Novel High-Power Radio-Frequency Sources for Ionospheric Heating

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Abstract: Development of Mobile Ionospheric Heating sources (MIHs) would allow investigators to conduct needed research at different latitudes without building permanent and costly installations. As part of an Air Force Multi-University Research Initiative (MURI), the University of Maryland is designing a prototype of a powerful Radio Frequency (RF) source utilizing Inductive Output Tube (IOT) technology operating in class-D with a mod-anode controlled electron gun [1]. This technology was chosen because it has the potential to operate at efficiencies exceeding 90% [2].

Keywords: Inductive output tube, Ionosphere, Radio frequency, Space-charge, Inductive adders, Transformers, High-frequency Active Auroral Research Program (HAARP)

Introduction
The ionosphere plays a controlling role in the performance of critical civilian and defense systems including low frequency communications, radars, navigation and other systems. Traditional space weather research emphasizes passive observations and measurements of natural phenomena that result in physics based forecast models. A complementary approach to passively studying the ionosphere is through its modification. The objective of ionospheric modification is to control and exploit triggered ionospheric and magnetospheric processes in order to improve the performance of trans-ionospheric Command, Control, Communications and Intelligence (C3I) systems and to develop new applications that take advantage of the ionosphere as an active plasma medium. A key instrument in ionospheric modification is the ionospheric heater, a powerful high frequency transmitter that modifies the properties of the ionospheric plasma by modulating the electron temperature at preselected altitudes [3].

A major reason to develop MIHs is that practically in most applications proximity to the application region or particular L-shell is critical for reducing power requirements and allowing investigators to conduct the needed research at different latitudes within the ionosphere without building permanent installations. For example, research has indicated a major advantage to utilizing locations in the dip-equantor. Mobile sources would allow users to conduct the needed research without constructing large and costly heating sites. These sources would be substantially smaller than HAARP and located on a platform the size of a barge, ship, or transported in pieces and assembled on the ground.

A mobile heater for ionospheric modification studies requires a new class of RF sources at the megawatt level. The MIH will operate with an antenna that is roughly 1/100 in area of the HAARP antenna. Thus, in order to deliver an effective power density to the ionosphere comparable to that of HAARP, the total source power must be in the range of up to 100 MW. This high power places a premium on efficiency.

Some of the technical advances presented in this paper include: a novel Megawatt (MW) level gun design based on an annular emitter that eliminates intercepted current, a prototyping test-stand, a modulator system capable of driving the mod-anode of a MW level gun and a tunable constant impedance cavity operating in the 1-10 MHz range

High Power IOT
A major concern with the gridded class-D operation of an IOT device is that grid heating caused by intercepted beam current can limit the operational range of the gun, therefore limiting its performance. A novel design that produces an annular beam, avoids this complication as a small mod-anode local to the thin annular cathode is used to bias the beam on and off without intercepting any electrons. The geometry of the cathode, focusing electrode, gap and mod-anode of the gun as well as the particle trajectories with solenoidal confinement as calculated from MICHELLE [4] are shown in Fig. 2a-b.

![Figure 1a-b. (a) - Geometry of emitter, focusing electrode, gap and mod-anode of the electron gun, (b) - Particle trajectories of a 70 kV-15 A beam (solenoidal confinement).](image-url)
Prototyping Test-Stand

*HeatWave Labs Gridded Gun:* A nearly off-the-shelf gridded gun is being constructed by HeatWave Labs that will allow us to prototype fast RF mod-anode/grid modulators, tunable cavities and compare beam measurements with MICHELLE calculations. The prototyping test-stand, shown in Fig. 3 is under construction.

![Figure 2](image) CAD drawing of the prototyping test-stand for the development of mod-anode/grid modulators and tunable cavities. Cavity not shown.

The gridded gun will generate a 20 kV-3.3 A beam in pulse mode operation with a maximum macro duty cycle of 3% at peak where the RF pulse widths will vary from 50 ns to 150 ns. The cavity will be installed at the end of the beam line.

*Mod-Anode/Grid Modulator:* The modulator design is capable of driving both the gridded and mod-anode controlled guns. The required grid drive for the HeatWave gun is a factor of 10 smaller than that predicted from MICHELLE simulations of the annular beam gun. Results indicate that for a 70 kV-15 A beam, the mod-anode voltage required is approximately 2.4-2.5 kV. With an inductive summer utilizing multiple stages (shown in Fig. 4), we will be able to achieve a sufficiently large and fast drive pulse. A single stage (shown in Fig. 5) has been constructed and is undergoing testing.

![Figure 4](image) Single stage of the inductive summer undergoing testing.

*Tunable Constant Impedance Cavity:* The cavity design for the test-stand consists of a parallel combination of a low leakage transformer (similar to that shown in Fig. 6) and a variable capacitor to form the resonant circuit in the frequency range of interest.

![Figure 5](image) Maxwell drawing of the transformer with primary (red) and secondary (green) coils.

The maximum theoretical efficiency of the extracted beam power from this circuit determined by analyzing the limiting current across a gap can exceed 90% [2].

**Summary**

The University of Maryland is underway in the design and construction of various systems for prototyping novel efficient RF sources utilizing IOT technology running in class-D amplifier mode. Efficiency is critical as a mobile ionospheric modification antenna array of dimensions 30 m by 40 m would require a total RF source power of 100 MW to achieve the same radiated power density in the ionosphere as HAARP.

**Acknowledgements**

This work is supported by the Air Force Office of Scientific Research under grant FA95501410019.

**References**