ELECTRON GUN AND COLLECTOR DESIGN FOR 94-GHZ GYRO-AMPLIFIERS

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Abstract

This paper presents the electrical design of the magnetron injection gun and collector for high average power TE_{01} gyro-amplifiers. Both the gun and collector are currently under construction.

1 INTRODUCTION

The development of high-average power w-band gyro-amplifiers is currently being pursued by the Naval Research Laboratory, together with Litton Electron Devices and Communication & Power Industries as industrial partners. In addition to interaction circuit design aspects [1], key issues include the design of a high-quality electron gun and a collector capable of high average power operation. The gun and collector electrical designs were performed with the EGUN code [2], and were independently confirmed with the deformable-mesh gun code, DEMEOS [3]. Excellent agreement between the two codes has been realized.

The magnetron injection gun (MIG) design employs an optimized double-anode geometry and a radical cathode angle of 50^0 to achieve superior beam optics that are relatively insensitive to electrode misalignments and field errors. Perp. velocity spread of 1.6% at a velocity ratio of 1.52 is obtained for a 6 A, 65 kV beam. The design objective of the collector, which also serves as the output waveguide, is to minimize the required collector length while avoiding hot spots on the collector surface. Average power density of < 350 W/cm^2 on a 1.28" diameter collector is achieved for 59 kW average beam power.

2 94-GHZ MAGNETRON INJECTION GUN DESIGN

Efficient operation of gyro-devices depends critically on the quality of the electron beam. Consequently, for the current design, special emphasis has been placed not only in obtaining the best point design which exceeds all the requirements of the interaction circuit, but also in identifying and evaluating all factors which may contribute to the beam velocity spreads. Such factors include cathode surface roughness, electrode misalignments, and fabrication tolerances.

Specifically, the MIG design is subjected to the following RF circuit requirements:

Beam Current	5 - 7 Amperes
Beam Voltage	65 - 70 kV
Velocity Ratio	1.3 - 1.8
Perp. Vel. spread	2.5%
Max.Beam Radius	1.25 mm
Guiding Radius	0.8 - 1.1 mm
Oper. Magn. Field	36 - 38 kG

In addition, practical considerations dictate the need to maintain cathode loading, J_{cat}, below 8 A/cm^2 for reasonable cathode lifetime, peak electric field, E_{max}, well below 100 kV/cm to avoid arcing, and gun magnetic compression ratio, B_f/B_o, at or below 25 to minimize electron reflection and beam alignment problems. Moreover, since the gun will be operating at high-repetion rate, the modulating voltage required for beam pulsing must be minimized to avoid stressing the voltage modulator. It is due in part to this last requirement that the present gun design employs the double-anode geometry. The other key advantage of this geometry is the ability to adjust the beam perpendicular to axial velocity ratio, α, independent of the magnetic field profile.

Shown in Figure 1 is the MIG geometry and beam trajectory. It is essentially comprised of three regions: the cathode–mod-anode region, the mod-anode–anode region, and the beam tunnel or adiabatic compression region (partly shown). In performing the design, care has been taken to ensure to the largest extent possible that each region will perform mainly one key function. Such modular approach allows a much more rapid convergence

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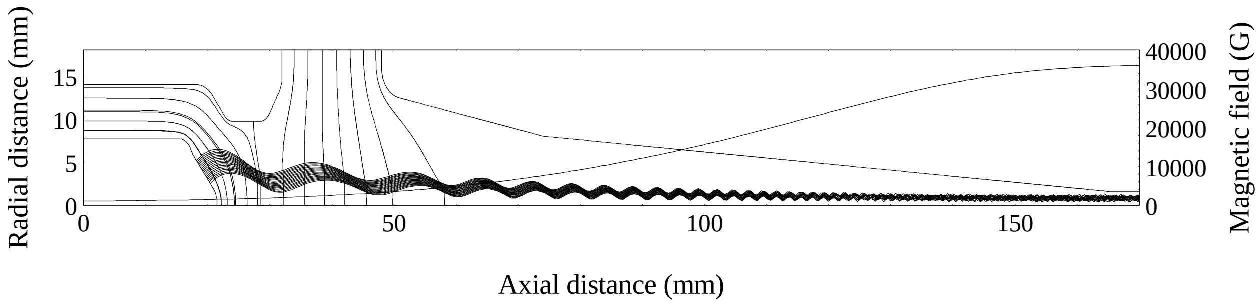

Figure 1: Geometry and beam trajectory of the 94 GHz magnetron injection gun point design

to the final design. Consequently, in the design, the initial beam perpendicular velocity is controlled mainly by the geometry and voltage of the cathode–mod-anode region, the mod-anode–anode region provides mainly axial acceleration to bring the beam up to full potential, and the beam is adiabatically compressed in the beam tunnel region to the final beam velocity ratio. An additional advantage of the modular approach is the ability to locally pinpoint and control beam velocity spread. For instance, the transverse beam spread can be minimized by shaping the cathode and mod-anode geometries.

Key elements of the design include a cathode well-recessed under the mod-anode shroud, a relatively large cathode angle of 50^0, and relatively parallel potential contours in the mod-anode–anode region. We shall discuss these key elements in turns.

The recessed cathode is critical for three reasons. First, by recessing the cathode deep inside the mod-cathode shroud, we essentially shield the cathode from the high anode potential (~65 kV relative to cathode). This design choice reduces the maximum electric field on the cathode tip to less than 67 kV/cm (This value has also been independently confirmed with ANSYS [4]), well below the dc breakdown threshold. Second, it allows for the relatively independent control of the beam initial transverse velocity ($\mathbf{E}_c/\mathbf{B}_c$) with just the voltage and geometry of the cathode - mod-anode region. Finally, it minimizes the leakage electric field (i.e., when $V_{mod\text{-}anode} = V_{cathode}$) on the thermionic emitting strip from the anode voltage. This reduces the required negative mod-anode voltage swing relative to the cathode for complete beam shutoff (i.e., less stress on the modulator). For this design, this is -1.7 kV.

The relatively large cathode angle of 50^0 is a consequence of trading off between various conflicting requirements. Chief among these is the need to maintain the overall coherency of the cyclotron phase for all beam electrons at least until the electric field is primarily axial. This is important because to the lowest order unless all beam electrons picks up the same amount of transverse energy, in their cycloidal motion through the region of substantial radial electric field, serious beam spread will result. For this design, because of the small mean radius of the emitter strip, the relatively high beam current, and cathode loading considerations, the emitter strip width is a substantial fraction of the cyclotron period; thus, the need for large cathode angle to compensate.

In the relatively long region between the mod-anode and anode, it is critical that the electric field is primarily axial. Even though, in principle, for a fixed set of operating parameters, one can shape the potential contours in this region to greatly correct for any initial beam spread. However, due to the fact that the beam can perform more than two cycloidal orbits in this region, any deviation from the operating parameters will also greatly degrade the beam quality; hence, reducing flexibility. Consequently, it is more advantageous to ensure that mainly axial acceleration is performed in this region, consistent with the modular design methodology.

The optimized point design parameters are shown in the table below. Agreement between EGUN and DEMEOS is excellent in terms of beam velocity ratio, velocity spreads, position, and size.

Anode Voltage	65 kV
Mod-anode Voltage	17 kV
Beam Current	6.0 A
Velocity Ratio	1.5
Perp. Velocity Sprd.	1.6%
Max. Beam Radius	1.25 mm
Beam Guiding Center	0.82 mm
Circuit Magnetic Fld.	36 kG
Mag. Comp. Ratio	25
Cathode Loading	6.76 A/cm^2

Additionally, simulations have been performed to explore the gun performance under various operating parameter ranges, i.e., mod-anode voltage, beam current, and beam voltage. This study indicates that the perpendicular velocity spread does not exceed 2% within the operating range required by the interacting circuit, and that the design is indeed optimized. This is exemplified by Figure

2 which shows the beam velocity and perpendicular velocity spread as a function of mod-anode voltage.

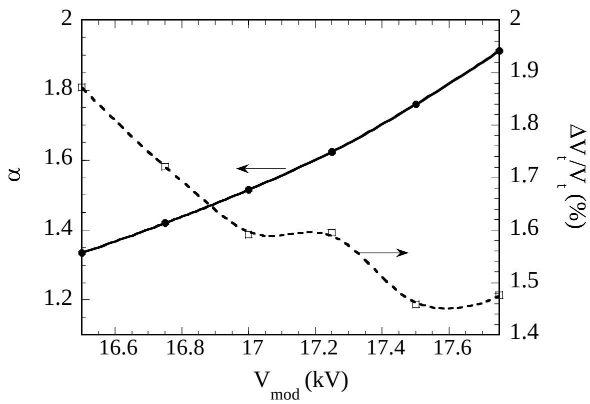

Figure 2: Beam velocity ratio and perp. velocity spread versus mod-anode voltage.

Of the 1.6% final perpendicular velocity spread in the point design, 0.6% of which is a direct result of electron phase-mixing in the present of the beam space-charge in the adiabatic compression region. This is independently confirmed with the Univ. Of Maryland code MAGUN [5].

We have also investigated the impact of cathode surface roughness on beam spread [6-7]. Our results indicate an additional 0.7% beam transverse velocity spread can be expected from bumps of 1 microns in height and width.

In addition, an exhaustive study of the resulting beam quality sensitivity with respect to misalignments, fabrication tolerances, and geometric deviations from the design has been performed. Within the fabrication tolerance and alignment specifications, the study indicates that the beam perp. velocity spread does not exceed 2%.

3 COLLECTOR DESIGN

The design requirements for the collector of the 94-GHz gyroklystron call for: no voltage depression, the ability to handle up to 91 kW average beam power (7A, 65kV, 20% duty), collector loading below 750 Watts/cm^2 desirable (1.0 kW/cm^2 is hard limit), collector compatible with RF output requirements, and no sweeping of collector magnetic field. Numerous collector sizes and magnetic profiles were evaluated for various beam parameters from the MIG design. The final collector design employed a 1.28” diameter pipe with 4 collector magnet coils. The resulting peak loading of 600 W/cm^2 for a 7A, 65kV beam at 20% duty is well within the cooling limit.

Shown in Figure 3 are the EGUN beam trajectory plot in the collector for a 6 A, 65 kV beam from the MIG point design. Good agreement between EGUN and DEMEOS has also been obtained as illustrated by Figure 4. A sensitivity study of the collector power loading with respect to the magnetic field profile has also been performed. It indicates that the peak power loading (but not necessarily the profile) on the collector remains relatively constant if the current in each of the four collector coils can be maintained within +/-5% of the design value.

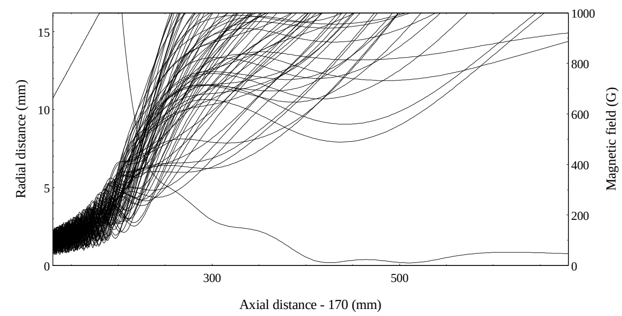

Figure 3: Beam trajajectory in the 1.28” collector

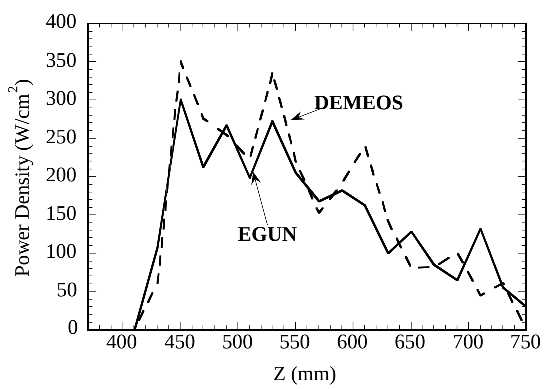

Figure 3: Comparison of average power loading on collector wall between EGUN and DEMEOS.

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