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SCALED STUDIES ON RADIO FREQUENCY SOURCES FOR MEGA-WATT-CLASS IONOSPHERIC HEATERS

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Abstract

The ionosphere plays a prominent role in the performance of critical civilian and military communication systems. The properties of the ionosphere can be modified by Ionospheric Modification (IM). The key instrument in IM research is a powerful, ground-based, High Frequency (HF) source of electromagnetic waves known as a heater. Existing heaters operate with large, fixed location antenna arrays. With a mobile heater, investigators would be able to conduct IM research at different latitudes without building a costly permanent installation. Developing a mobile heater that operates with an antenna array that is 1/20 the area of HAARP requires a new highly efficient Megawatt class of Radio Frequency (RF) source to reduce the overall power demands on a fully deployable system [1]. Such a source, similar to an Inductive Output Tube (IOT) has been described previously.

This work describes the measurements of various extraction circuits driven by a kW gridded electron gun at the Naval Research Laboratory (NRL). This thermionic gun is conventionally driven through an input coupler in order to resonantly excite the grid and extract current from the cathode at the RF drive fundamental of 700 MHz. For the experiments presented, the input coupler is terminated and we drive the grid directly using a fast grid driver floated with the cathode high-voltage long pulse. The Transistor-Transistor Logic (TTL) burst of pulses that sets the gun drive frequency is created using a function generator that is optically isolated from the floating fast grid driver. In this configuration, the beam energy is adjustable up to 20 kV with currents ranging from 0.5-1.6 A and pulse widths of 50-150 ns.

PROGRAM SUMMARY

This Multi-University Research Initiative (MURI) team was tasked to investigate the possibility of a mobile highly efficient megawatt level ionospheric heater. This requires taking a fix ground based installation such as HAARP, with a size of 300 m by 400 m and shrinking it to approximately 110 m by 70 m [2]. To deliver an effective power density comparable to that of HAARP, the total source power must be in the range of 16 MW, thus demanding highly efficient sources [3]. The development of a whole multi-megawatt system for mobile ionospheric heaters is a complex engineering problem.

Figure 1: Developing a mobile heater that operates with an antenna array that is 1/20 the area of HAARP.

The type of tube, which is currently under development at the University of Maryland for mobile IM research, is a modified Inductive Output Tube (IOT) operating in class D [3], [4] and [5]. Conventional IOTs commonly used in radio and TV broadcast use grids to density modulate the beam on and off and generate RF in the output resonant cavity [6]. Our concept eliminates the grid, using instead a modulation anode and an annular beam, thus avoiding the issues of heat dissipation in the grid. In addition to using an annular e-beam to reduce beam space charge and enhance efficiency, our design also uses an external resonant lumped element circuit to extract the beam kinetic energy at RF frequencies from 3 – 10 MHz [7]. The beam passes through a decelerating gap, and its kinetic energy is extracted using a tunable resonant pi-circuit. Here we investigate the efficiency of a pi-type circuit used to extract power from the beam. To facilitate studies on extracting RF power using pi-circuits, we are using an IOT electron gun at the Naval Research Laboratory (NRL).

PI-CIRCUIT EXTRACTION OF E-BEAM POWER

The electron kinetic energy is extracted using a decelerating gap connected to a tunable resonant circuit that presents an AC impedance to the beam. The designed value of the impedance is such that the voltage that develops across the decelerating gap in response to the

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modulated beam current is sufficient to extract nearly all the beam energy. The type of resonant circuit we are considering is a pi-circuit (shown in Fig. 2), the topology of which resembles that of the Greek letter π.

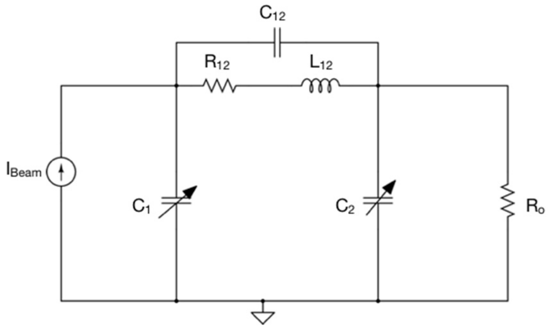

Figure 2: Pi-circuit model with parasitic elements C_{12} and R_{12} for L_{12}. C_1 is used to tune the frequency and C_2 is used to tune the impedance for the driving current source.

The main components of the pi-circuit are the input capacitor C_1, the output capacitor C_2, and the inductor L_{12} connecting the two capacitors. The quantity I_{Beam} is the time dependent beam current driving the circuit and R_o is the output impedance. The circuit parameters are selected so that the circuit presents a real impedance to the AC portion of the current source I_{Beam} at the operating frequency. The dominant parasitic elements C_{12} and R_{12} for L_{12} in the circuit are also included [4].

PROTOTYPING TEST-STAND

A pi-circuit was built at the University of Maryland with circuit elements and properties that are suitable for the NRL electron gun (shown in Fig. 3). The gun has a gated and gridded thermionic cathode and was originally designed to operate in the frequency range from 500 MHz to 2.5 GHz by direct coaxial coupling to the grid. The grid is composed of concentric wires and placed in front of the tungsten dispenser cathode that has a Pierce configuration for a focused beam [8]. The cathode-anode voltage is designed to operate from 20 to 35 kV with a cathode-grid voltage 10 – 200 V. We were able to drive the grid directly through its biasing electrode with square pulses extracting 1A of current [4].

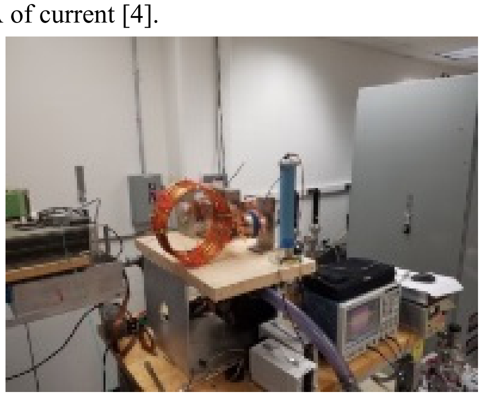

Figure 3: Pi-Circuit extraction resonator and the low power IOT electron gun at NRL. The inductor is made of copper tubing and the capacitors of the pi-circuit sits on top of the IOT gun.

RESULTS ON POWER EXTRACTION AND EFFICIENCY

The circuit was driven at its resonant frequency of 3.1 MHz. The power entering the pi-circuit, P_{in}, was estimated from the phased product of the alternating voltage V_{in} and the alternating beam current I_{Beam}. The output power P_{out} is inferred from measurement of the voltage across the output 50 Ω resistor. Figure 4a illustrates the input and output power and Fig. 4b illustrates the efficiency measured at various capacitances for C_2, at an RF drive frequency of 3.1 MHz.

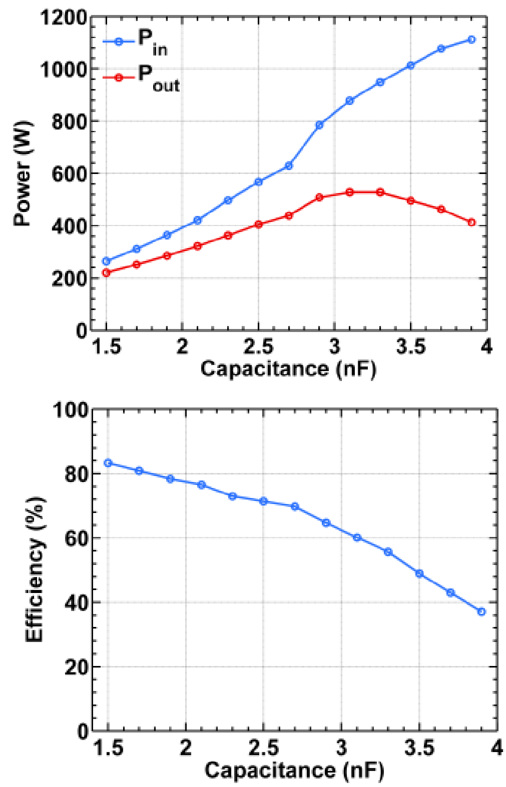

Figure 4: (a) – Input and output power versus capacitance C_2 at an RF drive frequency of 3.1 MHz. (b) – Efficiency versus capacitance C_2 at an RF drive frequency of 3.1 MHz.

The output power peaked between 3.1 – 3.3 nF, corresponding to a circuit efficiency of 60 – 56 %. At lower output powers (or lower C_2), the efficiency is much greater, as there is less power dissipated in the inductor branch of the circuit.

CONCLUSION

A scaled experiment for MW class RF source design was described. Using the electron beam produced by a gridded thermionic electron gun operating in class D mode, we drove an external lumped element circuit. Detailed analyses of efficiency has showed that we were able to extract at most 84 % of the power when the circuit was tuned to have a low Q-factor, thus dissipating less power in the effective resistance of the inductor. In terms of a MW class RF source, careful consideration must be

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placed on the design, location, length and strength of the guiding field as well as the collector geometry, in order to collect all the beam current when a pi-circuit is connected, with an acceptable density of deposition.

In terms of a MW class RF sources, the required gap impedance Z_{gap} will be significantly lower as compared to the gap impedance needed for the NRL experiment. If the ratio of the gap impedance to output resistance is small, as in the design UMD is pursuing for a MW class RF source, then the parasitic resistance of the inductor will have less of an impact on limiting efficiency [4].

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