

## Simulation of an Injection-Locked Relativistic Klystron Oscillator

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### Abstract

The Relativistic Klystron (RK) geometry has been extensively studied to create modulated Intense Relativistic Electron Beams (IREB) for production of High Power Microwaves (HPM) and driver beams for some accelerator schemes. Recently, a new variation of the Relativistic Klystron Oscillator (RKO) has been investigated by the U.S. Air Force Research Laboratory (AFRL) wherein an IREB is placed in a RK geometry with the driver and booster cavities close enough to couple together electromagnetically {see figure}. This coupling provides feedback which allows the system to oscillate even after the external drive has been shut off. Thus, the device operates in an injection-locked mode. These oscillations occur without reflected particles. The feedback is solely electromagnetic.

Computational research of HPM sources at AFRL is committed to developing design tools and techniques that accurately predict quantitative performance of sources before the experimental devices are built. This mission is all the more important in the current era of fiscal instability. One step in developing these tools is simulation of existing experiments and comparison with observed data. This work focuses on two-dimension Particle-In-Cell (PIC) simulation of the RKO with the MAGIC code. The device is split up into three regions: the cathode, the interaction circuit, and the extractor. Each piece is then compared against experimental evidence. We will note the agreement of the simulations with data and note issues that are raised in the comparison. The resulting understanding furthers the long term goal of this project which is end-to-end simulation of the RKO in three dimensions.

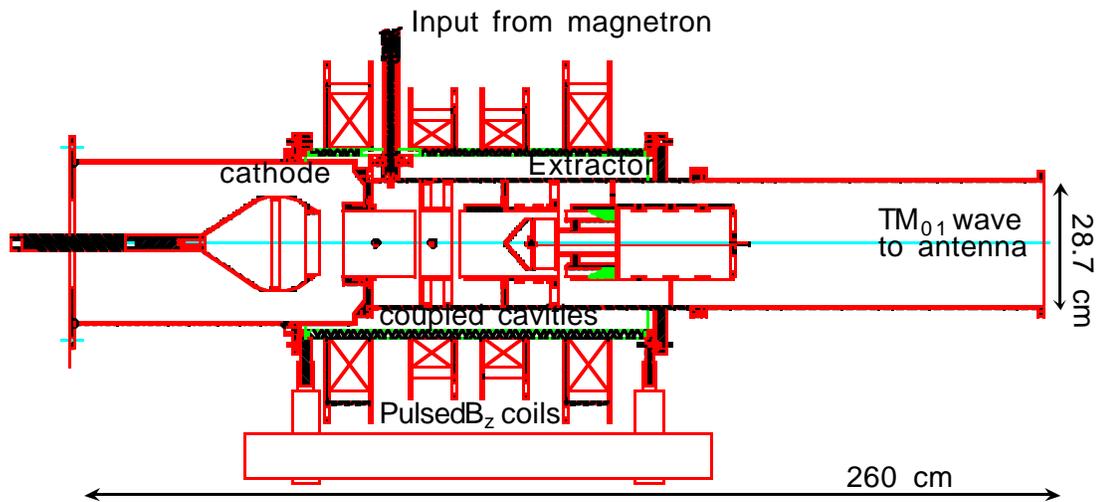
The cathode simulations focus on the current level and beam position as a function of emission region. The desired profile is a 10+ kA, 500 kV, 5mm wide beam placed 5mm from the interaction cavity. The voltage is applied over a 4 ns ramp and then held constant. The simulation is then evolved to a steady state. Excellent results are achieved for two cathode configurations (agreement within 5% of experimental values). The emission current, however, shows dependence on the aspect ratios of the grid cells. Surprisingly, the best case is not 1:1 ratios, or square cells. The excellent agreement only holds for certain aspect ratios, but the same ratio "works" for both configurations of cathode. A new cathode design resulting from simulation is currently being built and will be tested in the near future.

The next set of simulations focus on the interaction circuit. The cavities are individually tuned to 1.269 GHz. The cavities are then moved relative to each other to produce a +/- 7 MHz split due to cavity coupling. This point occurs within 2.5% of the experimental axial position of the cavities. The desired operating regime of the injection-locked RKO is a strong function of the cavity quality factor Q. This requires the cavity to use a resistive wall model, as the geometrical losses do not account for the total Q. A cold tube Q=200 in the simulation produces gap voltages within 7.5% of the experimental value (120kV on the first gap, 280kV on the second gap). The rf production is quenched with a cold Q=100. The gap voltages produce virtual cathodes at Q=400, resulting in severe mode competition. This dependence on Q agrees with the trends predicted from theory. It should be noted, however, that the experimental cold tube Q > 400. This discrepancy is unexplained, but possible reasons include slight differences in the geometry, improper accounting of the reactive component in the resistive wall model, or improper interaction of the lossy walls with the beam-induced loading. Despite these issues, simulation shows electromagnetic feedback can produce rf radiation in an RKO geometry without reflected particles.

The extractor simulations focus on the transition from co-axial tube to waveguide. The extractor is an inherently three-dimension structure with radial return-current posts. Thus, two-dimensional simulations can only give a qualitative picture of the operation. Despite this fact, the simulations accurately predict the impedance mismatch in the transition region. Three-dimensional simulation of the extractor has been initiated to complete the analysis.

Overall, two-dimensional simulation has proven reasonably successful in quantitative simulation of the AFRL/RKO. Future work focuses on understanding the unexplained issues raised in these studies. Resolution of these questions will be incorporated into three-dimensional, end-to-end simulations with AFRL's parallel PIC code ICEPIC.

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U.S. Air Force Research Laboratory's Injection-Locked Relativistic Klystron Oscillator