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Extrapolation of the FOM 1MW Free Electron Maser to a Multi-Megawatt Millimeter Microwave Source

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Abstract

A Free Electron Maser is now under test at the FOM Institute (Rijnhuizen) Netherlands with the goal of producing 1MW long pulse to CW microwave output in the range 130GHz to 250GHz with wall plug efficiencies of 60%. An extrapolated version of this device is proposed, which would produce microwave power levels of up to 5MW CW. This would allow for practical applications in such diverse areas as space power beaming, heating of fusion plasmas and heating of high Mach number wind tunnels.

1. Introduction

The FOM Institute (Rijnhuizen) Netherlands has constructed and is beginning test of a Free Electron Maser with the goal of producing 1MW long pulse to CW microwave output in the range 130GHz to 250GHz with >60% wall plug efficiency. The key design features of this FEM [1] consist first of a conventional DC accelerator system at high voltage (2MV) which supplies only the unwanted beam interception current (<25mA) and a depressed collector supply at 250kV which provides the main power. The second key feature is the use of a low loss step corrugated waveguide circuit (HE mode) for broad band CW power handling and beam/RF separation. The basic FEM configuration is illustrated in Fig. 1. Since all key design features are applicable to much high powers, an analysis was done

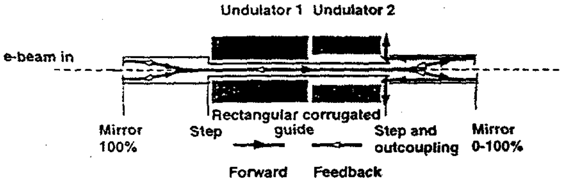

Fig. 1. Schematic of generic FEM interaction circuit showing step-tapered undulator, corrugated waveguide and stepped reflection/outcoupling system.

using the beam particle code described in [2] on how the microwave output depended on beam current up to 30 Amps. Fig. 2 illustrates that almost 5MW of output power could be achieved with this basic configuration. A multi-megawatt system is highly desirable since the cost per kW can be reduced as a result of the high voltage system costs increasing slowly compared with increases in microwave output. The technological

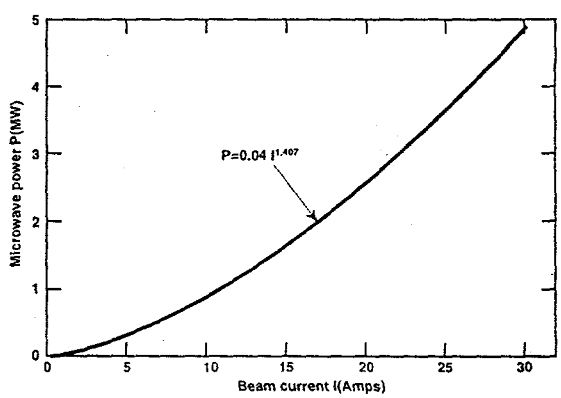

Fig. 2. Dependence of microwave output poweron beam current for FOM-FEM design.

problem of vacuum window barriers for multi-megawatt millimeter wave systems has also been recently overcome with the recent developments in synthetic diamond microwave windows.

The above considerations have led to develop a prototype for a multi-megawatt (4.7MW) FEM extrapolated from the 1MW FOM design.

2. Performance predictions for a multi-megawatt FEM prototype

The design parameters for a 4.7MW FEM prototype extrapolated from the FOM 1MW device are shown in Table 1.

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Table 1. Extrapolation of the FOM 1 MW device to a Multi-Megawatt Prototype.

FEM Parameters	FOM Device	Multi-Megawatt Prototype
Voltage (frequency)	1.75 MV	2.0 MV
Current	12 A	25 A
Output power	1.2 MW	4.7 MW
Wiggler period	4.0 cm	4.5 cm
Waveguide width	1.5 cm	1.75 cm
Waveguide height	2.0 cm	2.25 cm
Wiggler Field/N° periods 1	2.0 kG/20	2.3 kG/17
Wiggler Field/N° periods 2	1.6 kG/14	1.9 kG/11
Wall-Plug efficiency	60%	60%

A beamline design was generated using the same components as already exist for the FOM device except the 12 Amp, 80kV electron gun was replaced by a 25 Amp, 120 kV gun. Simulations using the Herrmann theory [3] are shown in Figure 3 indicating that 99.9% current transmission is possible.

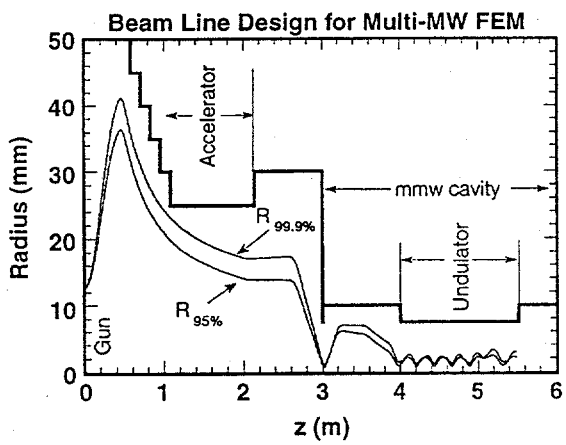

Fig. 3. Predicted radius versus distance for 99.9% and 95% abeam transmission in the 2 MV, 25 Amp beamline configuration. RMS beam emittance = 20 pi-mm-mrad.

Simulations of the FEM interaction using the 3D code described in [2] are shown in Figure 4 predicting operation between 137GHz and 242GHz with at least 4.4MW output by tuning the high voltage. Simulations were also performed using the multi-frequency code MALT [4]. Figure 5 shows that single frequency operation is achievable at 4.7MW output using the frequency dependent microwave system developed at FOM [5].

3. Conclusions and applications

The 1MW FOM-FEM now under test can in principle be extrapolated to an almost 5MW tunable millimeter wave microwave source in the range 135GHz to 250GHz. The original application has been to provide the fusion community with a versatile (tunable) cost effective source (<$2/watt) for heating magnetically confined plasmas. Another possible application air (thousands atm) in a wind tunnel in order to obtain up to Mach 15 flow. Finally, there is a renewed interest in space power beaming at 245 GHz to supply power to commercial satellites.

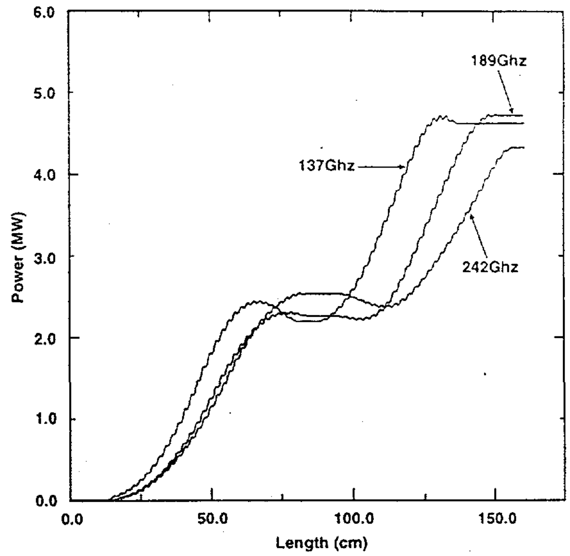

Fig. 4. FEM tunability. Power versus length for operation at 137 GHz (1.68 MV), 190 GHz (2.0 MV) and 242 GHz (2.3 MV). Output power is respectively 4.6 MW, 4.7 MW and 4.4 MW.

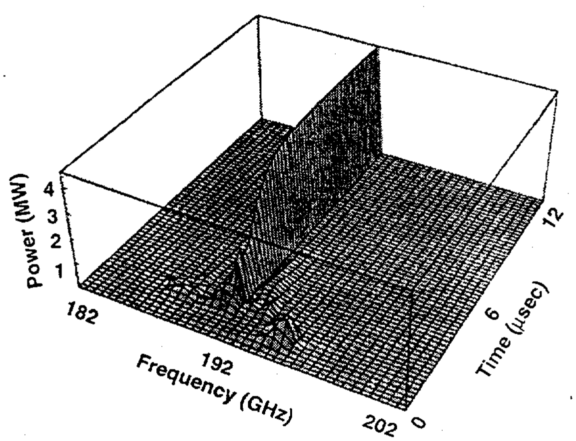

Fig. 5. Power spectrum versus time showing single mode output at 4.7 MW, voltage = 2.0 MV.

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