

Overview of HPM as a Pulsed Power Application at FOI

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Overview

- Introduction
- High-voltage generators
 - Explosive flux compression generators
 - Cable based high-voltage generator
 - Repetitive Marx generator
- Vircator studies
- System simulation and propagation models
- Summary

Introduction



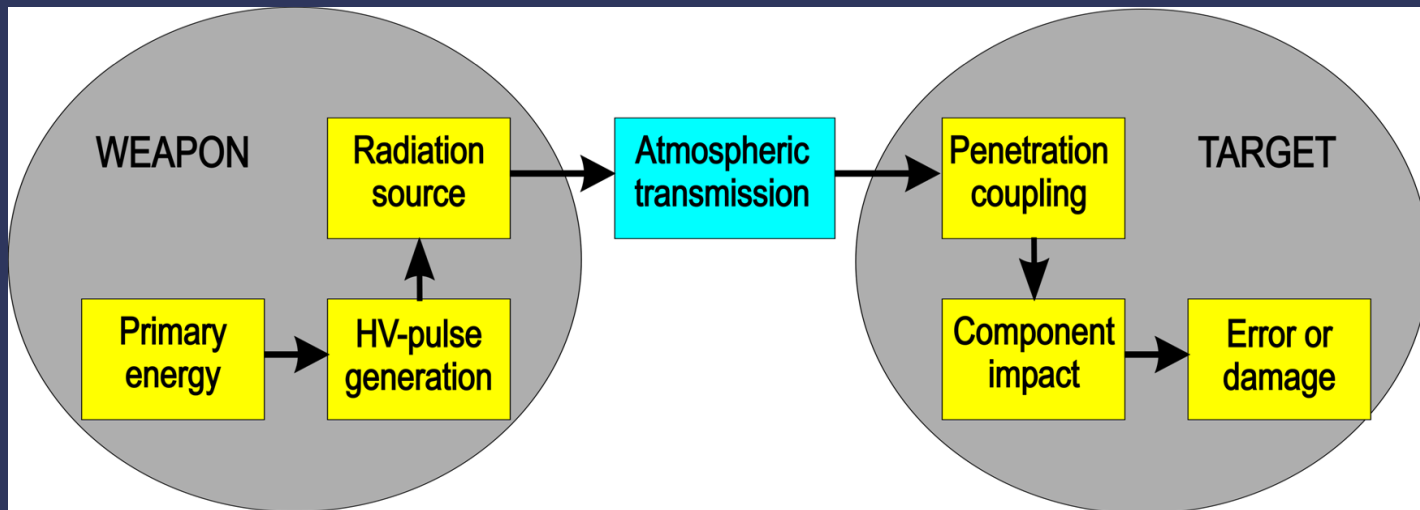
Swedish Defence Research Agency (FOI), Defence & Security, Systems and Technology
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Pulsed Power Applications at FOI

- HPM generation research
- Electro-Thermal Chemical launch techniques
- Electromagnetic launch techniques
- Electric armour
- Electrohydrodynamic flow control
- Plasma-assisted combustion

HPM research at FOI

- HPM-susceptibility and protection 1988-2008
- HPM-weapons technology 1993-2008
- Joint project "HPM" 2009-...

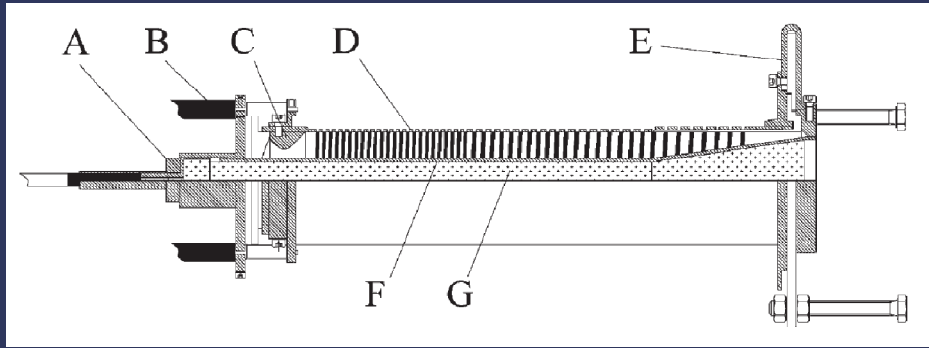


Issues considered in HPM source research

- Energy conversion efficiency
- Compactness for usage on mobile platforms
- Repetitive operation and durability
- Output pulse parameter tuning

High-voltage generators

Explosive flux compression generators

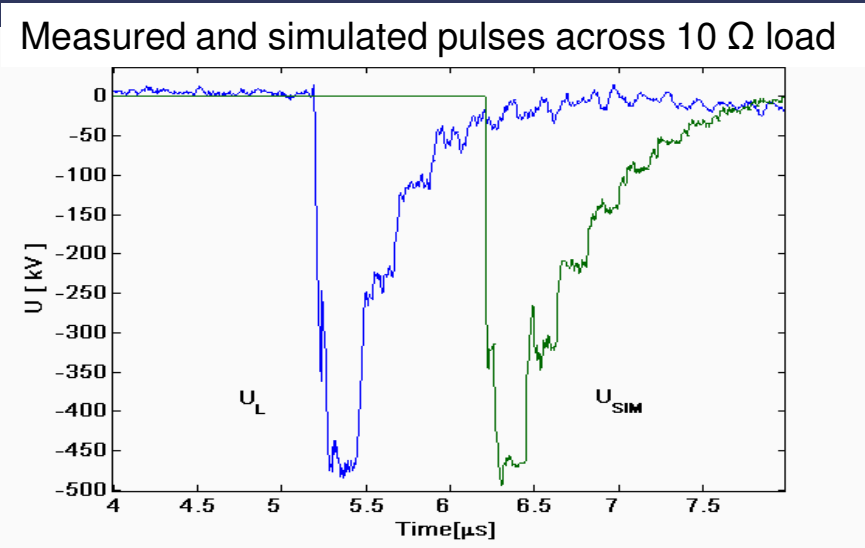
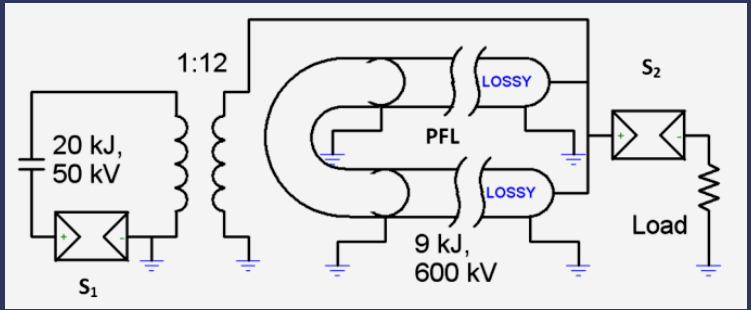
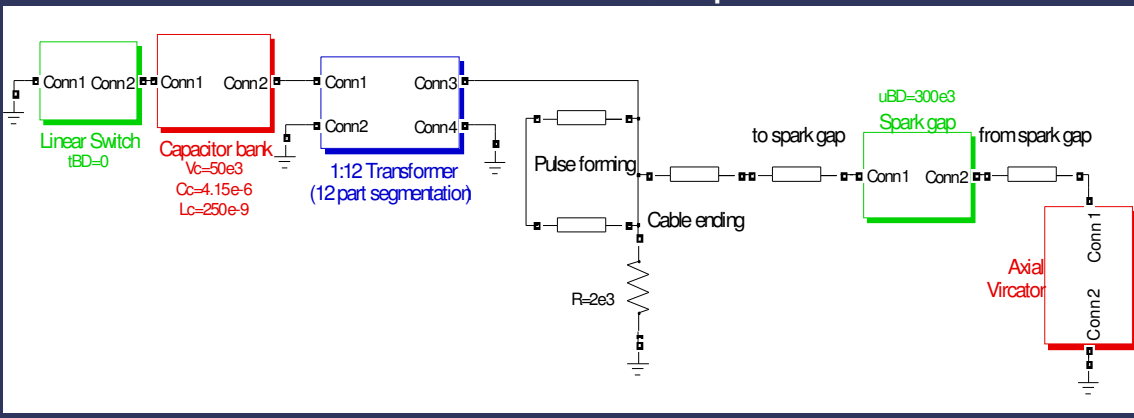
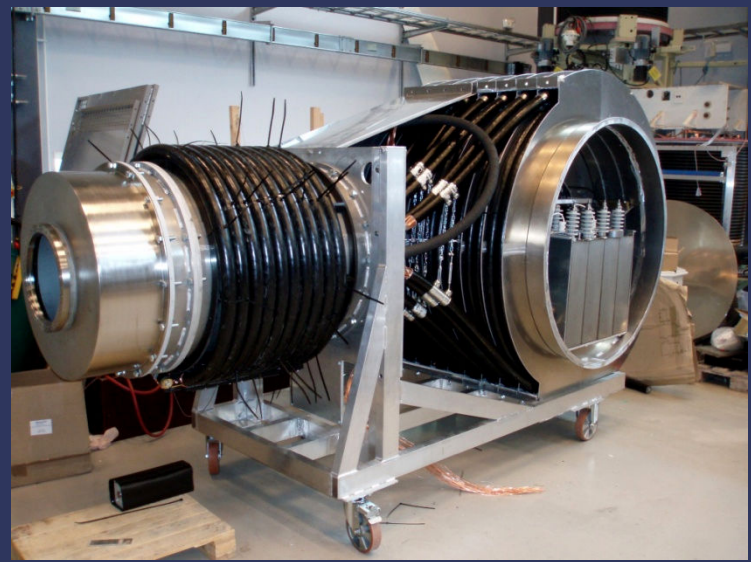


- length = 300 mm, diam = 70 mm
- $L_{\text{initial}} = 23 \mu\text{H}$, $L_{\text{final}} = 0,2 \mu\text{H}$
- Seed current 5.7 kA, 11.2 kA
- Peak current 269 kA, 436 kA
- Current amplification 47, 39

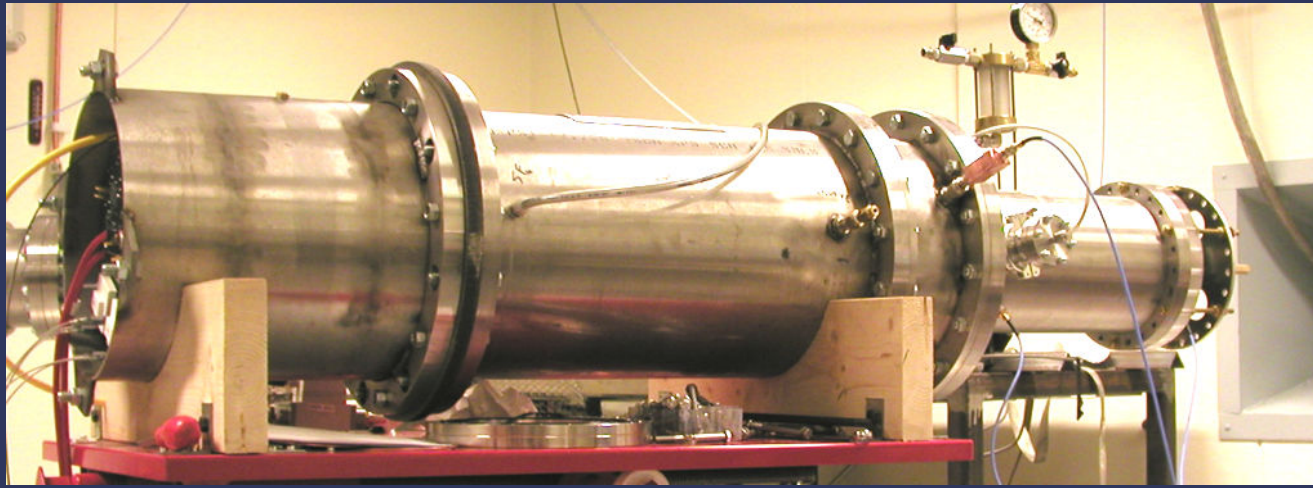


Cable based high-voltage generator

Simulink model, top level



Repetitive Marx generator

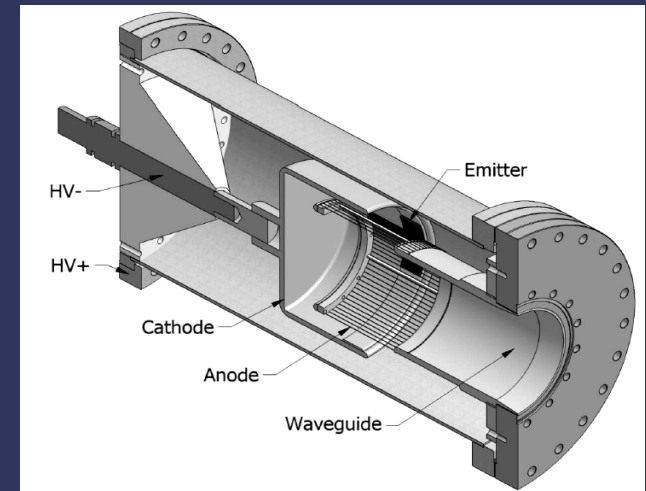
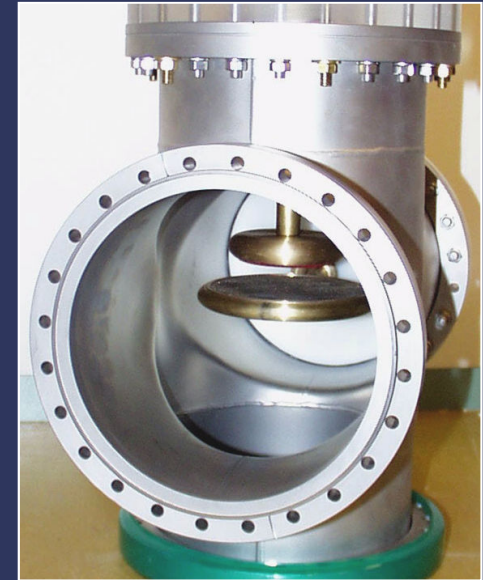


- 25 stages of 100 nF and 55 nH each
- length = 1.1 m (incl. charger), outer diameter = 0.3 m
- Characteristic impedance 18.5 Ω
- Repetition rate 10 Hz (burst mode)

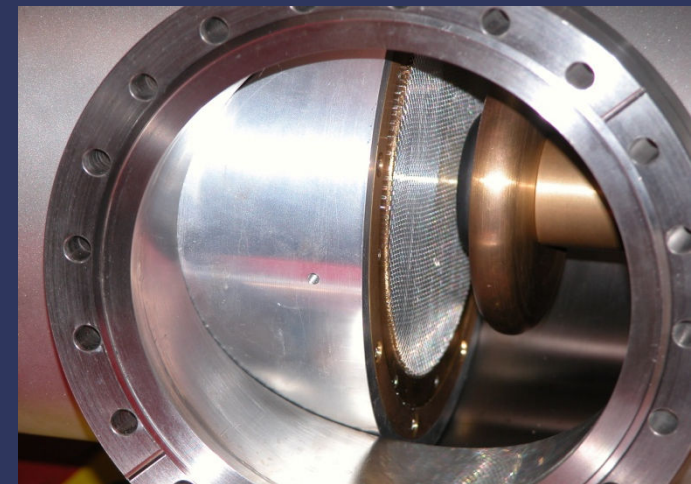
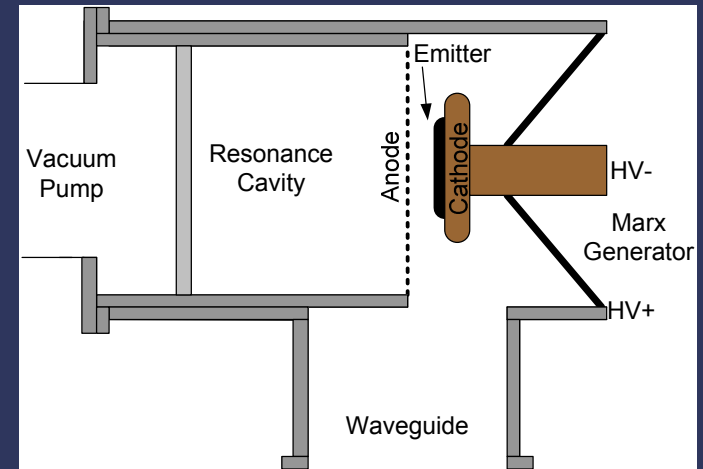
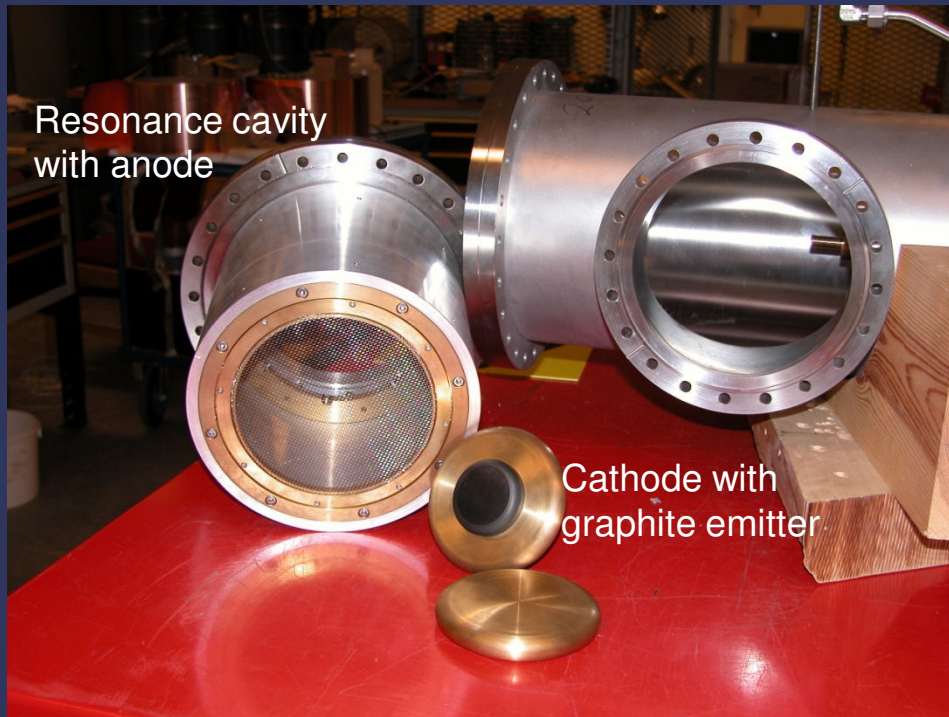
Vircator studies

Vircator studies

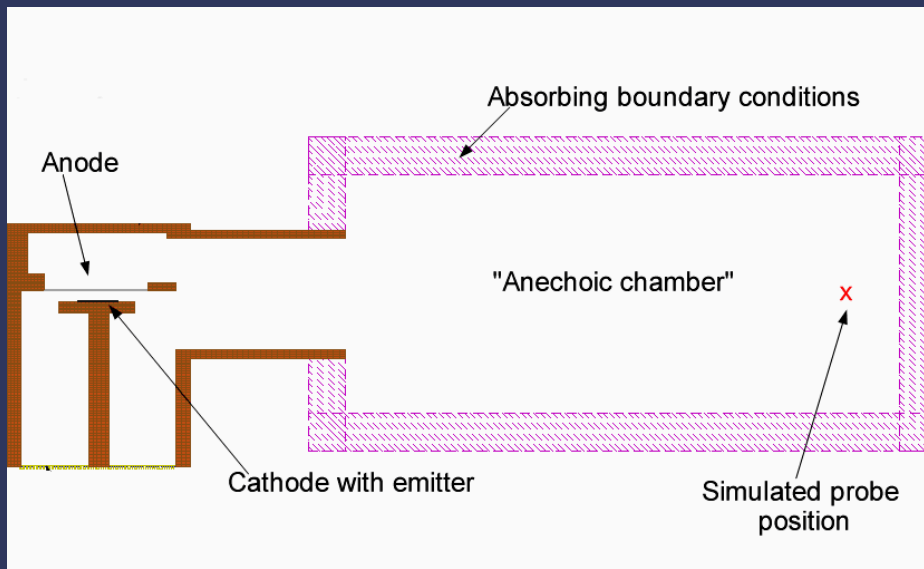
- ❖ Initial experiments with a reflex triode and single shot Marx generator.
- ❖ Axial vircator and repetitive Marx generator used in electrode material studies.
- ❖ Coaxial vircator and Marx generator used in radiation mode control experiments.



Axial vircator - experimental

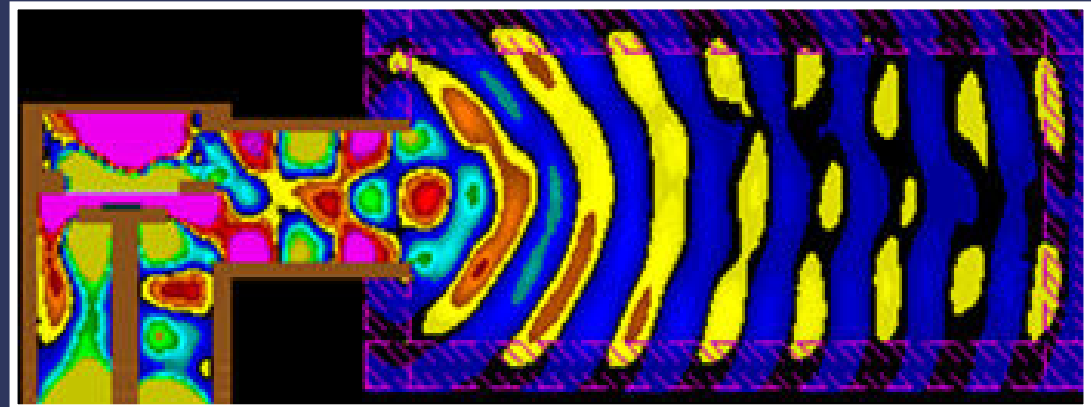


Axial vircator simulation in Magic

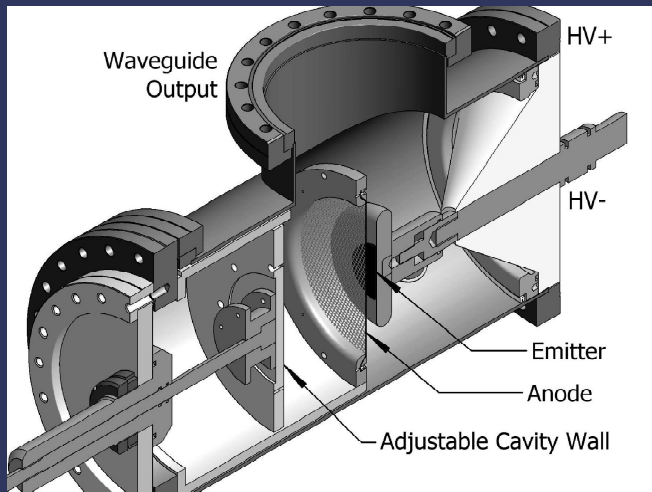


Simulation volume with small anechoic chamber representation

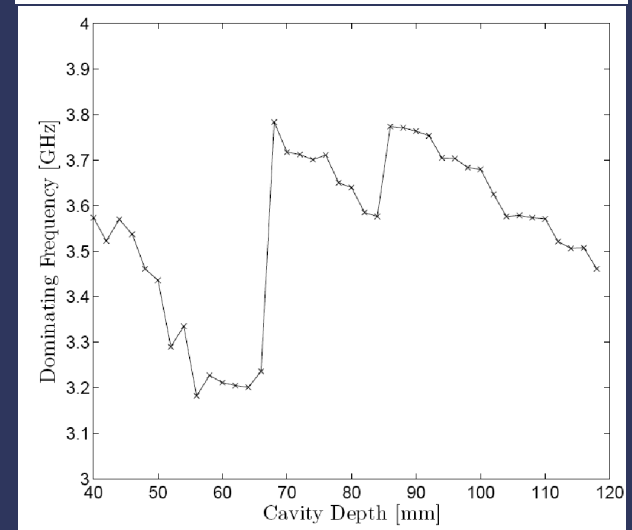
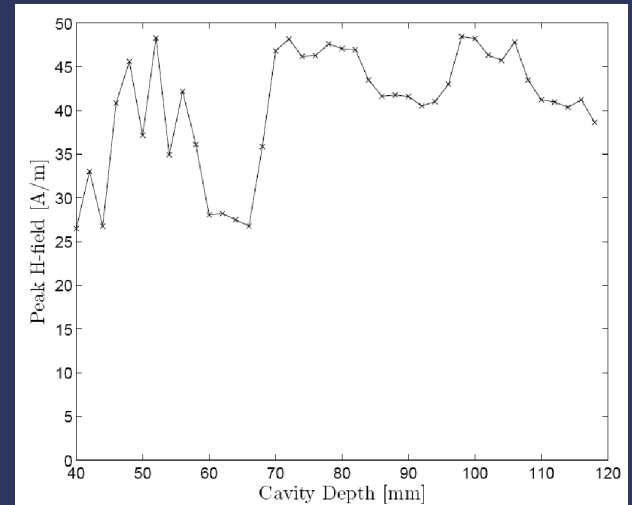
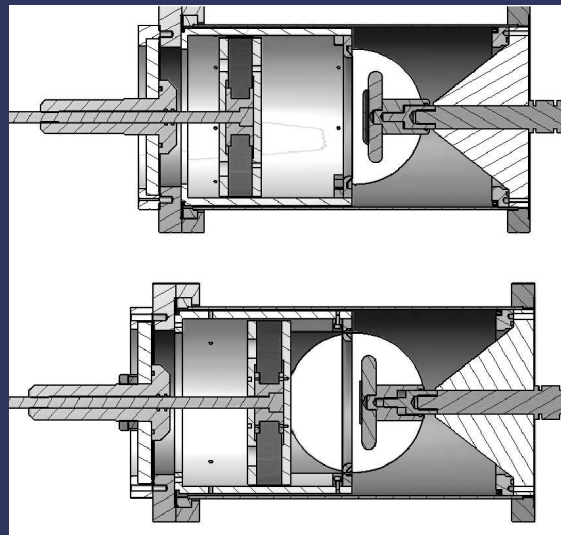
Simulated electric fields at one instant:
TE₂₁ dominant mode



Axial vircator geometries

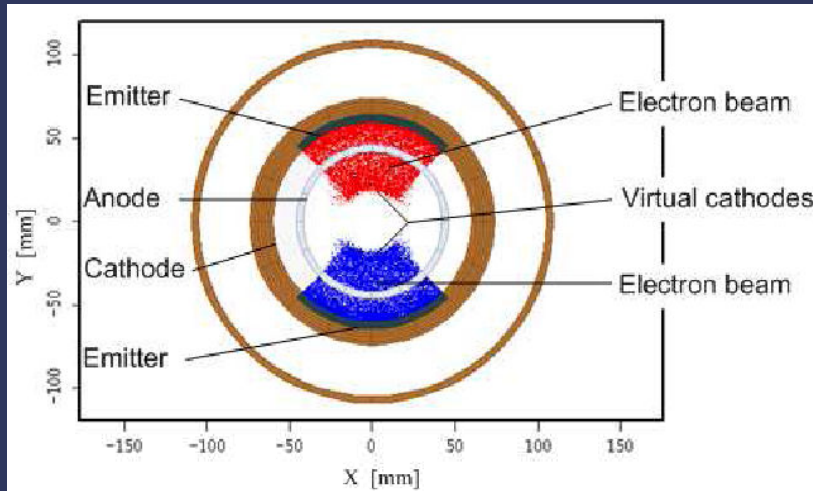


- Selectable output window towards waveguide.
- Cavity depth variation.



Coaxial vircator geometry

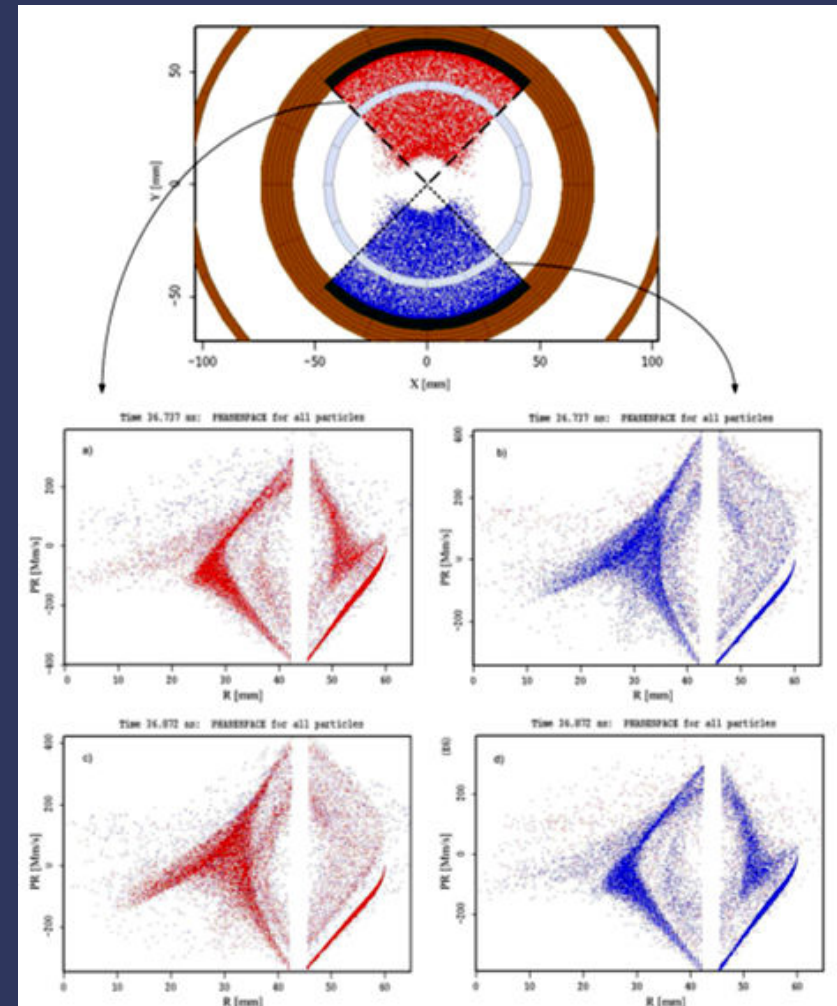
Coaxial vircator with sectioned emitter



Virtual cathodes oscillating in opposite phase

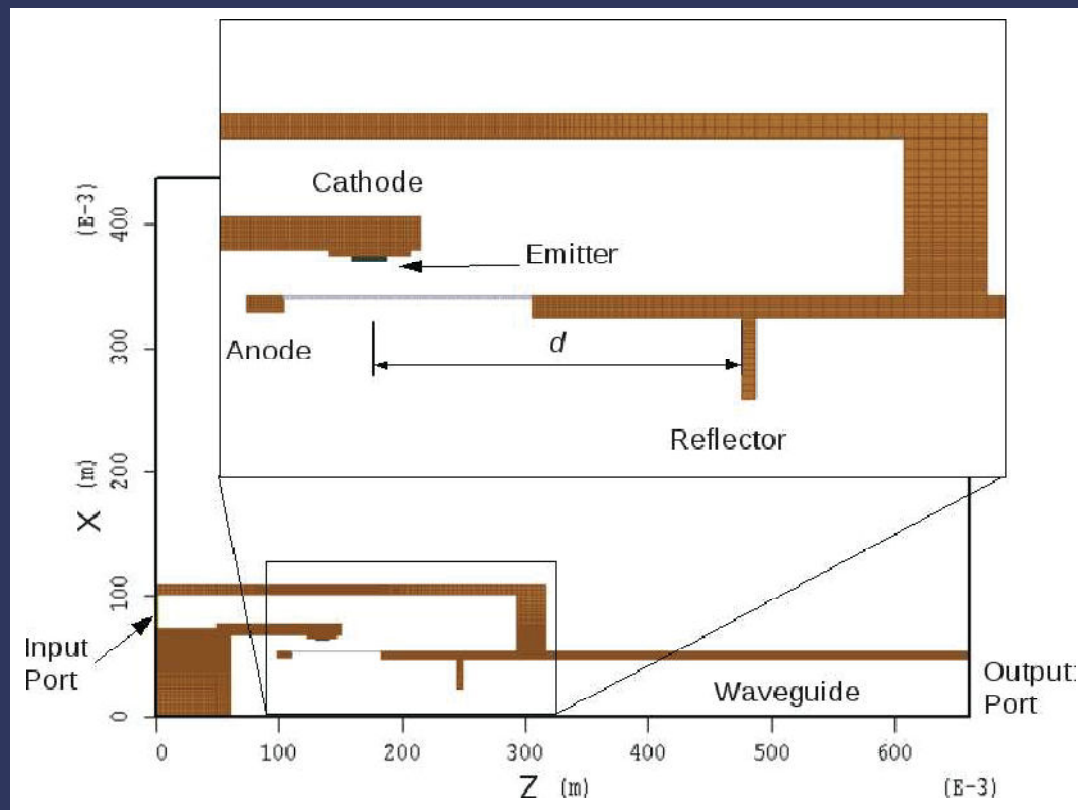
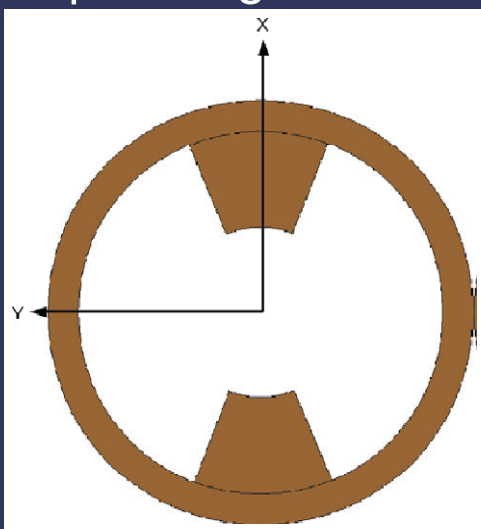
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Recently verified in experiments !



Waveguide reflector

Two-strip waveguide reflector



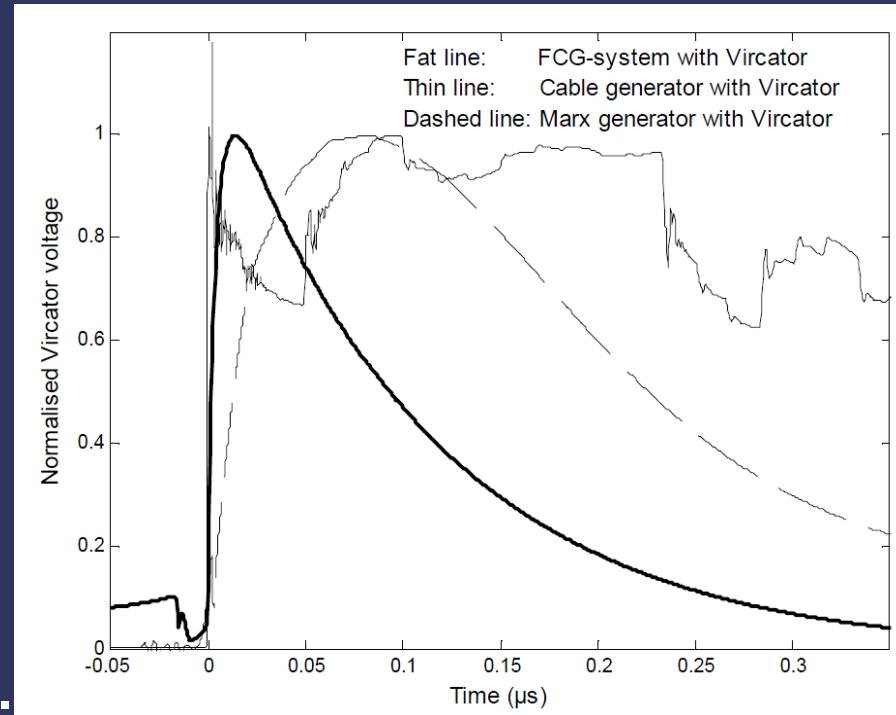
Simulations and experiments are performed this autumn.

System simulation and propagation models

Energy system simulation

Electric circuit simulation models of

- FCG system
 - Cable generator
 - Marx generator
- together with a vircator model for comparison of normalised voltage pulses.



Energy system model in Simulink

Energy sources

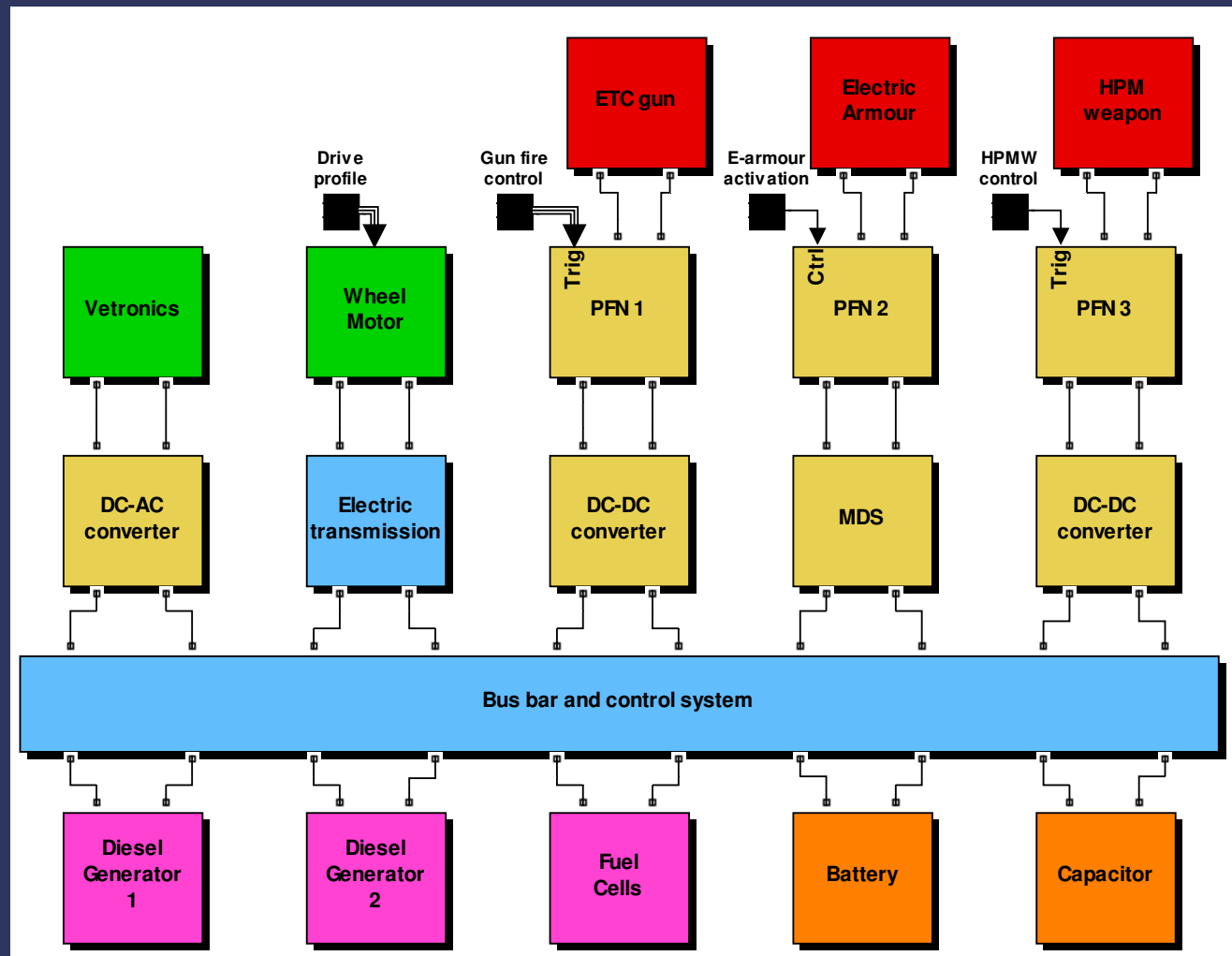
Intermediate storages

Transmission and control

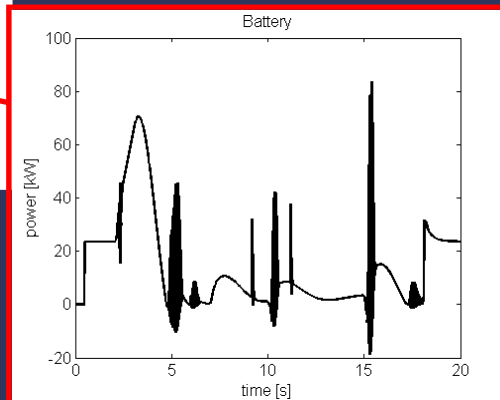
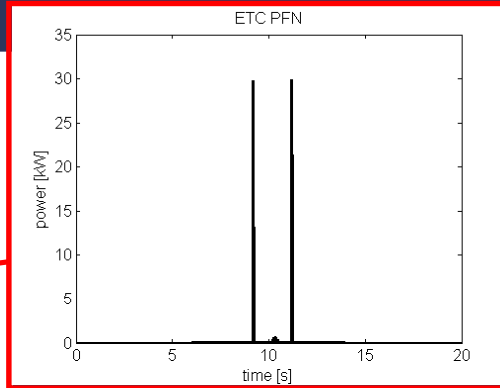
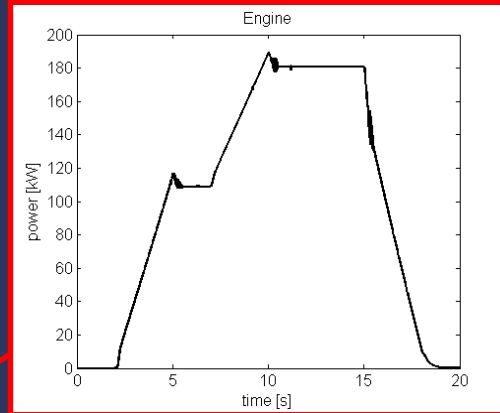
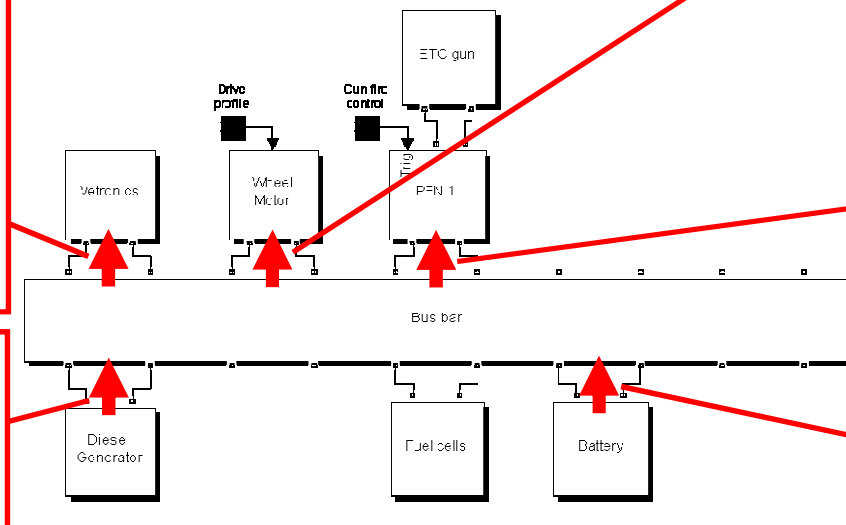
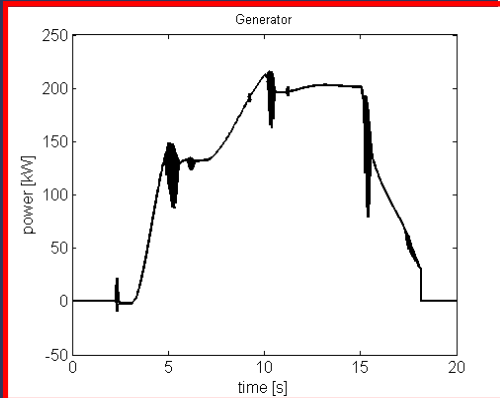
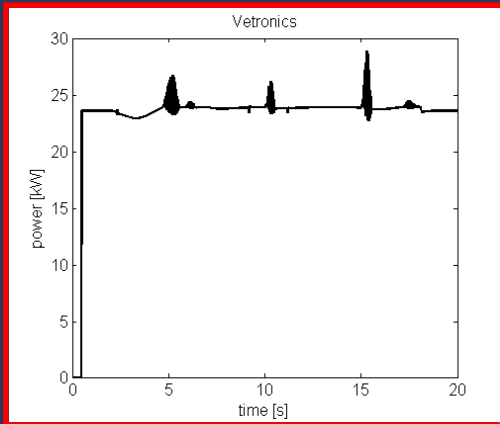
Adaptation units

Continuous consumers

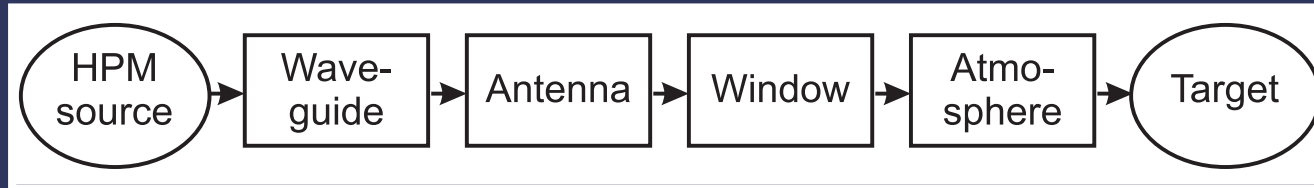
Pulsed consumers



Simulated power flows

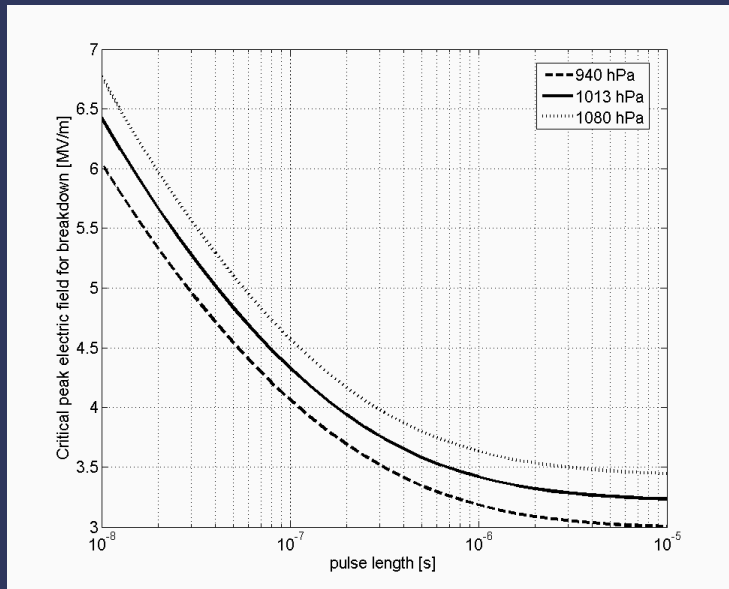


HPM pulse propagation



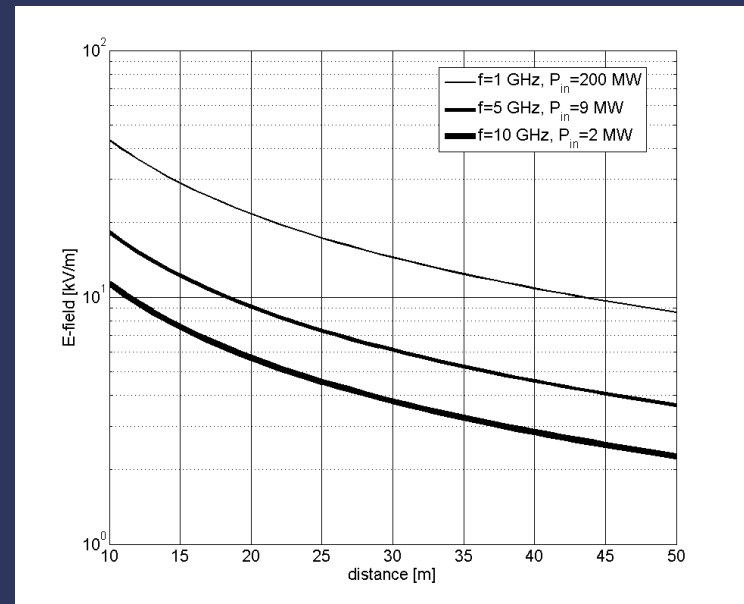
- Wave propagation and attenuation
- Microwave induced breakdown
- Energy loss due to absorption
- Energy loss due to pulse shortning

HPM pulse propagation



Critical electric field strength as function of the microwave pulse length for three atmospheric pressures

Electric field strength as function of distance for different systems



HPM pulse propagation

Energy budget calculation for a 1 GW, 1 μ s, TE01 HPM pulse injected in rectangular copper wave guide, without microwave breakdown, but with microwave power absorption in atmosphere, primarily due to heavy rain.

Radiation frequency	1 GHz	10 GHz
Energy input	1 kJ	1 kJ
Resistive losses in waveguide	0.4 J	13 J
Energy loss caused by microwave breakdown	0	0
Energy loss caused by rain ($r=100$ mm/h)	0.5 J	400 J
Energy loss caused by fog (visibility 30 m)	0.1 J	17 J
Energy loss caused by snow ($r=10$ mm/h)	0.2 J	1.7 J
Energy loss caused by ambient atmosphere	1.4 J	1.4 J

Summary



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Summary

- Studies of pulsed power supplies for HPM includes explosive flux compression, cable based pulse forming line generator, and repetitive Marx generator.
- The Marx generator has been used extensively in various vircator studies.
- The work focuses on means to improve the energy efficiency of HPM generation, compactness for mobile use, and on repetitive operation combined with dynamic parameter tuning.