Power Capabilities of Vircators: A Comparison between Simulations, Experiments, and Theory

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Abstract
Maximum power that can be radiated by an Axially Extracted Vircators is calculated using a mathematical model. The established limits are compared against the results of experiments and simulations available in the literature.
High-power microwaves, High-power microwaves sources, Vircator.

POWER MODEL
A model calculating the average power radiated by an axially extracted Vircator has been presented by the authors in [1]. If that model is optimized, the maximum rating of the Vircator in terms of its output power can be established as

$$\bar{P} = \frac{27\pi^4(2+kV)^3}{4k\sqrt{kV(2+kV)}}x, \quad (1)$$

where $k = 1.9542 \times 10^{-6}$, and

$$x = \begin{cases} e^{-4\left(1-\frac{8\sqrt{2kV}\left((kV+1)^{2/3}-1\right)^{3/2}}{9(kV+2)}\right)^2} & \text{if } V < 1.85MV \\ 1 & \text{if } V > 1.85MV \end{cases} \quad (2)$$

Notice that Eq. (1) is an uni-variable function depending only on the feed voltage (V). So, if the right values of design parameters are chosen, the radiated power shall be limited only by the feed voltage. The black solid line in Fig. 1 shows the maximum average output power according to (1).
In next Section, we compare the limit given by Eq. (1) in terms of the average power, against both simulations and experiments reported in the literature. The comparison includes only the Axially Extracted Vircator typology. Different strategies including reflectors, slow-wave structures, and multiple-VC are also considered for comparison, although the model does not include these strategies.

COMPARATIVE ANALYSIS
Equation (1) defines the maximum average power radiated by the VC oscillation at the dominant frequency. However, the majority of reported experiments have presented the peak power. If the Vircator were radiating only at one single frequency, the peak power would be two times the average power defined by Eq. (1). However, the overlapping of frequencies and reflexions are present, thus, peaks of power of more than two times the average power could be produced.

Table 1. Reported power and voltage ratings of Vircators

	Author	$P_p[GW]$	$V[kV]$	Type
1	Choi [2]	0.2	290	E
2	Sze [3]	1	850	E
3	Zhiqiang [4]	0.795	700	S+M
4	Zhiqiang [4]	1.8	700	S+M
5	Zhiqiang [4]	1	6.3	E+M
6	Verma [5]	0.014	171	E.
7	Shukla [6]	0.015	150	E.
8	Shlapakovski [7]	0.1	550	E
9	Maiti [8]	0.2	210	S.
10	Brombrorsky [9]	22	6500	E.
11	Champeaux [10]	1280	511	S+M
12	Baryshevsky [11]	0.83	600	S.

E.	Experiment
S.	Simulation
M.	Modification (reflectors, slow-wave structures, etc)

Table 1 summarizes reported results from experiments and simulations that were considered for this analysis. Those results corresponds to published work from 1988 and 2017. Column one indicates an internal number assigned. The author is shown in Column two. Columns three and four give the reported power and voltage, respectively. Finally, column five defines if the author published an experiment (E.) or a simulation (S.). For those cases where the Vircator was simulated including a modification or add-on as reflectors, slow-wave structures, or and multiples VC, such types are labeled as (M.).
Figure 1 depicts the data presented in Table 1 against the upper limit defined by the model, stated as (1). The dashed line shows the value of two times the average power limit, i.e., the peak power under the assumption of single-frequency radiation. Lighted dotted lines represent leaps of 3dB.
Thus, it can be concluded that reported simulations and experiments of Axially Extracted Vircator agree with the upper limit defined by the model presented in [1]. In contrast, Vircators with modifications overcome the upper limit defined by (1). It can also be inferred that if correct sizes are considered, the Vircator maximum output power is limited only by the feed voltage regardless of the dominant frequency.

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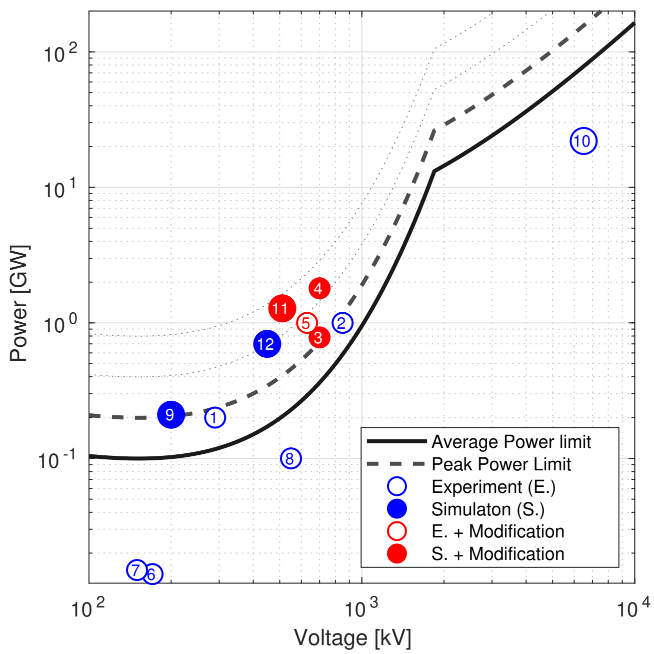

Figure 1. Comparison between Axially Extracted Vircator's limit given by the model presented in [1], the experiments and simulations reported.

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