Simulations and Experiments on Magnetically Insulated Line Oscillators at the University of Michigan

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Abstract: *The magnetically insulated line oscillator (MILO) is a compact source of high power microwaves (HPM) that creates a self-generated magnetic field for crossed field interaction. At the University of Michigan, multiple efforts in simulation and experiment are underway to improve MILO operation in different ways. A new pulsed power test bed BLUE (Bestowed LTD from the Ursa-Minor Experiment) is under development, capable of generating different output voltages. BLUE will be used to drive a GW-class MILO, testing operation at various injected voltages. Simulations of the MILO in CST-Particle Studio have demonstrated accurate predictions of output power and current across a range of input voltages that BLUE is projected to generate. Investigations in simulation and experiment of a planar MILO are also underway. A planar MILO could enable operation at higher efficiencies than possible in the more conventional cylindrical geometry.*

Keywords— oscillators; electron beams; high power microwaves; magnetic fields; CST-Particle Studio

Introduction

High power microwaves (HPM) are important in applications such as fundamental science, industrial heating, and various defense technologies. One example would be radar, where the microwave source may need to be mobile, carried by a terrestrial or airborne vehicle. In these types of operations, the form factor and weight of the overall system are of crucial consideration. The magnetically insulated line oscillator (MILO) is an HPM source shown to be capable of generating up to gigawatts of power [1]. Similar to the magnetron [2], the MILO is a crossed field device, but differs in the way its magnetic field is applied. The MILO generates a self-insulating magnetic field that allows for synchronism between the beam and slow wave structure (SWS). This eschews the need for permanent magnets, which reduces the overall weight and size of the microwave source, making it more appealing for applications that requires mobility.

The Linear Transformer Driver and Compact HPM Technology

The linear transformer driver (LTD) [3] is a new and compact form of pulsed power technology. Its architecture charges capacitors in parallel, each connected by a switch in a configuration known as a brick. The LTD charges multiple bricks in parallel. Pulsing the LTD requires breaking down the switch in each brick simultaneously, allowing the capacitors to discharge in series, often into a radially convergent transmission line to the load. The LTD is capable of delivering sub-megaampere currents at voltages on the order of hundreds of kilovolts. The LTD is also unique in that multiple modules can be stacked on top of each other to generate varying output voltages at the same current.

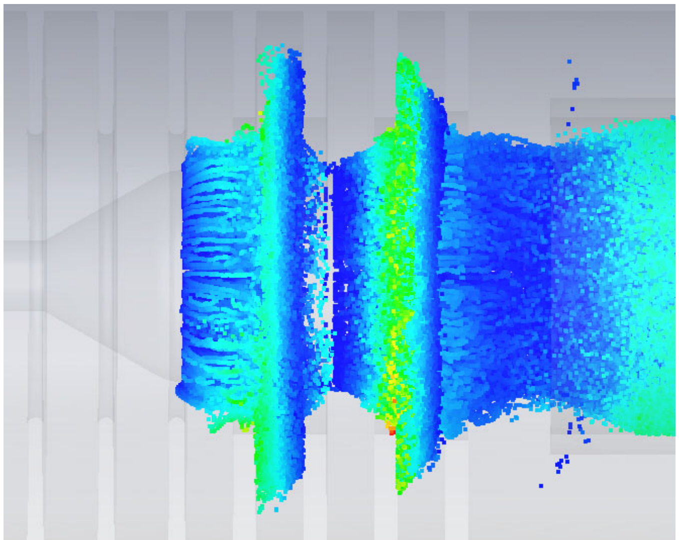

Figure 1: A CST model of the GW-class MILO demonstrates π-mode operation.

Because of its ability to drive large currents, the LTD is an ideal partner for the MILO. Generation of the insulating magnetic field in a MILO often requires dozens of kiloamps or more, which the LTD is more than capable of delivering. The combination of the two would produce an overall compact and viable HPM system. At the University of Michigan, the LTD test bed BLUE (Bestowed LTD from the Ursa-Minor Experiment) is under development. BLUE consists of multiple LTD cavities configured to can deliver varying voltages tuned to the specific application.

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Plans have been made to test a GW-class MILO [4] on BLUE, investigating injected voltage as an independent variable. As experiments await the completion of the BLUE facility, particle-in-cell simulations of the MILO have been performed in CST-Particle Studio. These simulations successfully reproduced results from prior MILO experiments. Operation of the MILO in π-mode is demonstrated in ***Figure 1***. The conclusions drawn from these simulations and their comparison to experiments will be discussed.

The Application of External Magnetic Fields to MILO

A significant drawback of the MILO is its low efficiency, often limited to 10-20% because of its need for high current. While the MILO is advantageous because it does not require an external magnetic field, this issue could be assuaged to some degree with the application of a modest magnetic field that does not affect the overall footprint of the device. By providing some of the insulating field externally, forming a magnetron-MILO hybrid, perhaps the advantages of the MILO can be maintained but with operation at higher efficiencies.

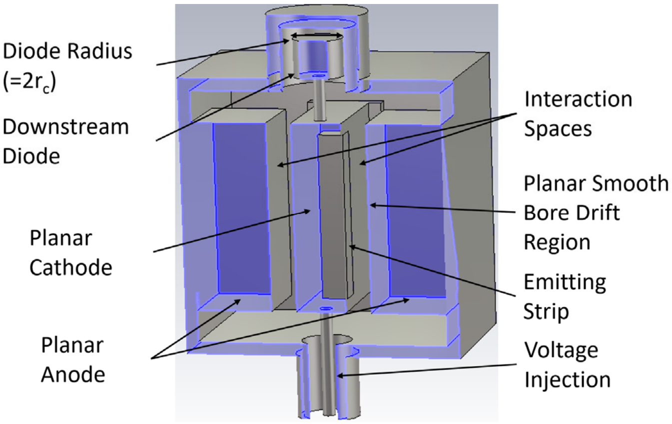

Figure 2: The planar MILO geometry is depicted, equipped with a downstream cylindrical diode for magnetic field generation.

It would be difficult to achieve appropriate application of an external magnetic field in the cylindrical geometry. Thus, investigators at the University of Michigan are designing a planar MILO, similar to the Recirculating Planar Magnetron (RPM) [5]. Depicted in ***Figure 2***, a planar cathode and anode are implemented, where microwave generation is allowed with emission of charge from the emitting strip and the placement of a synchronous slow wave structure on the anode. The downstream cylindrical diode generates the self-magnetic field. Simulations in CST-Particle Studio have demonstrated generation of spokes in the electron hub in this scenario, shown in ***Figure 3***. Various methods for the magnetic field application are under consideration.

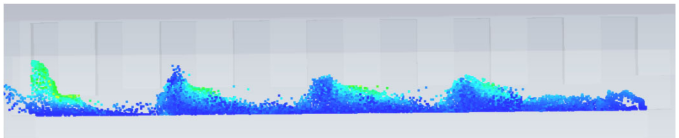

Figure 3: Space charge flow in the planar MILO AK-gap. Synchronous interaction between the electron beam and slow wave structure is demonstrated.

An additional advantage the planar MILO could have over the cylindrical MILO is the choice of microwave extraction. In the planar MILO, microwave power can more easily be extracted from the SWS along a different axis from the downstream cylindrical diode. For example, coaxial all cavity extraction (CACE) [6] could be deployed on the SWS, optimized to operate at a low Q for high efficiency operation. Additionally, the separation of axes could avail the application of a depressed collector placed on the downstream cylindrical diode to further improve device efficiency [7].

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