X-BAND MAGNICON AMPLIFIER FOR THE NEXT LINEAR COLLIDER

Steven H. Gold and Arne W. Fliflet
Beam Physics Branch, Plasma Physics Division,
Naval Research Laboratory, Washington, DC 20375–5346

Allen K. Kinkead
Sachs/Freeman Associates, Inc., Landover, MD 20785

B. Hafizi
Icarus Research, Inc., P.O. Box 30780, Bethesda, MD 20824–0780

Oleg A. Nezhevenko,† Viacheslav P. Yakovlev,†
and Jay L. Hirshfield
Omega-P, Inc., 202008 Yale Station, New Haven, CT 06520
†Permanent Address: Budker Institute of Nuclear Physics, Novosibirsk, Russia 630090

Richard True and Robert J. Hansen
Litton Systems, Inc., Electron Devices Division, San Carlos, CA 94070

Abstract

The magnicon is a scanning-beam microwave amplifier that is being developed as a high power, highly efficient microwave source for use in powering the next generation of high gradient electron linear accelerators. In this paper, we present a progress report on a new thermionic magnicon experiment designed to produce more than 50 MW at 11.4 GHz, using a 210 A, 500 kV beam from an ultrahigh convergence thermionic electron gun driven by a rep-rated modulator. This new design has a predicted efficiency in excess of 60%.

1 INTRODUCTION

The magnicon [1] is a scanning-beam microwave amplifier tube that is under development as a radio-frequency (RF) source to power future high gradient electron accelerators such as the proposed TeV Next Linear Collider (NLC). The magnicon uses rotating TM modes to spin up a pencil electron beam to high transverse momentum in a series of deflection cavities, the first externally driven, and then a synchronously rotating RF mode of the output cavity is used to extract the transverse momentum as microwave power at the drive frequency or one of its harmonics.

The Naval Research Laboratory (NRL) has been investigating magnicon physics for the past five years with the goal of building a high power 11.4 GHz magnicon tube. We published a design study for a 50 MW, 50% efficient frequency-doubling 11.4 GHz magnicon employing a 500 kV, ~170 A, 2-mm-diam. electron beam from an advanced thermionic electron gun [2], and then designed and built an initial magnicon experiment using a cold-cathode diode on the NRL Long Pulse Accelerator Facility. However, the experiment employed a 5.5-mm-diam. beam, for which the predicted efficiency falls to ~20%. The experiment demonstrated high power operation (14 MW ±3 dB) at ~10% efficiency in the synchronous magnicon mode at 11.120 GHz, but a plasma loading problem restricted operation to parameters for which the final deflection cavity (the penultimate cavity) was unstable. Nevertheless, good agreement was found with predictions of a simulation based on the actual experimental parameters [3,4].

The Budker Institute of Nuclear Physics (INP) is carrying out thermionic magnicon experiments at 7 GHz [5]. They recently reported 46 MW at 49% efficiency in a 1 μsec pulse. Some members of the INP magnicon team are collaborators in the present work.

In this paper, we present a progress report on a new thermionic magnicon amplifier (see Fig. 1) that is under construction at NRL in collaboration with Omega-P, Inc. The design has been optimized for the parameters of a new ultrahigh convergence 500 kV, 210 A thermionic electron gun, and incorporates improvements that should raise the efficiency while reducing the possibility of RF breakdown. The predicted efficiency is greater than 60%.

The essential components of a high power thermionic magnicon experiment are a high power mod-

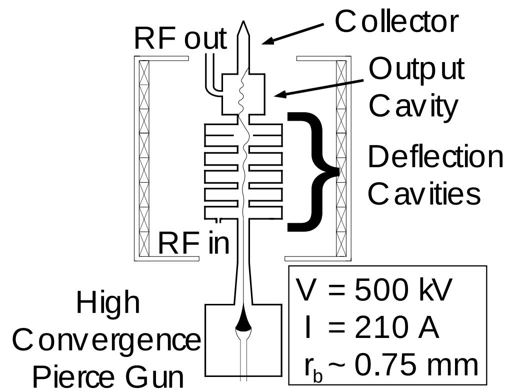

Figure 1: Schematic of the high efficiency thermionic magnicon amplifier.

0-7803-4376-X/98/$10.00 © 1998 IEEE

ulator, an ultrahigh convergence electron gun, a matched magnet system, and a set of cavities designed for high vacuum, high temperature bakeout, and high efficiency operation. In the next sections, we discuss the design of a novel high convergence electron gun to produce a 500 kV, 210 A, <2-mm-diam. beam, and the redesign of the magnicon circuit to optimize the efficiency, to lower the peak surface RF fields, and to side-couple the microwave power from the output cavity into X-band waveguide.

2 THE ELECTRON GUN

The point design for the 11.424 GHz magnicon amplifier uses a 500 kV, 210 A, 1.5-mm-diam. electron beam, with a 1.5 μsec pulse width and a 10 Hz repetition rate. It should be noted that the Brillouin diameter is ~1.3 mm at 6.5 kG. The electron gun is a novel high convergence relativistic Pierce gun using a dispenser cathode. The gun design and beam matching into the magnetic field were carried out using the codes DEMEOS [6], SAM [7], and SUPERSAM [8]. Beam compression in the gun must be high in order to limit the field gradient at the focus electrode and to limit cathode loading. A 7.5-cm-diam., 30°-half-angle cathode was used, implying an overall compression ratio of 2500:1 and a mean cathode loading of 4.5 A/cm^2. The gun design is shown in Fig. 2, and its properties are summarized in Table I. A key feature of the gun is an electrically isolated focus electrode next to the cathode. This electrode is biased negatively by a few hundred volts with respect to the cathode in order to control the beam edge discharge angle and to eliminate emission from the outer cathode cylinder, both of which can give rise to unwanted halo electrons. This gun is being built by Litton Systems, Inc., with delivery expected in July of this year, and a matching magnet has been built by the INP.

3 THE MAGNICON CIRCUIT

The new magnicon circuit consists of a drive cavity, three gain cavities, a penultimate cavity, and an output cavity, as illustrated in Fig. 1. The drive and gain cavities are similar to those in the previous NRL design [2].

TABLE I. Electron gun design parameters

Current	210 A
Voltage	500 kV
Microperveance	0.59
Cathode radius	3.77 cm
Beam radius	0.75 mm
Compression ratio	2500:1
Current density	12 kA/cm^2
Maximum field on focusing electrodes	186 kV/cm
Mean cathode loading	4.5 A/cm^2
Pulse duration	1.5 μsec

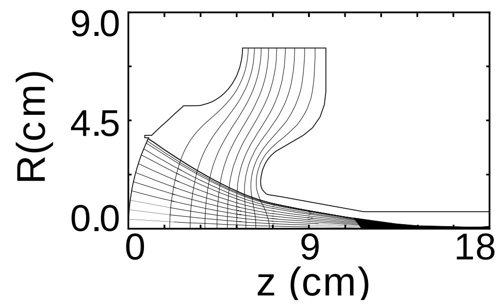

Figure 2: Design for the 500 kV, 210A magnicon electron gun, showing electrode geometry, selected electron trajectories and equipotentials.

In the following subsections, we discuss the redesign of the penultimate and output cavities, and the simulation of the entire magnicon circuit.

3.1 The penultimate cavity

The penultimate cavity is an iris-coupled TM_{110} π-mode two-section cavity that carries out the final stage of beam spin up. As a result, it contains very high RF fields, creating the danger of RF breakdown. The objective of the new design was to optimize the beam spin-up, while minimizing the surface RF fields. The redesign involved adjusting the beam pipe diameter, rounding of the beam tunnel and the iris, and reducing the length of the first cavity section. For the new penultimate cavity, the combination of reduced field enhancements, and of more effective beam spin-up due to shortening the first cavity section, reduced the maximum surface electric field from 670 kV/cm in the original design to 572 kV/cm, comparable to values employed in high power X-band klystrons at SLAC. The maximum electric field on the iris aperture is 472 kV/cm.

3.2 The output cavity

In order to improve the efficiency and lower the rf fields, the output cavity was also redesigned, reducing the beam tunnel diameter, increasing the rounding of the beam tunnel apertures, and shortening the cavity from 5 cm to 4 cm. This is discussed in greater detail in Ref. 9. As a result, the maximum surface rf field in the output cavity was reduced from 830 kV/cm to 520 kV/cm. The second goal is to redesign the cavity for side coupling rather than end coupling, in order to extract the output power directly into X-band waveguide, rather than through a circular pipe that must also serve as the beam collector. The INP 7 GHz magnicon employs two rectangular waveguides separated by 135° to couple out both non-rotating components, and uses additional wall perturbations to restore the quadrupole symmetry [5]. This is the approach that we have adopted.

Figure 3 shows a cross section of the new magnicon circuit, and shows the ten magnet coils and a portion of

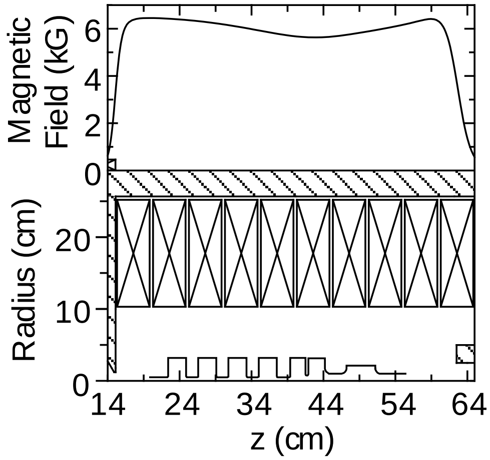

Figure 3: Cross-section of the magnicon circuit, showing the axial magnetic field.

the iron yoke and pole pieces. The new circuit consists of a drive cavity, three simple gain cavities, and a redesigned penultimate cavity, all operating in the TM_{110} mode at 5.712 GHz, followed by a new output cavity operating in the TM_{210} mode at 11.424 GHz. The addition of a gain cavity has increased the gain to 58 dB, reducing the drive power for a 66 MW device to approximately 100 W at 5.712 GHz. This gain is consistent with values used at SLAC in the design of X-band klystrons for the NLC. Figure 3 also shows the calculated on-axis magnetic field. The magnetic field is decreased in the vicinity of the penultimate and output cavities by lowering the current through the sixth coil, in order to stabilize the penultimate cavity against oscillation and to increase the output efficiency.

3.3 The complete circuit

Figure 4 shows a simulation of the complete magnicon circuit for a 1.5-mm-diam. electron beam, showing the trajectories and the spatial evolution of the electron energy through the asymptotic rf fields from a complete time-dependent simulation. The transverse dimension is stretched in order to show details of the orbits. The beam scalloping that is evident results from simulating a zero canonical momentum beam without space charge. Notice that energy spreads and large energy excursions occur in the region of the penultimate cavity, but that the energy loss in the output cavity is remarkably uniform. The result is 66 MW at 63% efficiency. The magnicon design parameters are shown in Table II. Our simulations show a loss in efficiency of only a few percent at beam diameters up to 2.5 mm.

TABLE II. Thermionic magnicon design parameters

Frequency	11.424 GHz
Power	66 MW
Efficiency	63%
Pulse width	1.5 µsec
Repetition rate	10 Hz
Drive frequency	5.712 GHz
Drive power	100 W
Gain	58 dB

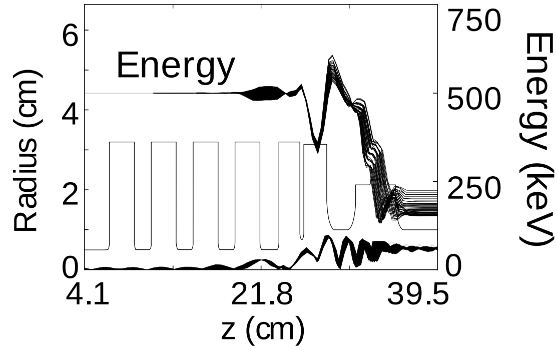

Figure 4: Steady-state simulation of the thermionic magnicon design for a 1.5-mm-diam. beam.

4 SUMMARY

We have designed an electron gun and circuit for a high gain, high efficiency 11.424 GHz frequency-doubling magnicon amplifier. The beam parameters are 500 kV, 210 A, and 1.5-mm beam diameter. The electron gun will be driven by a 1.5 µsec, 10 Hz modulator. The predicted power is 66 MW at 63% efficiency. The maximum surface electric field is approximately 570 kV/cm, a value that is consistent with 1.5 µsec pulse widths. This design is the basis of a new thermionic magnicon experiment, which we plan to assemble and test in 1997.

5 ACKNOWLEDGMENTS

This work was supported by the U.S. Department of Energy (DoE) and the Office of Naval Research under Interagency Agreement DE-AI02-94ER40861. A portion of this work was also supported by a DoE Small Business Innovation Research (SBIR) grant to Omega-P, Inc. and carried out under a Cooperative Research and Development Agreement (CRADA) between NRL and Omega-P.

6 REFERENCES

[1] O.A. Nezhevenko, *IEEE Trans. Plasma Sci.* **22**, 765 (1994).

[2] O.A. Nezhevenko *et al.*, *IEEE Trans. Plasma Sci.* **22**, 785 (1994).

[3] S.H. Gold *et al.*, *IEEE Trans. Plasma Sci.* **24**, 947 (1996).

[4] S.H. Gold *et al.*, *Phys. Plasmas*, May 1997, in press.

[5] E.V. Kozyrev *et al.*, paper in this proceedings.

[6] R. True, in *Handbook of Microwave Technology*, ed. K. Ishii (Academic, New York, 1995), Vol. I, p. 497.

[7] D.G. Myakishev and V.P. Yakovlev, Int. J. Mod. Phys. A **2** (Proc. supp.), 915 (1993).

[8] M.A. Tiunov *et al.*, in *Proc. 13th Int. Conf. on High Energy Accelerators* [NAUKA (Siberian Branch), 1987], Vol. 1, p. 353.

[9] S.H. Gold *et al.*, *NRL Memo Report 7857* (1996).