Prospects for an Inductive Output Tube (IOT) Based Source

MURI

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Inductive Output Tube (IOT) R&D Program

- Design, develop and demonstrate a high power IOT operating as a class D (pulse modulation) amplifier
  - IOTs currently not available in the 1-10 MHz frequency range

- Advantages of Pulse Modulation:
  - Simplifies driver circuitry
  - Enhances efficiency

- Technical Challenges:
  - Grid performance, interception and heat loading (solved ?)
  - Cavity tuning at MHz Frequencies with mechanical frequency sweeping
Class D IOT Transmitter Concept

- J.C. Rodgers, MURI Kick-off 2014.
Staged Plan

• Initially, utilize a gridded gun for prototyping, to optimize various subsystems (modulator, tunable cavity, etc)

• In parallel we are designing a pulsed high peak power source based on a Magnetron Injection Gun (MIG)
Prototype Gridded Gun

• Used to optimize design details, such as the anode shape and electrical interface, using an existing gun from an established vendor

• Used to test:
  – Fast pulse modulators capable of operating at 1-10 MHz.
  – Lumped resonant cavity circuits that are mechanically tunable over the frequency range of interest
**Beam Specifications**

- Cathode voltage: 20 kV
- Beam current: 5.7 A
- Grid drive: +235 v
- Perveance: 2\(\mu\)Pervs
- Pulse width: 100\(\mu\)s max
- Duty cycle: 0.04 max (or 400Hz)
- Grid power dissipation: 3 W max
Time-Domain Michelle Simulation of the HeatWave Gridded Gun

Square wave grid input pulse

Class D

Emitted beam current at 20 kV

Burst mode operation of the gun

\[ T = \frac{1}{f} = \frac{1}{5\text{MHz}} = 200\text{ns} \]
Grid Modulator

IXYS boards with FETs capable of 1 kV at 20 A within 5 ns

Grid modulator mounted directly to the gun, eliminating transmission line effects. Large voltage pulses will be generated based on an inductive summer technology.

Capable of operating up to 30 MHz

Pulse voltage into 50 Ω

\[ T = \frac{1}{f} = \frac{1}{5MHz} = 200ns \]

Finger stock connection to circuit

300 v
Cathode Test Stand

**Vacuum Chamber**

**Controls**

**Power Supplies**

Diagnostics include:
1 – Residual gas analyzer (RGA)
2 – Phosphor screens, Faraday cup
3 – Pyrometer

**MIG Style Cathode**

$0.15 \text{ m}$
Michelle Simulation of Decelerating Gap Limits
**Cavity with Frequency Invariant Impedence**

**Operating Conditions and Design:**
- Power Output: 1-2 MW (Total Power)
- Frequency of Operation: 1-10 MHz
- Input Pulsed Beam Current: 30 A (1/4th period)
- Potential Difference across Gap: 70kV

**Designed Values with above Constraints:**
- \( C = 63.6 \text{ pF} \) (once \( Z_{\text{gap}} = 5\text{k}\Omega \), \( Q = 10 \), \( f_0 = 5\text{MHz} \) are fixed, no flexibility)
- \( L_1 = 15.9 \text{ } \mu\text{H} \) for the above values.
- \( N/M \approx 10 \)

Hence, if Inductance and number of turns are to remain constant, then quality factor needs to change when the resonant frequency changes (by changing the capacitance) satisfying the equation as follows: \( N^2L = Z_{\text{gap}}/Q\omega_o \)
Cavity with Frequency Invariant Impedance

Bench circuit

Mock coil

Copper box for Gun
Magnetron Injection Gun for IOT

- Next stage in design phase
Magnetron Injection Gun for IOT

Annular Beam Cathode (Emitter)

No intercepted current (grid-less)
Beam is controlled through a mod-anode

Beam Trajectory with peak on-axis field of 1.4kGauss
Beam ripple minimized

Emitter

Solenoid Field Calculations

We have the Cathode

Time-Domain Simulation of Magnetron Injection Gun

I-V Curve for mod-anode voltage at a fixed anode voltage of 60 kV

Beam current vs. Mod-Anode Voltage

Square wave input pulse driving mod-anode and the emitted beam current from the gun at 60 kV

Class D

Turn on -308 V

17.7 μPervs
Artist Rendition of the Magnetron Injection Gun

In progress

Ion pump and heater connections to be placed here

Vacuum Pumping holes to be placed here

Beam
# Experimental Program Timeline

## Tasks for HeatWave Labs

<table>
<thead>
<tr>
<th>Year</th>
<th>Task Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Review design with UMD, manufacture gridded gun</td>
</tr>
<tr>
<td>3</td>
<td>Assemble and test gridded gun</td>
</tr>
<tr>
<td>4</td>
<td>Review and finalize MIG gun design with UMD-RF Lab – physics review</td>
</tr>
<tr>
<td>5</td>
<td>Manufacture MIG gun</td>
</tr>
<tr>
<td>6</td>
<td>Assemble and test MIG gun</td>
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</tbody>
</table>

## Tasks for UMD-RF Lab

<table>
<thead>
<tr>
<th>Year</th>
<th>Task Description</th>
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<tbody>
<tr>
<td>2</td>
<td>Construct beam line for gridded gun as well as cathode test stand</td>
</tr>
<tr>
<td>3</td>
<td>Design and assemble prototype tunable cavity circuit for gridded gun and test with beam</td>
</tr>
<tr>
<td>4</td>
<td>Design and assemble fast RF modulator for gridded gun and test with beam</td>
</tr>
<tr>
<td>5</td>
<td>Review and finalize MIG gun design with HeatWave Labs – engineering review</td>
</tr>
<tr>
<td>6</td>
<td>Retrofit beam line for MIG gun</td>
</tr>
<tr>
<td>7</td>
<td>Design and assemble fast RF modulator for MIG gun and a tunable cavity (capable of handling average power)</td>
</tr>
<tr>
<td>8</td>
<td>Test MIG IOT</td>
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Where we go next

• The HeatWave Labs gridded gun provides us with a prototyping source in the short term, to test and optimize various subsystems for a low frequency Magnetron Injection Gun (MIG) based IOT.

• Solenoid fields are currently being optimized for both guns and a fast RF modulator and a beam ready prototype constant impedance cavity is under construction for the gridded gun from HeatWave Labs.

• At the end of the 2\textsuperscript{nd} into the 3\textsuperscript{rd} year we will finalize the design of the MIG gun with HeatWave Labs, once the gridded gun is completed. We will have them create the manufacture component drawing package and begin the manufacturing into the 4\textsuperscript{th} year.

• We will design and assemble the fast RF modulator capable of driving the MIG gun as well as a tunable cavity capable of handling the average power, using the knowledge gained from the small gridded gun.

• We will test the MIG IOT into $50\Omega$ in the 5\textsuperscript{th} year.