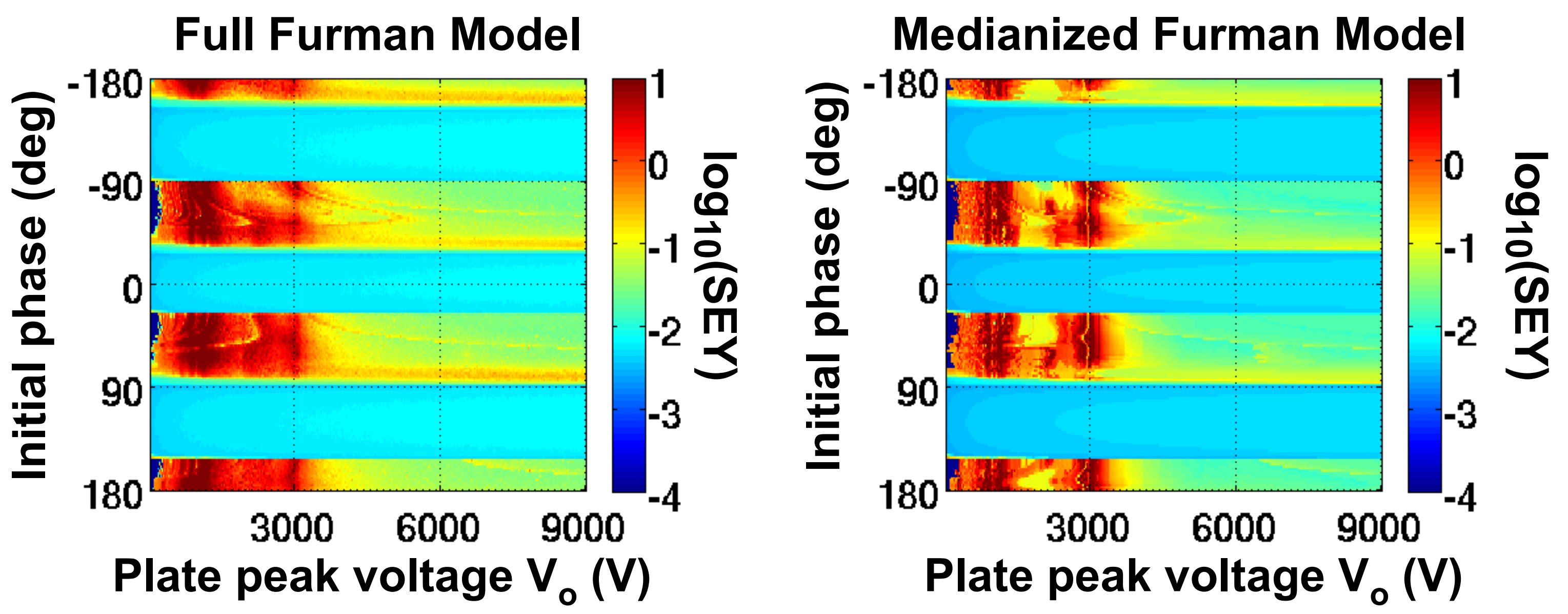

Figure 6: Multipactor sustainability in a notional coaxial geometry at z=0.2L with a perturbative TEM3 mode present, based upon Furman's full model averaged over 100 trials (left) and a single run using medianized model (right).

Acknowledgements

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