Scaled Experimental Studies on Radio Frequency Sources for Megawatt-Class Ionospheric Heaters

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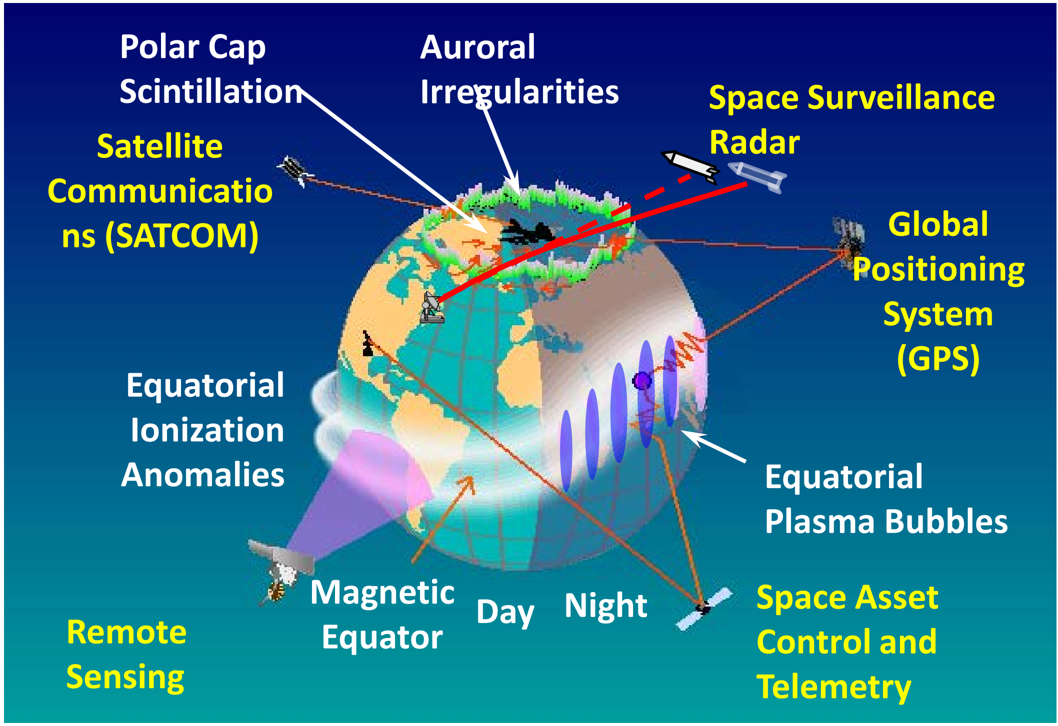
Ionospheric Modification (IM) Using HF Heaters

The Need for Transportable Heaters

- The ionosphere controls the performance of critical DoD and civilian communications and navigation systems
- IM research has identified new processes
- **Transportable Heaters** will provide:
  1. Research capabilities to explore latitudes different than high latitudes currently explored
  2. Proximity to relevant application sites



AFOSR MURI

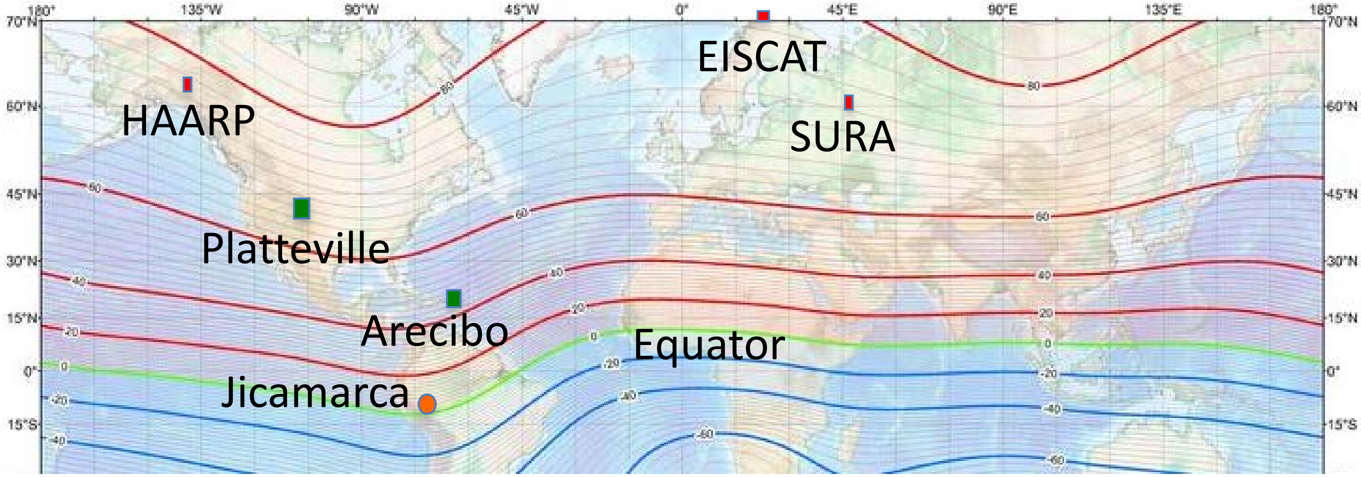
UMCP, Texas Tech, UCLA

Why Transportable?

- Past IM experiments, conducted at high latitudes indicated strong dependence of ionospheric processes on geomagnetic latitude.

- Transportable heaters will allow for the first time a quantitative exploration of the IM requirements vs. geomagnetic latitude without expensive ground installations.

- Proximity to application sites is a significant advantage (reduced ERP)



Technological Challenge – Transportable Heater

1/20

<u>HAARP size 300 m by 400 m</u>

<u>Array size 110 m by 70 m</u>

Requires ~16 MW to match *HAARP Effective Radiated Power

<u>Issues:</u>

- Frequency Tuning, f = 3 - 10 MHz
- Power consumption/Efficiency
- Antenna efficiency
- Polarization control

High Power High Efficiency Vacuum Electronic Source
R&D Program at the University of Maryland

- Operate in class D mode to maximize efficiency and makes the device compact
  - Beam current and voltage pulses are square
  - “On” phase $< \pi/2$
- Replace grid with modulation anode
  - No grid interception
- Develop solid state driver circuitry
- Design low loss extraction circuit

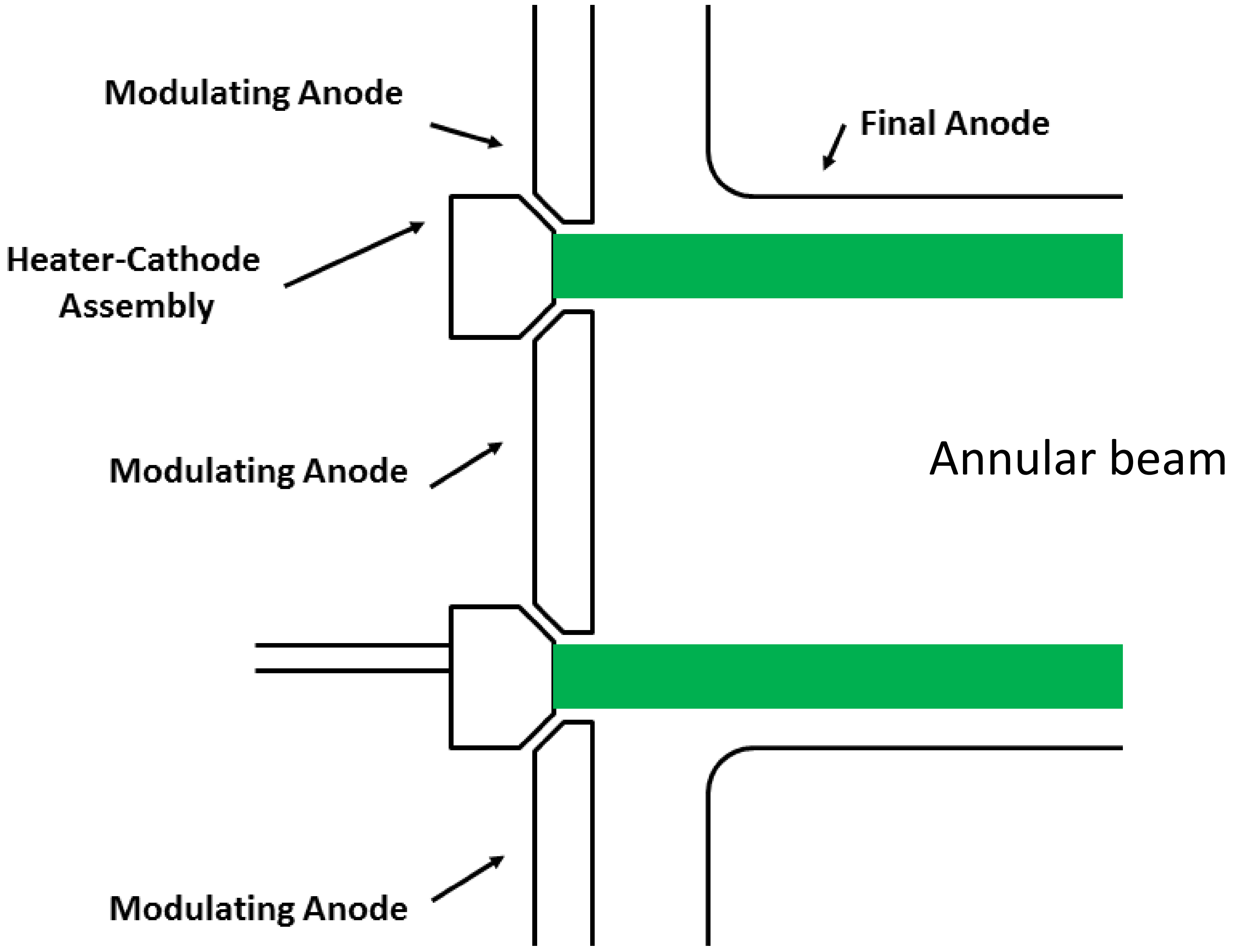
Progress this year

1. MW-Level design and optimization of gun/interaction space/collector/including secondaries

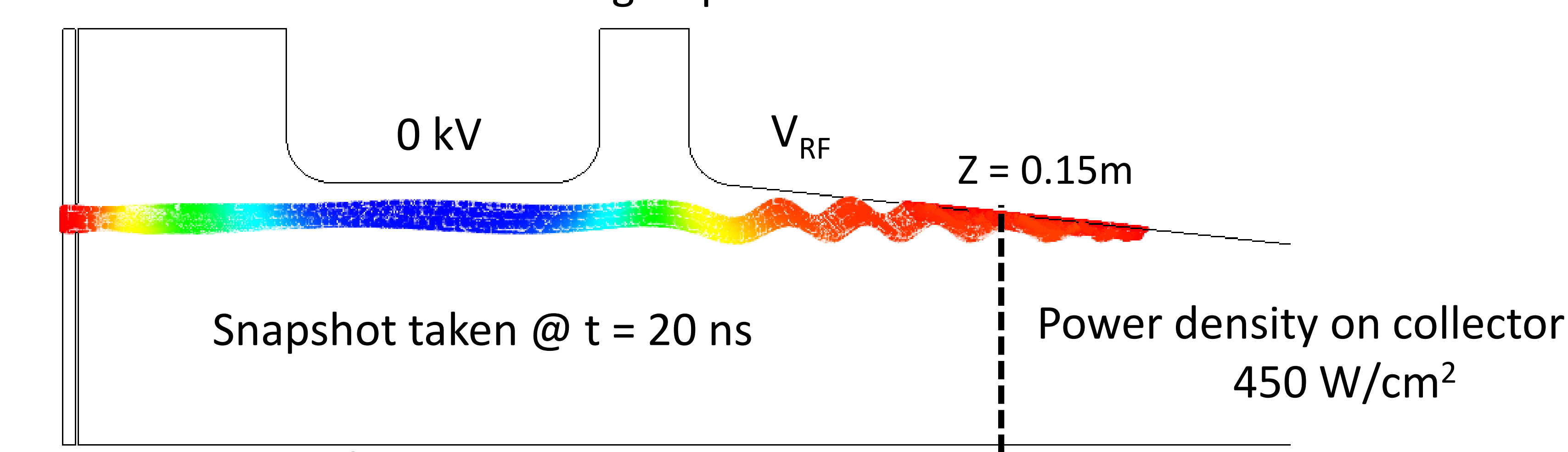
2. Optimization of extraction circuit (pi-circuit)

3. Experiments on low voltage electron gun at NRL at a fixed frequency to explore the efficiency limitations of the pi-circuit (located now at UMD)

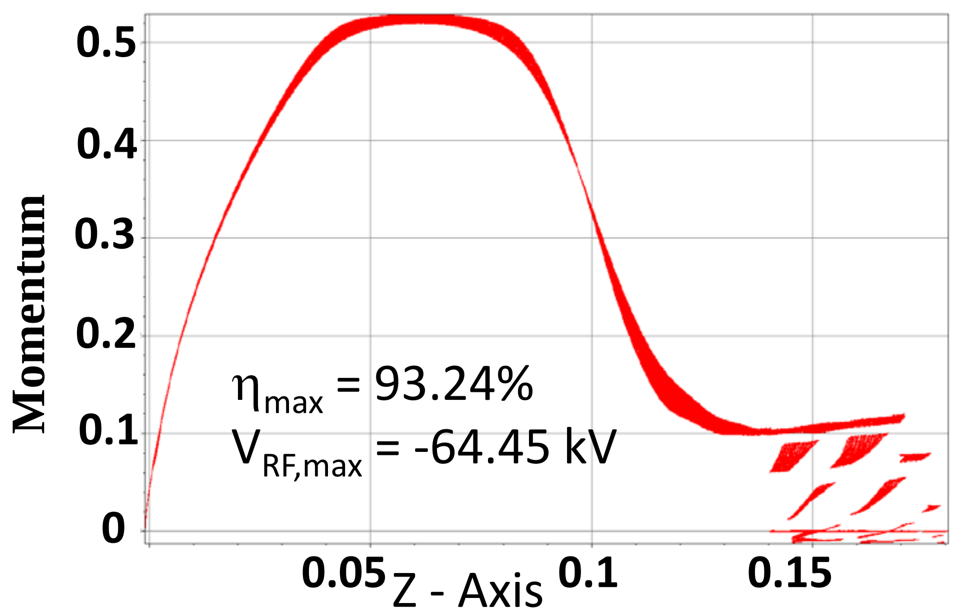
Mod-Anode Electron Gun Schematic

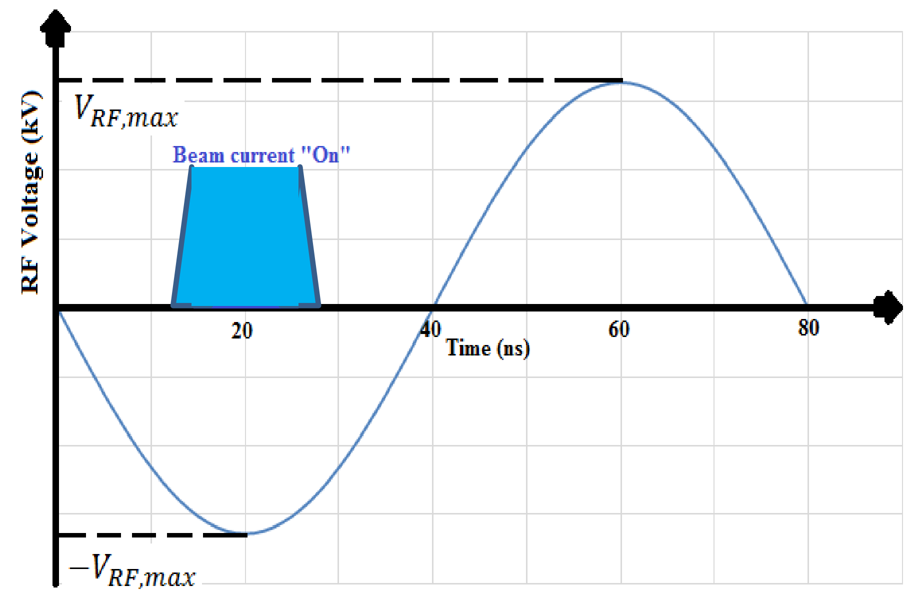


Electron Beam Trajectories for 1st Generation Model



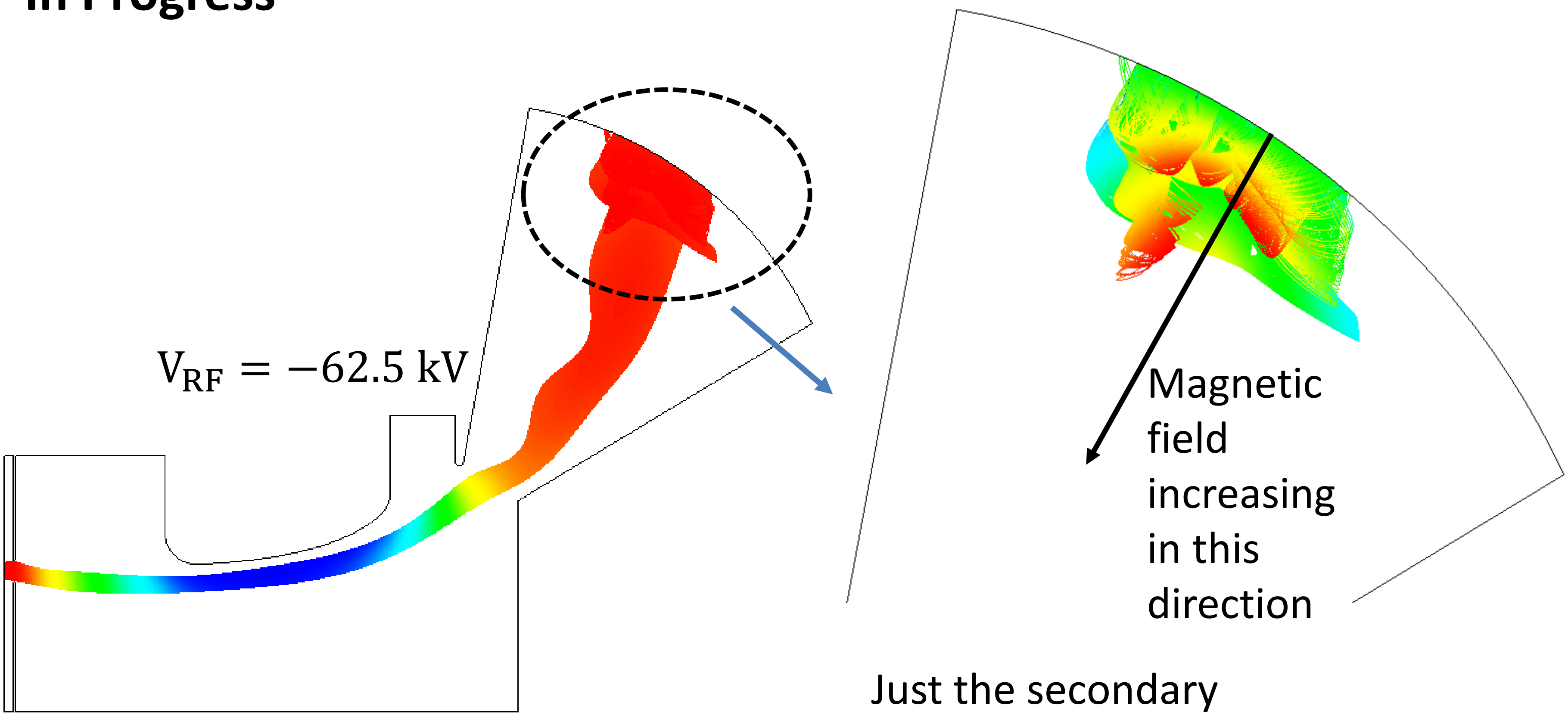
Uniform Magnetic Field





Static Simulation for a 2nd Generation Model with Solenoidal Field

In Progress

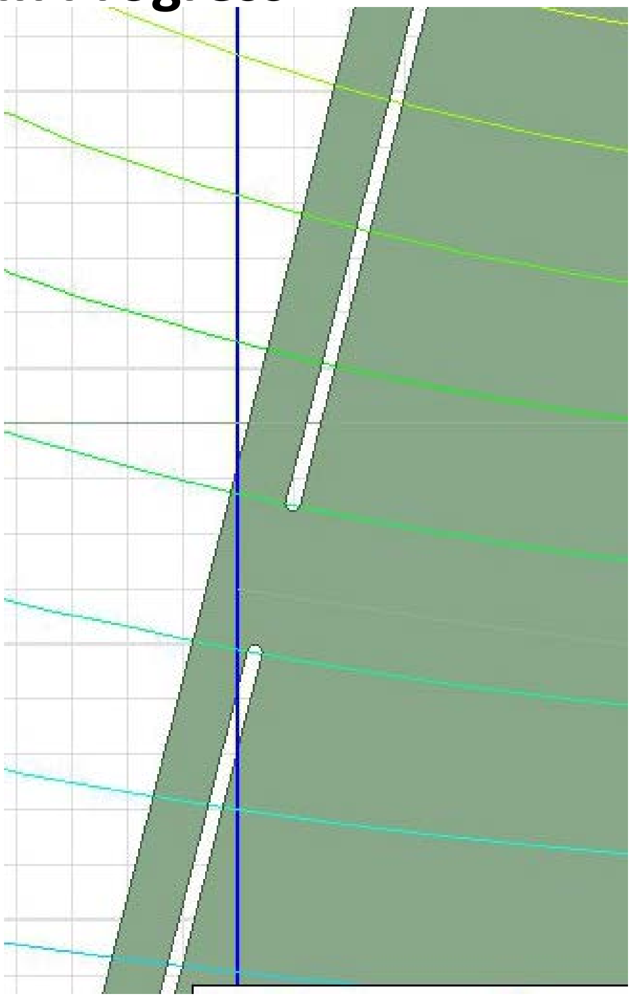


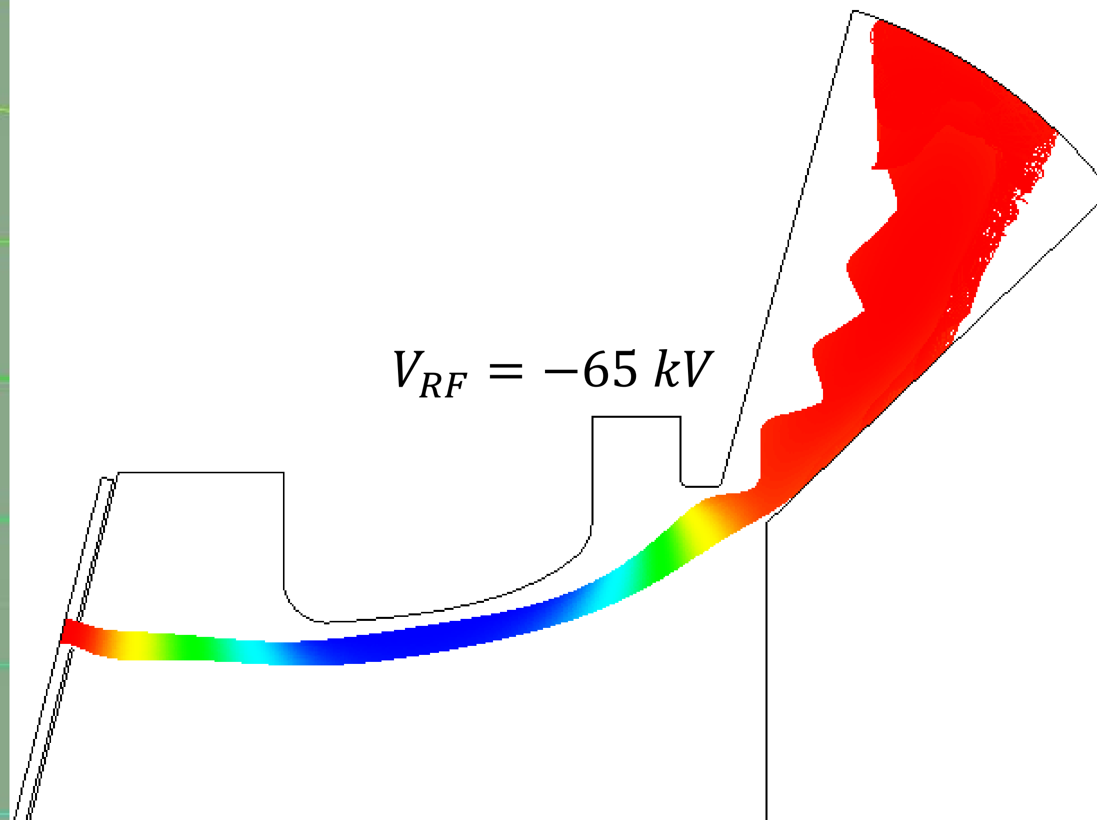
Primary + 3 generation of secondaries

Just the secondary generated electrons

Further Optimization of the Static Simulation for a 3rd Generation Model

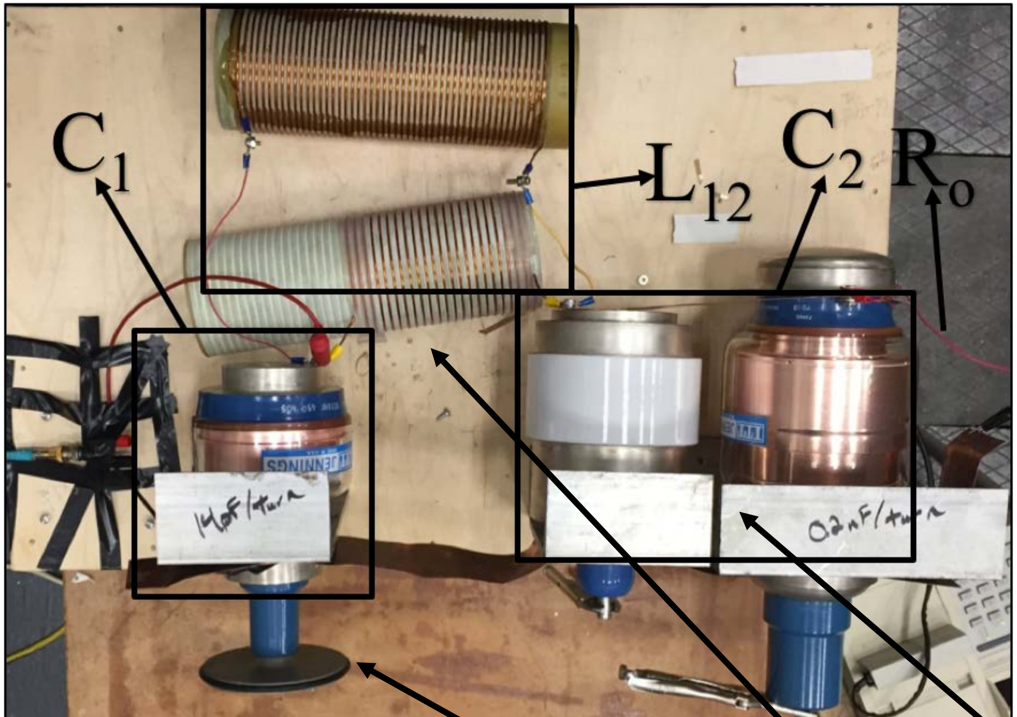
In Progress



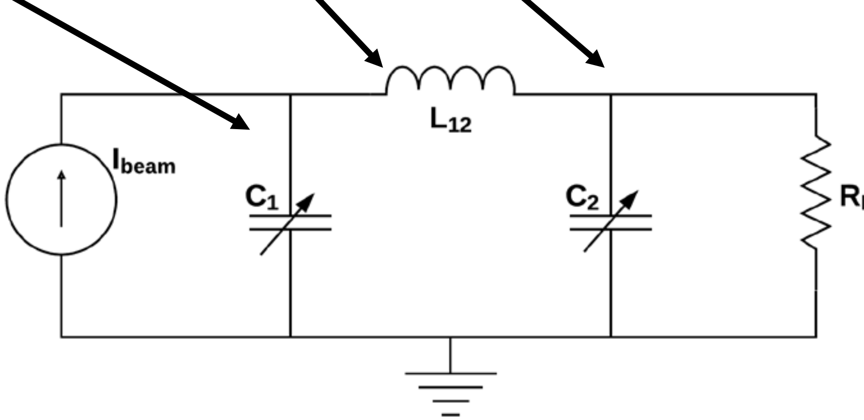


Electron trajectories showing both primary and secondary electrons

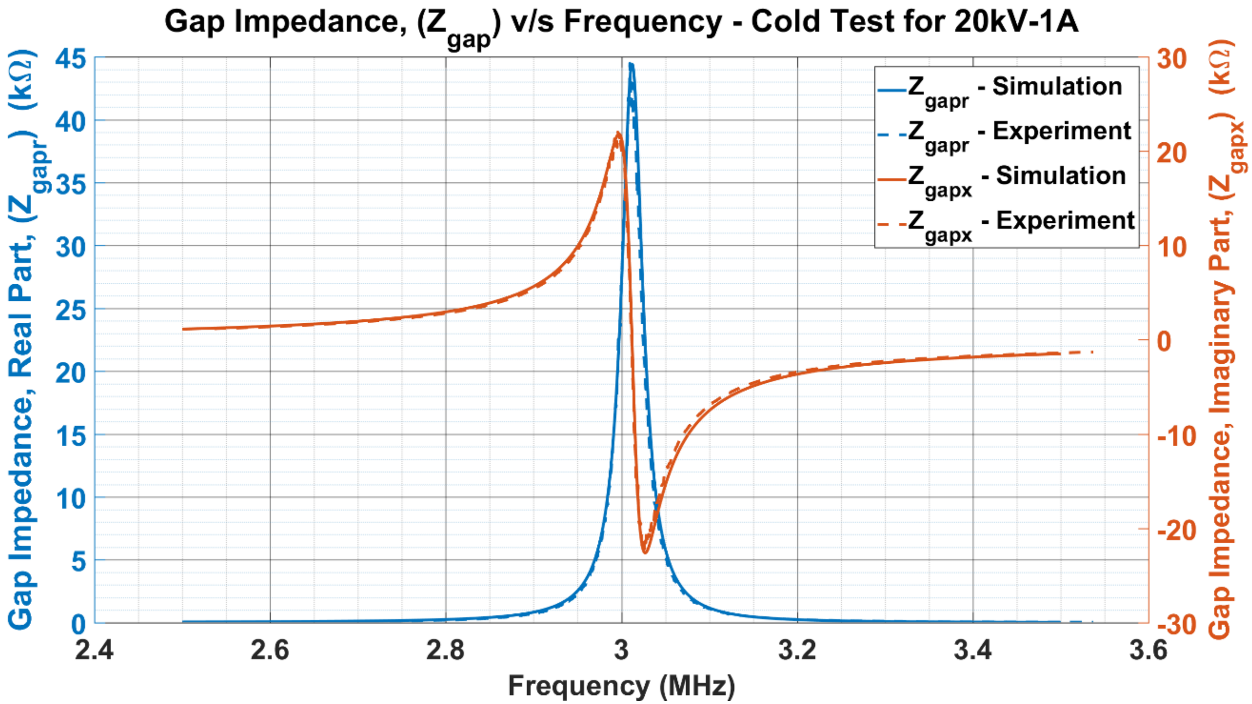
Extraction Circuit at Low Frequencies



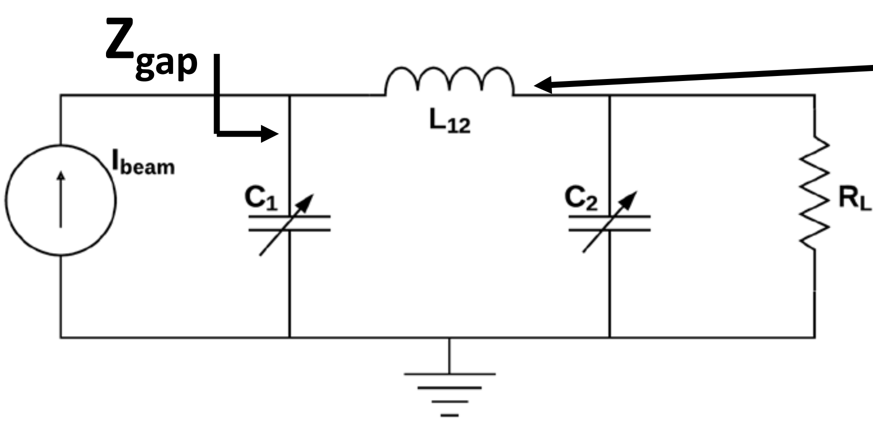
Tuning is accomplished with three vacuum variable capacitors

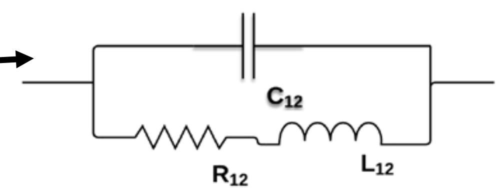


Impedance at Resonance



Circuit provides a real impedance of 44 kΩ at resonance



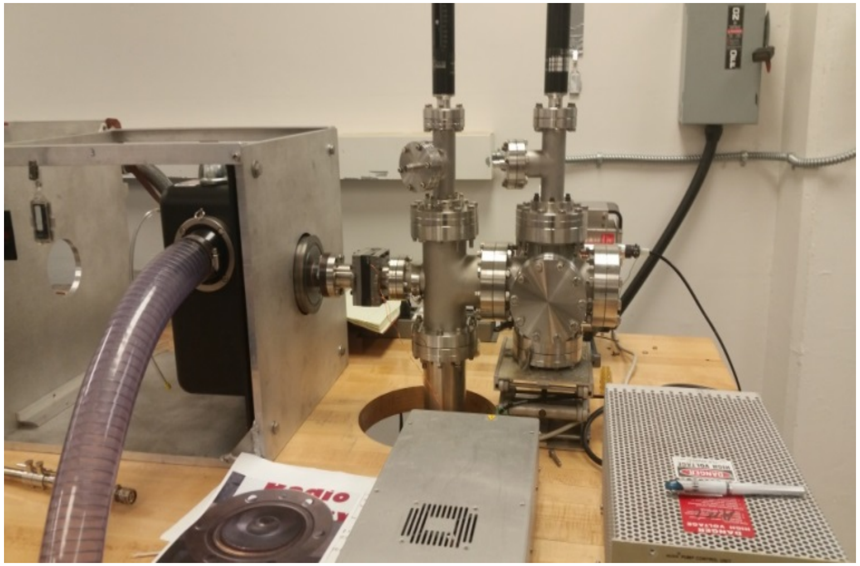


Parasitics of L_{12}
Leads to self resonance and the proximity effect

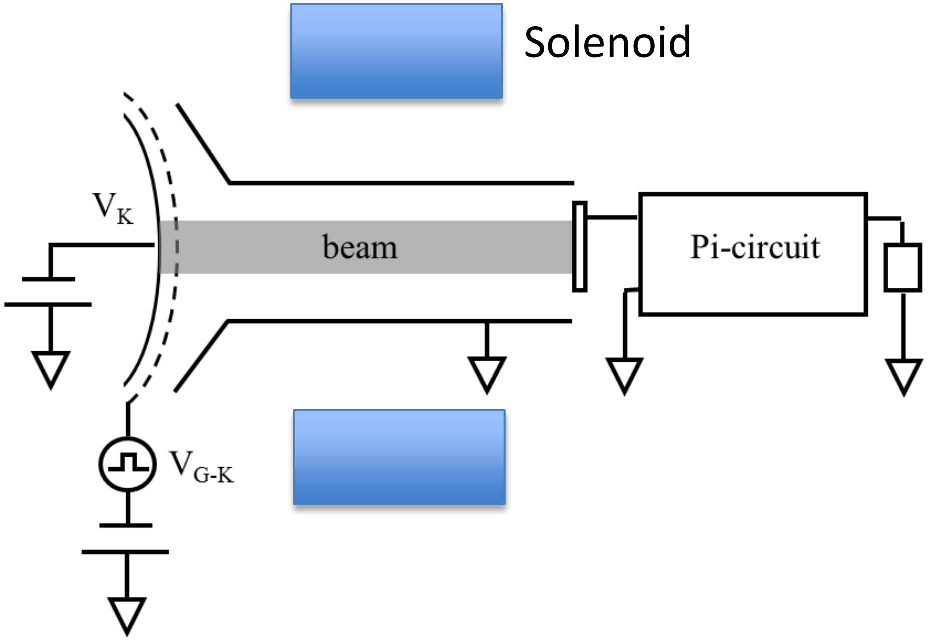
Low Power Experiments using Gridded Thermionic Gun at NRL

- Using a low power gridded gun to test the fundamental concepts behind various power extraction circuits.
- The beam current is collected onto a collector and connected directly to the extraction circuit (Triode style).
- The **20 keV, 0.5-1.5A** beam is generated using an electron gun modified, to run in "Class D" mode.

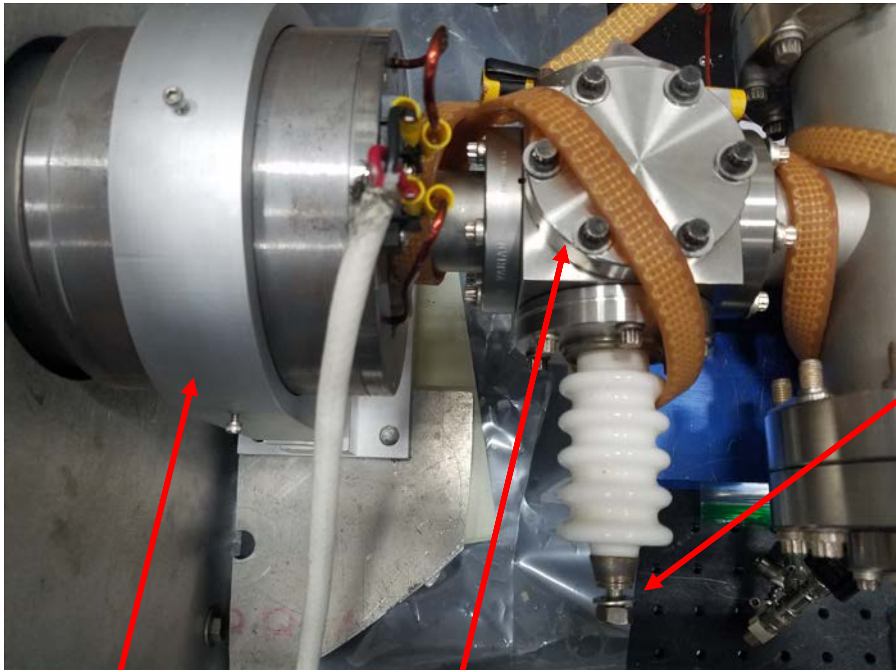
NRL Prototyping Stand



Tube connection to collector



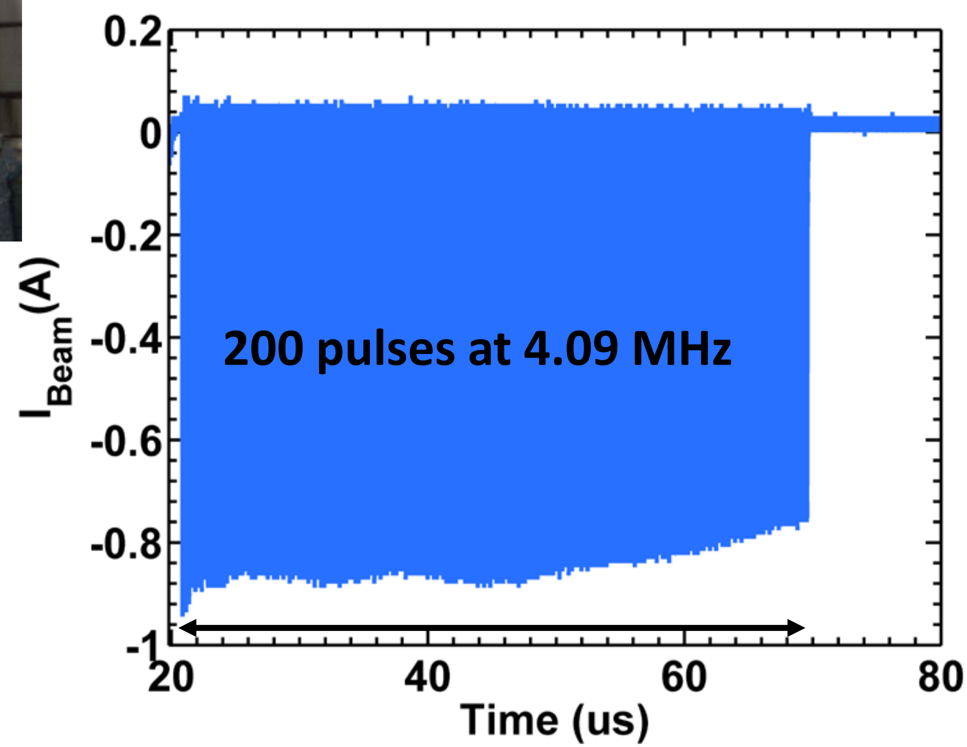
Beam Current at Collector Plate



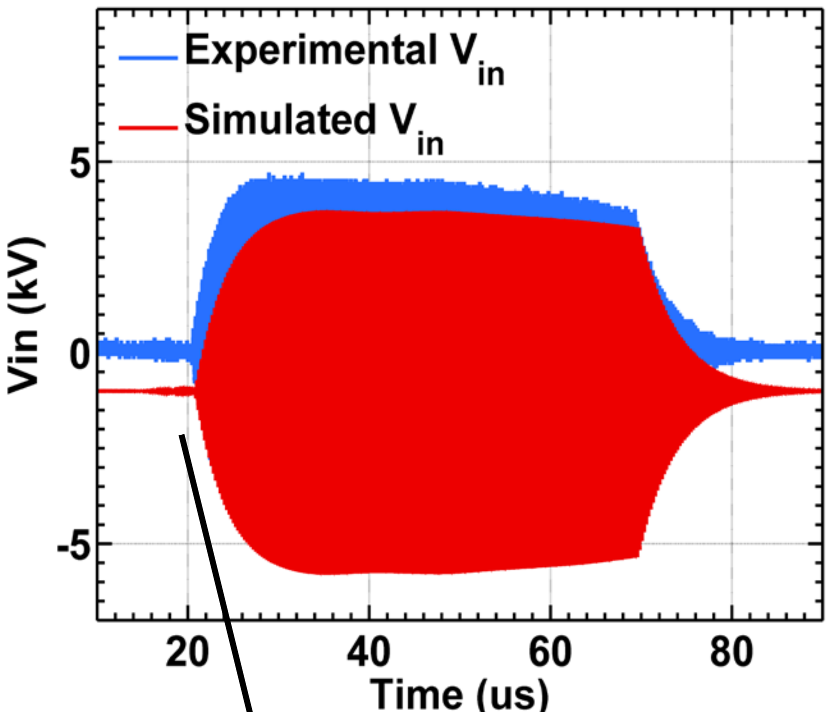
Collector connection terminated with a 50 Ω resistor

Solenoid

Collector plate within 2¾ cube

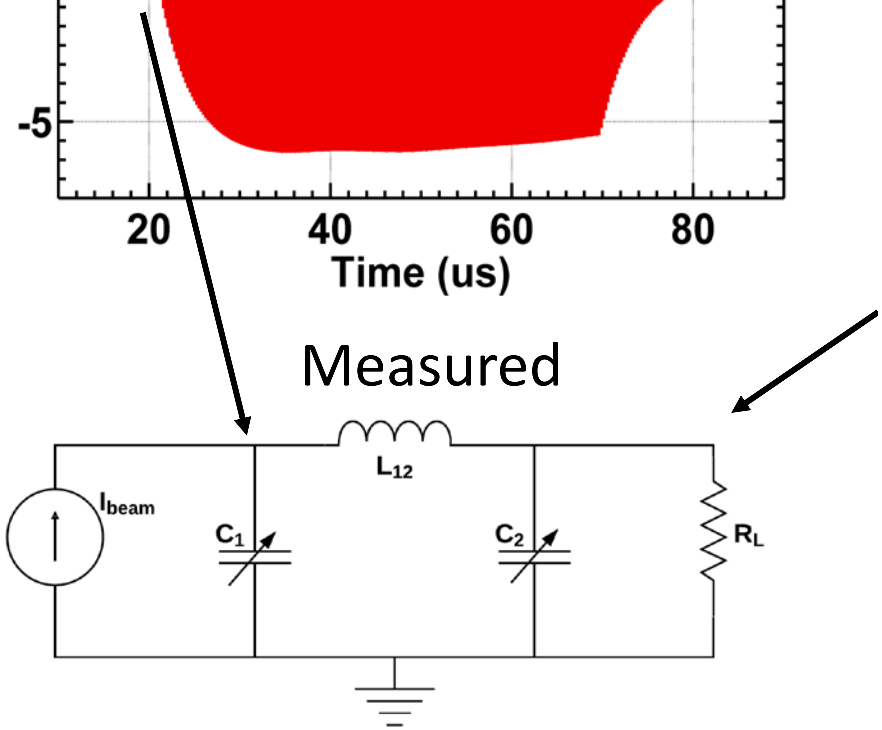


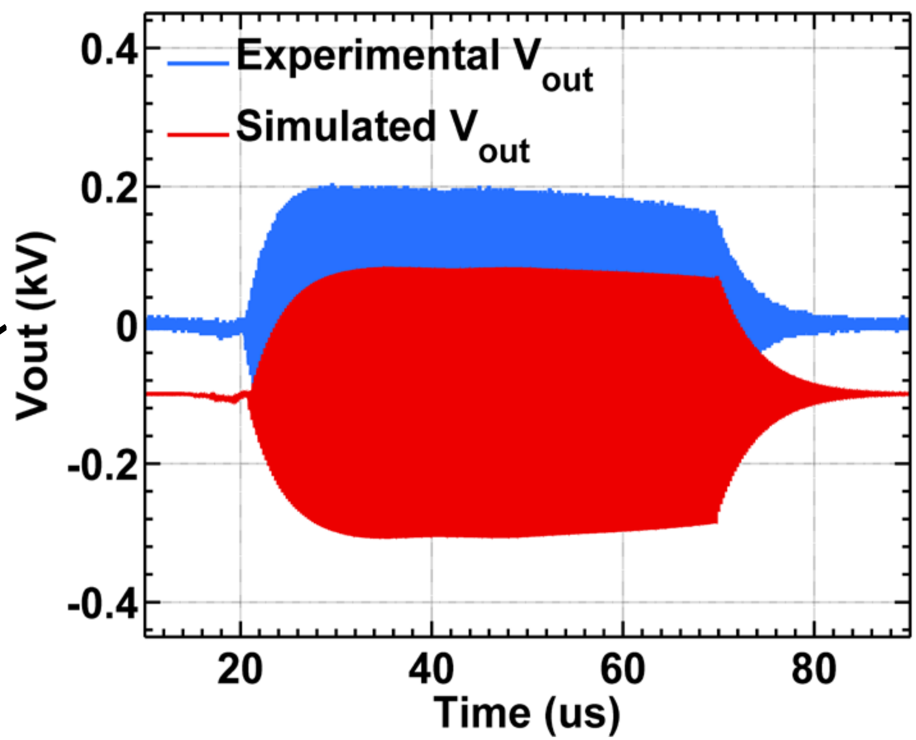
Induced RF Voltage at Collector



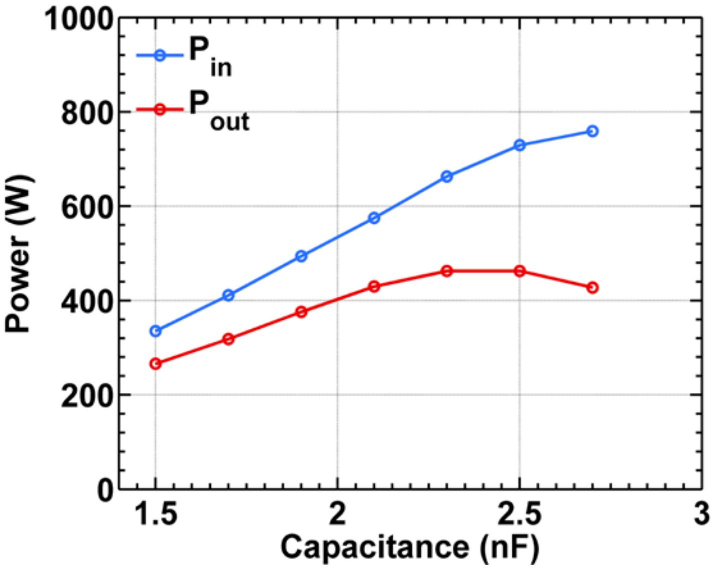
50 Ω resistor is removed and pi-circuit is connected to the collector

Measured

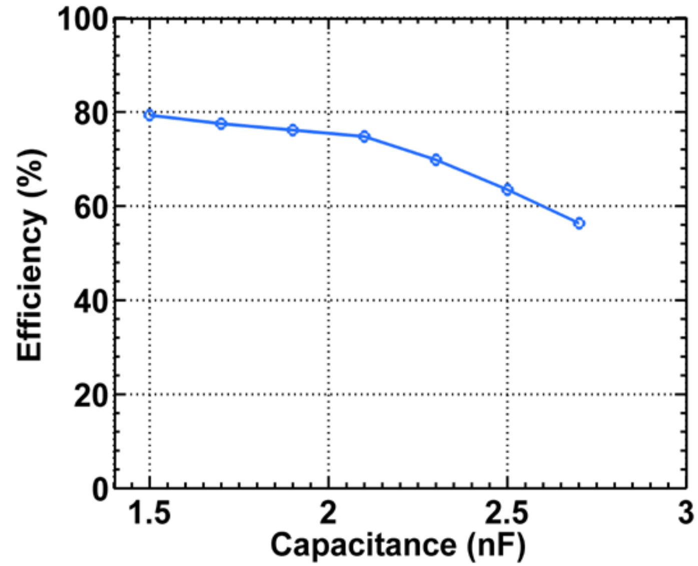




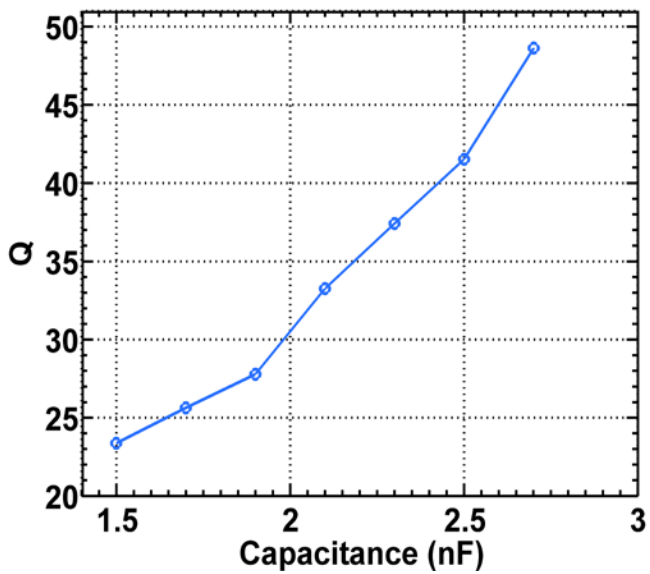
Power Extracted and Efficiency



Sweeping C_2 to increases the gap impedance



As C_2 decreases, the Q also decreases, correspondingly the transfer efficiency increases -> less power lost in the R_{12}



Summary

- Transportable Ionospheric Heaters (IOT like without a conventional cavity)
  - Class D operation
  - Grid less modulation
  - Compact (Cathode – Collector < 20 cm)
  - Electronic efficiency > 90%
- Collector geometry requires optimization to keep efficiency high while reducing secondaries
- Pi-circuits at these frequencies are a prime candidate as a conventional cavity would be too large
  - Inductor must be optimized to keep self-resonance frequency away from the operating frequency
  - Inductor must be optimized to reduce the proximity effect, which causes the resistance (R_{12}) to be larger