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Simulation of an Industrial Magnetron Using Cathode Modulation

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Abstract

Magnetrons can be phase-locked using external systems. An experimental setup using Gated Field Emission Arrays for the modulated electron injection offers a potential solution to this problem by permitting the injection of electrons into the interaction space. Current work focusses on extending previous simulation results into 3-D. A commercially available industrial cooker magnetron (the L3 CWM-75kW) has been successfully simulated by using the 3-D PIC code VSim under the magnetron's typical operating conditions (18kV, 5A, 1900G, 896-929GHz). The simulation generated results that are consistent with known experimental results in terms of power and frequency.



Simulation of an Industrial Magnetron Using Cathode Modulation

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Introduction

- The magnetron is a highly efficient (~90%) microwave signal source.
- Due to the randomness in the phase of the magnetron generated signals, it remains unfeasible to arrange the magnetron in an array configuration, which severely limits the maximum output power that can be generated by using the magnetron as the signal source.
- Magnetrons can be phase-locked using external systems. Previous 2-D PIC simulations of a rising sun magnetron¹ have shown that phase-locking is possible using modulated electron injection to control the spoke formation. An experimental setup using Gated Field Emission Arrays (GFEAs) for the modulated electron injection offers a potential solution to this problem by permitting the injection of electrons into the interaction space.
- Simulations of magnetrons in 3-D is known to be very difficult, **the device usually fails to oscillate in the absence of RF priming**.
- Cathode modulation offers a preferable alternative to RF priming for starting up magnetron simulations. Cathode modulation also allows the control of the phase of the generated signal.
- This work presents simulation results of the effect of cathode modulation. Parallel work on the fabrication of the GFEA-based cathode and the experimental study of the effect of cathode modulation is currently ongoing.
- The simulation and the parallel experiments are based on the CWM-75kW commercial magnetron from L3 Technologies.

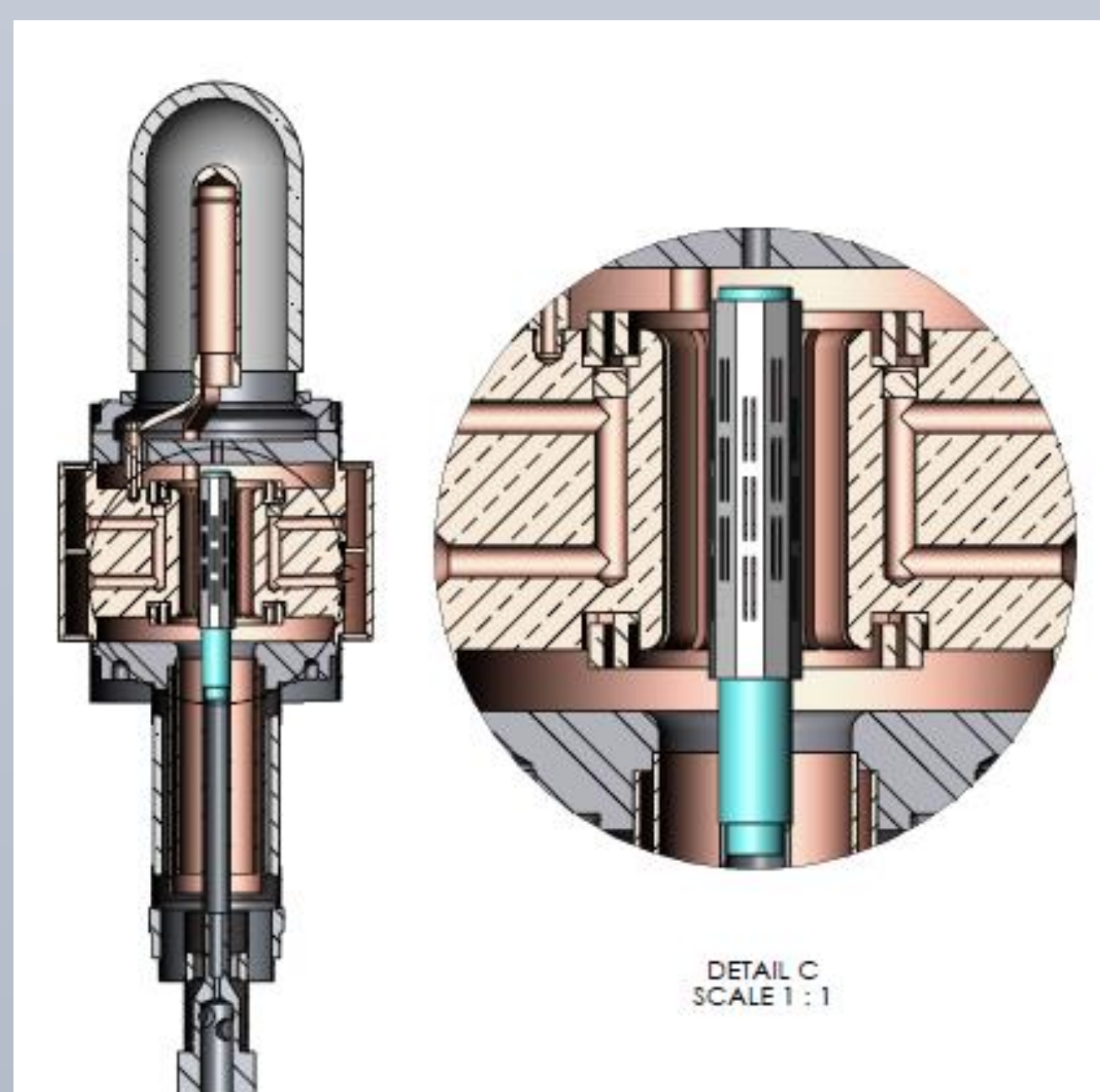
L3 Technologies CWM-75KW Magnetron

- The 10 Cavity strapped magnetron is capable of providing up to 75kW of continuous wave power.
- The original device uses a helix shaped thermionic cathode.
- The GFEA-based cathode has a 10-sided faceted geometry.
- The typical operating parameters are shown in the table below.

Typical Operating Parameters

| Magnetron | Cathode Voltage | Current | Magnetic Field | Frequency |
|------------------|-----------------|---------|----------------|-------------|
| Typical CWM-75KW | -18 kV | 4.75 A | 1800 G | 896-929 MHz |

L3 Magnetron with GFEA-Based Cathode



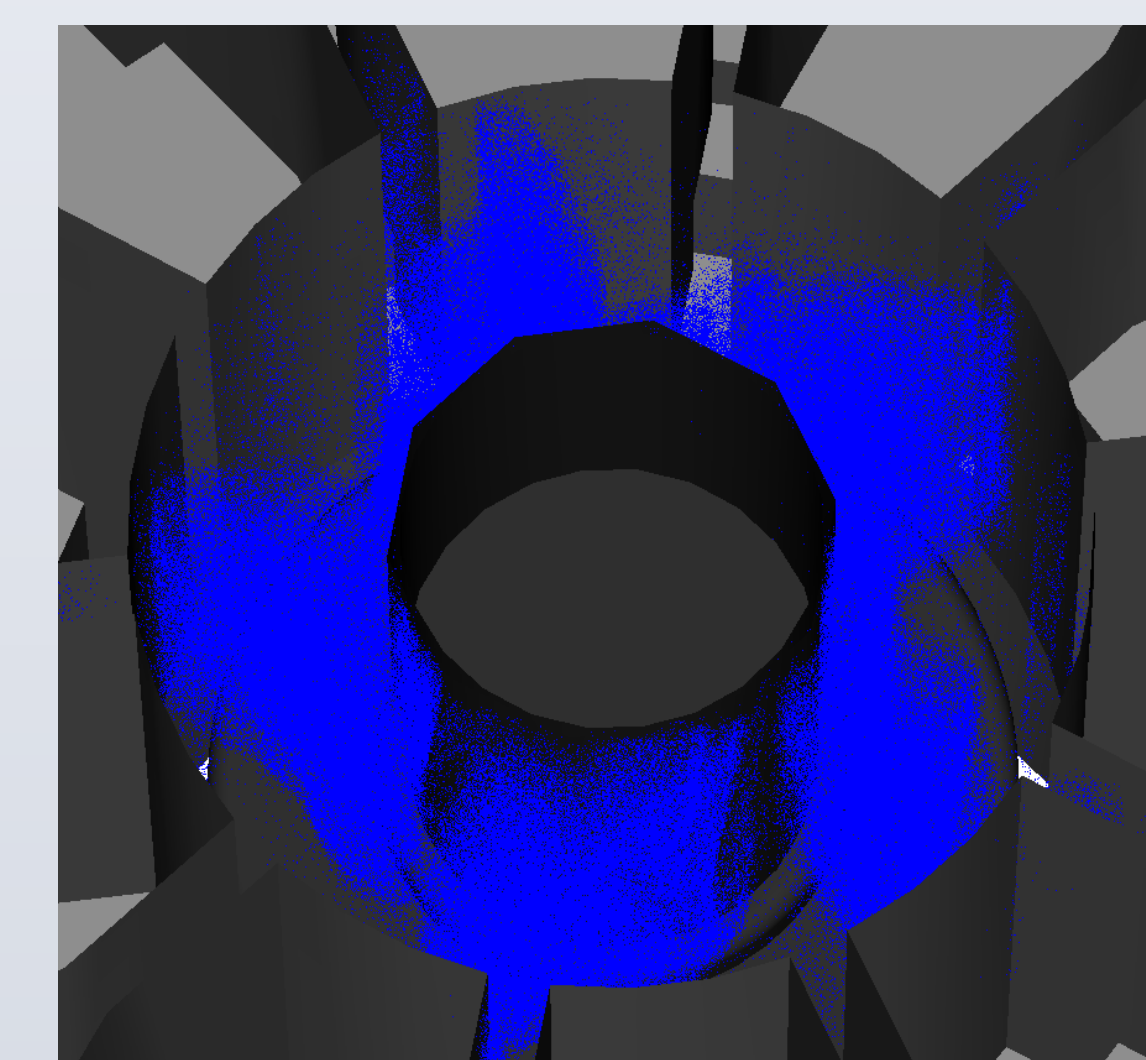
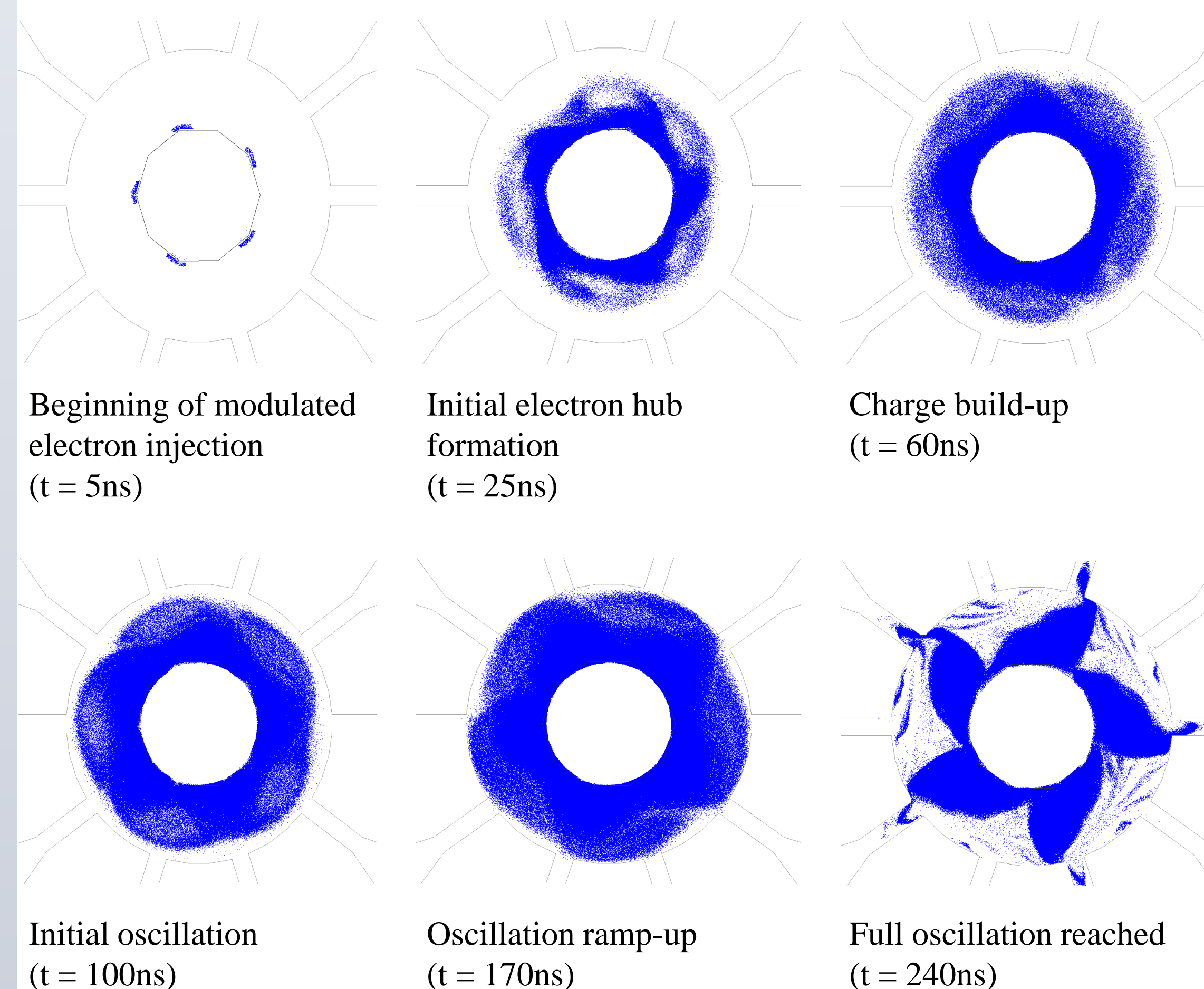
Simulation Setup

- The simulated magnetron geometry is a one-to-one CAD reconstruction of the physical device based on SolidWorks drawings provided by L3 Technologies.
- The magnetron was simulated by using the 3-D Particle-In-Cell code VSim.
- The 10-sided faceted cathode geometry was used in the simulation
- Typical operating parameters of the magnetron was used for the simulation other than the magnetic field was tuned to 2000G and the cathode was modulated at 904MHz.

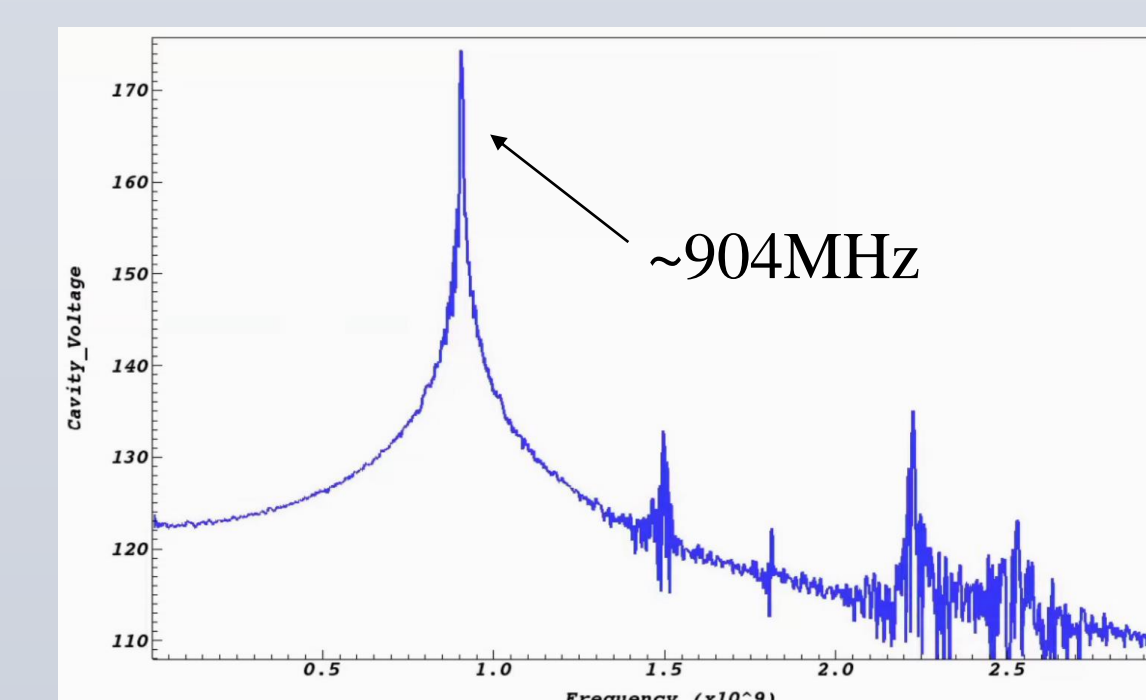
Simulation Results

- The simulated magnetron began oscillating under 100ns without any RF priming and reached full oscillation at about 240ns.
- Under full oscillation, the output signal reached a RMS power level of ~75kW, which is consistent with expectation.
- Under full oscillation, the cathode back-bombardment current is dramatically reduced
- The frequency of the oscillation matches the modulation frequency of the cathode

Cross-sectional View of Electron Distributions

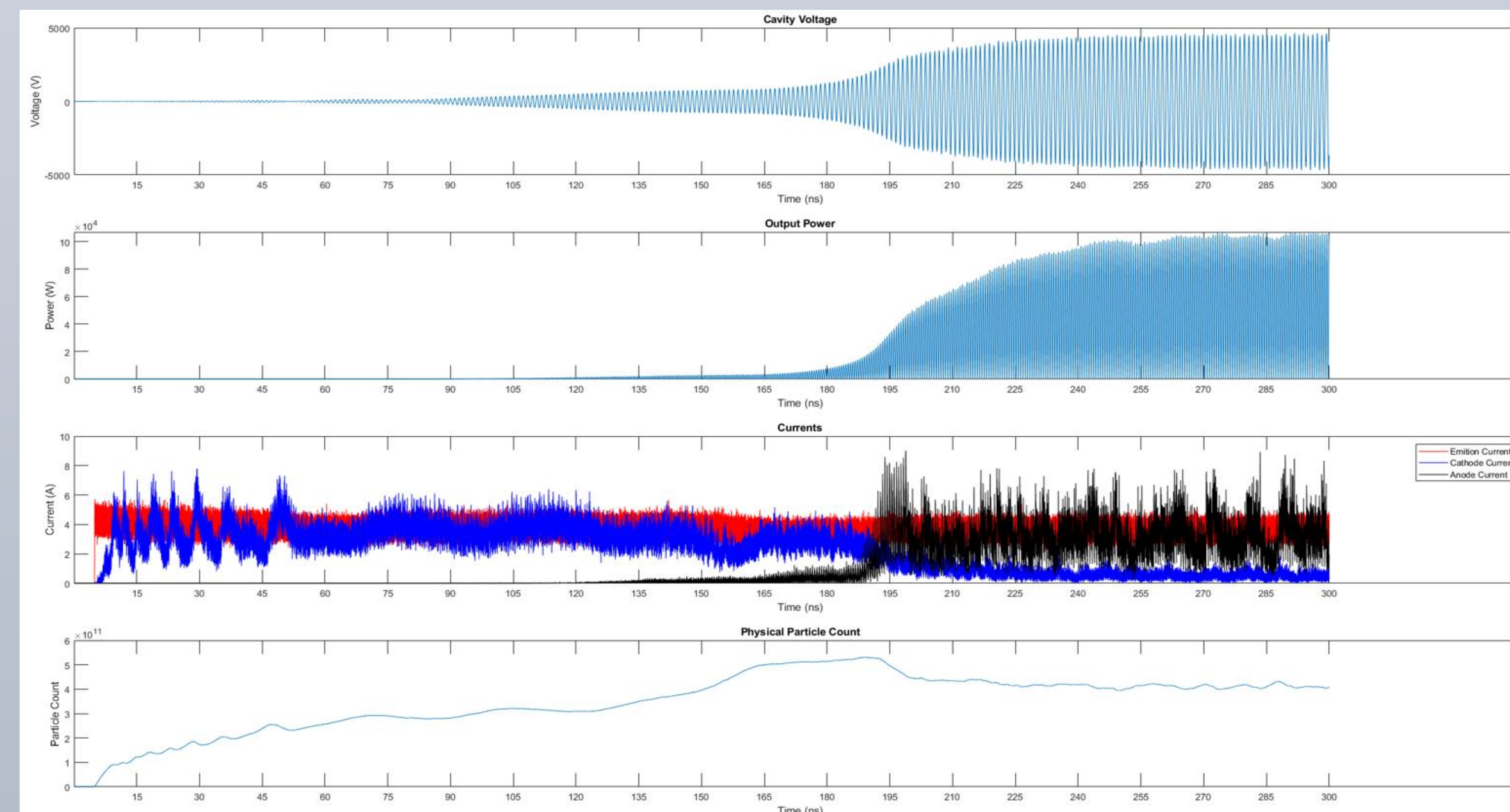


3-D view of the magnetron in full oscillation (t = 250ns)



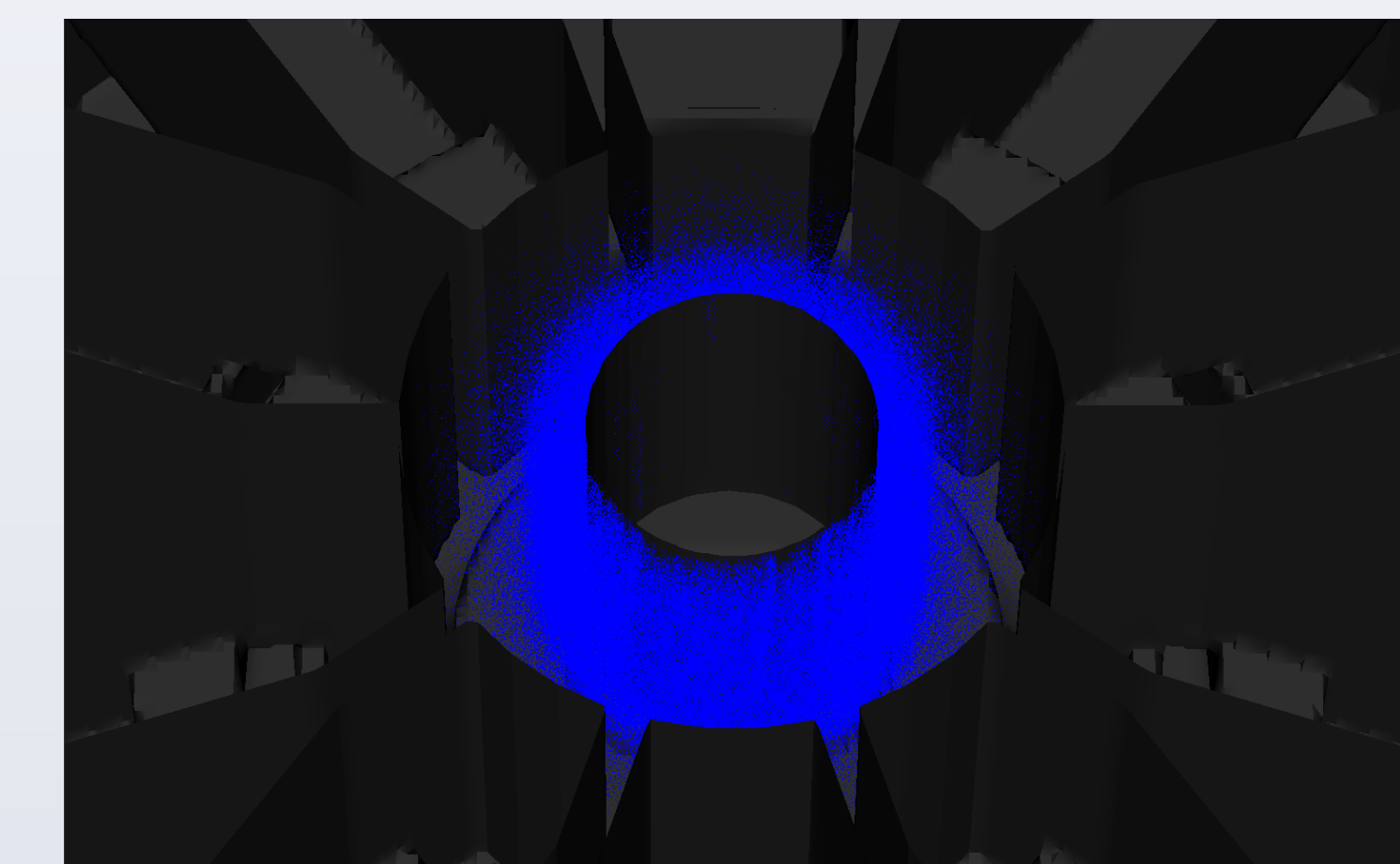
FFT of the cavity voltage

Plots of Key Parameters



Prior Results

- Previous simulations have shown that the magnetron fails to oscillate without any RF priming or cathode modulation, as shown below (t = 350ns):



- Uniform thermionic electron injections from cylindrical cathodes lead to serious electron back-bombardment issues which prevent the electrons from reaching the anode.
- Previous simulations have also shown that it requires 500kA of RF priming current between the cavities for 20ns to start oscillation within 100ns.

Conclusion

- This work has demonstrated cathode modulation is a feasible alternative to RF priming in the start-up process of magnetron simulations.
- Unlike RF priming, which serves only as a simulation technique, cathode modulation can be physically implemented in an actual device, which opens up a highly promising way to phase-lock magnetrons.

Future Work

- Collaborators from L3 Technologies have experimentally shown that the CWM-75kW is capable of operating at low power with the following set of parameters.

Low-power Operating Parameters

| Magnetron | Cathode Voltage | Current | Magnetic Field | Frequency |
|--------------------|-----------------|---------|----------------|-----------|
| Low-power CWM-75KW | -8.3 kV | 150 mA | 900 G | 909 MHz |

- Future work will focus on the simulation of the magnetron under low-voltage, low-current conditions to study the feasibility of experimentally testing the magnetron using GFEA-based cathodes.
- Future work will also investigate the effect of arranging multiple magnetrons with GFEA-based cathodes in array formations

Reference

- S. Fernandez-Gutierrez, J. Browning, M. Lin, D. N. Smith, and J. Watrous. "Phase-Control of a Rising Sun Magnetron Using a Modulated, Addressable, Current Source." Journal of Vacuum Science & Technology, vol. B 33, pp. 031203. 2015.

Acknowledgements

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