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Author
Staples, John

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Frequency Scaling VHF Photoinjector Cavity*

John Staples

Lawrence Berkeley National Laboratory
1 Cyclotron Rd., Berkeley CA 94720, USA

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John, Staples, LBNL

How does the power and power density of the VHF cavity scale with frequency if the gap voltage is held constant?

The wavelength scales directly with geometry. The rf surface resistance scales as:

$$R_{square} \propto \sqrt{f}$$

and the surface area of the cavity scales as

$$Area \propto f^{-2}$$

Combining these, for a constant gap voltage, the required power goes as $\sqrt{f}$ and the wall power density goes as $\sqrt{f^5}$ for exact geometry scaling.

To validate this, several cavity configurations, based on the original 65 MHz structure, were simulated with Superfish. Variants were included, such as varying the gap length and the ratio of the diameter of the inner line to the outer diameter for the otherwise half-scale cavity.

The following table lists some significant parameters with a constant 750 kV across the gap. The original cavity with 4 cm gap is duplicated at half scale with 2 cm gap, and 3 and 4 cm gap versions and a 4 cm gap version with larger center conductor are calculated.

Cavity	Frequency	Gap	Total Power	Peak E-field	Peak P_{wall}
	(MHz)	(cm)	(kW)	(MV/m)	(W/cm^2)
Original	65.5	4	62.6	27.6	6.95
half-scale	131.1	2	88.0	55.8	39.4
half, 3 cm gap	136.8	3	83.6	44.3	38.7
half, 4 cm gap	141.9	4	80.5	38.9	38.4
half, larger inner conductor	141.5	4	95.2	37.7	32.1

Caveats: the cavity has no beam tube, and the power is calculated for perfect copper with no additional losses. The real total power is expected to be 10-30% higher. This exercise is meant to show how some significant parameters scale with frequency and gap length for a constant gap voltage.

The peak wall power density becomes very large for the half-scale cavity and its variations.