Design of a Source for GHz Ultra-Wide Bandwidth Applications Using the Two-Stream Instability

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Abstract: *A novel source for millimeter-wave RF is being designed at Los Alamos National Laboratory (LANL) utilizing the two-stream instability. This source has the potential for consistent output power over a large bandwidth on a single device [1]. The characteristic length of longitudinal bunching due to the two stream instability is dependent, along with current, on the energy difference of the two beams [6]. The source is optimized for 1-5 kV energy differential between the electron beams coupled into a single solenoid using electrostatic focusing in the electron gun region. The source will use co-axial electron beams to evaluate the longitudinal bunching of the at millimeter wavelengths.*

Keywords: Two-Stream Instability; ultra-wide bandwidth; electrostatic focusing.

Introduction

The two-stream instability is well-known and its use, to generate centimeter-wave RF, dates to the late 1940's [2, 5]. The two stream instability is particularly interesting as a generator for millimeter and submillimeter wavelengths because it eliminates the need for resonant structures on these scales such as with slow-wave structures [1]. Furthermore, an RF generator based on the two-stream instability can be operated at an extremely wide bandwidth on a single device, because the longitudinal bunching frequency is dependent on current density and energy difference of the two beams [1, 6].

Initial proposals for a millimeter and submillimeter-wave generator using the two-stream instability relied on merging two electron beams in a dipole magnet [1]. However, due to the additional complexity and cost of merging electron beams of differing energies in a dipole magnet, a more compact co-axial cathode design was selected. The source notably differs from the UHF tube realized in [2] by using keV energies and up to a factor of five smaller beam radius. However, because co-axial beams never overlap in phase space from linear forces, the characteristic length of the longitudinal bunching is limited by the total radius of the electron beams [7]. The design and fabrication of a millimeter-wave two-stream instability RF test source to quantify longitudinal bunching in the electron beams from the instability is underway at LANL.

Design of a Dual Beam Co-Axial Two-Stream Instability Test Source

Design parameters for the source are listed in Table 1 and represent the basis to which the source was designed. Two co-axial thermionic cathodes, shown in Fig. 1 will be biased independently providing electron beams of differing energy. The cathodes will provide a combined current of 0.7 A. Heat shields between the cathodes reduce the electrical cross-coupling in addition to preventing electrons from streaming radially from inner to outer cathode. The electron beams will be pulsed in concert with the magnets allowing for peak magnetic fields of 2.5 kG without active cooling but at a low duty factor likely less than 10%.

Table 1. Design parameters for the millimeter-wave test source.

Parameter	Design Constraint	Design Value
Total Current	> 0.6 A	0.7 A
Current Difference	< 30%	30%
Inner Cathode Potential	-18-22 kV	-16-20 kV
Outer Cathode Potential	-15-20 kV	-15-19 kV
Energy Spread	< 2%	0.35 %
Beam Radius	< 2 mm	1.2 mm
Interaction Solenoid Field	< 2.5 kG	< 2.5 kG
Interaction Solenoid Length	> 30 cm	1.8 m
Pulse Duration	> 10 μs	> 10 μs

The space charge limited combined current from both cathodes follows the $I \propto \Phi^{3/2}$ law [4]. However, the perveance varies between 66-37 mA·kV$^{-3/2}$ depending on the ratio of outer cathode potential to inner. Equal space charge limited currents are reached for $\Phi_{outer} = 0.78 \cdot \Phi_{inner}$ corresponding to a perveance of 41 mA·kV$^{-3/2}$.

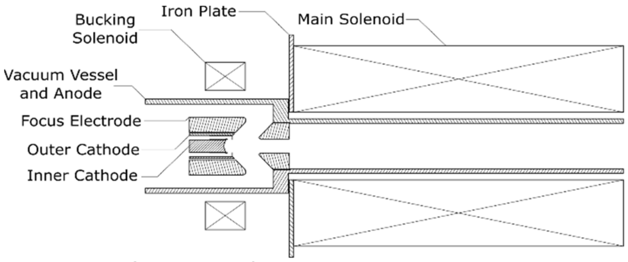

Figure 1. Geometry of the co-axial cathodes to generate the two stream instability. The bucking coil will be used to minimize the magnetic field on the outer cathode.

Decoupling Outer and Inner Cathodes: The electron guns need to be compact radially to minimize the distance between the beams in phase space, and the two co-axial cathodes need to be isolated from each other to reduce the influence of the inner cathode potential on the outer. The outer cathode protrudes 1.8 mm from the outer edge of the inner cathode to reduce shielding of the outer cathode emission area by the inner cathode potential. A heat shield on the outer cathode, although unnecessary to prevent electrons from streaming from inner to outer cathode because $\Phi_{inner} < \Phi_{outer}$, was vital to electrically isolate the cathodes particularly for $\Delta\Phi = \Phi_{inner} - \Phi_{outer} \rightarrow 0$ kV (see Fig. 2a). The outer electron beam without the heat shields in Fig. 2a is over focused and poorly coupled into the 1.7 kG magnet leading to a 36% increase in maximum beam radius as compared to the case with heat shields in Fig. 2b.

Magnetic Field and Interaction Region: Instead of one continuous winding that presents problems of transportation and electrical coil resistance, six individual solenoids each with independent power supplies will be conjoined. The solenoids are designed to have 12 layers of square 12 gauge wire (2 mm) to generate 1633 turns per 30 cm solenoid segment. The magnet bore will be 24 mm in diameter and enclosing a beam pipe with outer diameter of 22 mm. Vacuum pumping will take place at either end of the 1.8 m solenoid section. The longitudinal bunching of the electron beams will be measured on a low capacitance Faraday cup at the end of the interaction solenoid.

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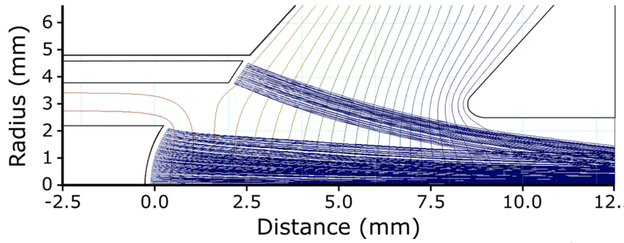
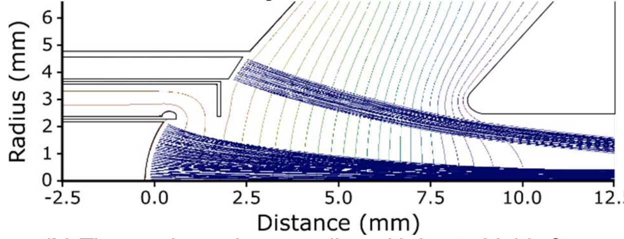


(a) The maximum beam radius without heat shields for a solenoid strength of 1.7 kG is 1.61 mm.



(b) The maximum beam radius with heat shields for a solenoid strength of 1.7 kG is 1.18 mm.

Figure 2. Electric equipotentials and beam traces for inner and outer cathodes generated using TRAK [3] for $\Phi_{inner} = -20$ kV and $\Phi_{outer} = -18$ kV. The electric potentials of the heat shields equal that of the nearest cathode.

References

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