Guest Editorial
Introduction to the Special Topics Issue on High-Power Microwave Generation

Introduction

THIS ISSUE of IEEE TRANSACTIONS ON PLASMA SCIENCE presents a collection of papers dealing with a wide range of topics pertinent to the generation of high-power microwave radiation. The purpose of this Special Topics Issue is to provide an update on the progress made by the many different types of microwave generation devices currently under investigation. The contents of the various papers should serve not only to keep researchers in the field abreast of the most recent developments in high-power microwave generation, but also to inform potential users of these devices as to the present and future capabilities of the various approaches.

The possible applications of these devices span a wide range of technologies. The plasma physics community has already taken advantage of some of the recent advances in producing high-power microwaves in the areas of plasma heating for magnetic confinement fusion, plasma production for numerous different processes, and plasma diagnostic measurements. Other applications which await the development of new high-power sources include space communications, high-resolution radar, and next-generation linear accelerators.

For the purposes of this issue we have grouped the papers into five different categories. These categories include: 1) gyrotrons and cyclotron-resonance devices, 2) free-electron lasers, 3) virtual-cathode and reflex oscillators, 4) Cerenkov radiation generators, and 5) magnetrons, klystrons, and backward-wave oscillators. The first four groupings are loosely based on the type of interaction mechanism employed in the devices to convert electron beam energy into microwave power. The fifth group includes papers which discuss advances based on "conventional" interaction circuit approaches.

Gyrotrons and Cyclotron-Resonance Devices

Gyrotrons and cyclotron-resonance devices continue to give promising results in producing high powers at short wavelengths. The high level of effort concentrated on cyclotron-resonance devices is exhibited by the large number of gyrotron papers included in this Special Topics Issue, as well as those published in a recent collection of gyrotron-related papers [1]. This research effort has already led to the commercial availability of high-average-power gyrotrons at frequencies up to 140 GHz.

We begin the section on gyrotrons and cyclotron-resonance devices with a paper by Kreischer *et al.* from the Massachusetts Institute of Technology, which gives a generalized gyrotron design analysis enabling the determination of design parameters for CW gyrotron oscillators over a wide range of frequencies and power levels. The initial results of high-peak-power gyrotron experiments are discussed by Gold *et al.*, and Danly *et al.* present experimental results for a 140-GHz gyrotron oscillator designed to operate in a whispering-gallery mode. Danly *et al.* also report on the use of a novel quasi-optical output antenna. The first experimental results on 100-GHz 200-kW gyrotrons, being developed by Thomson-CSF, are discussed in a paper by Bensimhon *et al.* They show that stable operation is possible with a high-order mode, complex interaction cavity. Saito *et al.* discuss tests on a 137-GHz gyrotron oscillator designed for plasma scattering diagnostics. They show that operation at beam currents well above the oscillation threshold is possible but leads to axial mode competition. This is of importance in scaling gyrotrons to very-high-power operation with large beam currents.

The possibilities of phase locking and frequency tuning in gyrotron oscillators are addressed experimentally in the papers by Read *et al.* and Park *et al.*, respectively. The device described by Park *et al.* can also operate as a gyrotron traveling-wave-tube amplifier. The next four papers discuss gyroklystron amplifiers. Ganguly *et al.* present a detailed theory for gyroklystron amplifier operation. A companion paper, written by Bollen *et al.*, presents experimental results for a three-cavity gyroklystron and compares the outcome of the experiment with theoretical predictions of the previous paper. The design of a 30-MW gyroklystron amplifier is given in a paper by Chu and a group from the University of Maryland. The goal of their work is to demonstrate the feasibility of producing gyroklystron amplifiers which are capable of driving next-generation linear accelerators. Gyroklystrons which operate at high harmonics of the cyclotron frequency and employ axis-encircling electron beams are discussed in a second paper by Chu, this time in collaboration with a group from the University of California, Los Angeles.

Harmonic gyrotron operation using an axis-encircling electron beam is also the subject of the work presented by Lawson *et al.* Their research is oriented toward the production of very-high-peak-power levels. The final paper in this section is a study of the mode competition present in a device called the peniotron. Though the peniotron is generally not classified as a gyrotron-type device, the operating frequency of a peniotron is related to the electron cyclotron frequency, just as it is for gyrotrons. In fact, as Vitello and Ko show in their work, mode competition in the peniotron comes primarily from normal gyrotron-type interactions.

0093-3813/85/1200-0361$01.00 © 1985 IEEE

Free-Electron Lasers

Though much of the research on free-electron lasers (FEL's) is aimed at producing radiation in the infrared and visible portions of the spectrum, some of this work is also applicable to microwave and millimeter-wave FEL's. As in the case of gyrotrons, a significant amount of experimental and theoretical work on FEL's is currently being carried out at numerous research institutions. Much of this work was recently reported in a Special Topics Issue devoted to work on free-electron lasers [2].

In this Special Topics Issue there are three papers which fall into the category of FEL's. The first of these describes a self-consistent kinetic theory for the FEL. In this paper, Davidson and Wurtele illustrate their work with specific calculations for the FEL experiments at Los Alamos National Laboratory and Lawrence Livermore National Laboratory. Yee and Marshall discuss efficiency enhancement in an FEL in the Raman operating regime. They also summarize the design for a planned experiment to be performed at Columbia University. The final FEL paper, by Hartemann *et al.*, summarizes the experimental results of an FEL of novel design. In this device, the crossed electric- and magnetic-field configuration of a magnetron is combined with a magnetostatic wiggler, characteristic of FEL's.

Virtual-Cathode and Reflex Oscillators

The devices discussed in this category are typically very-high-power microwave sources. This is due to the fact that in most cases the interaction depends critically on the formation of a virtual cathode, created when the electron beam current exceeds the space-charge limiting current in a hollow pipe. Though such a device was the basis of what is generally acknowledged as the first microwave tube and emitted powers in the milliwatt range [3], current research in this area has led to microwave powers at the gigawatt level.

The first paper, by Sze *et al.*, describes experiments on a virtual-cathode oscillator (also called a vircator) where radiation is extracted from the interaction region using two different techniques. Peratt *et al.* report on experiments performed on a reflex-triode oscillator. Their work also includes electromagnetic particle-in-cell simulations for the device. Theoretical and experimental work on a similar device at Lawrence Livermore National Laboratory is described in a paper by Scarpetti and Burkhart. In a paper entitled "The Turbutron," Brandt describes a new type of virtual-cathode device which may be more suitable for higher-frequency operation than other types of virtual-cathode and reflex oscillators. Finally, a paper by a group from the University of California at Irvine describes the microwave emission from a beam–plasma interaction. These experiments are aimed at understanding the basic interaction processes in the beam–plasma system rather than optimizing the configuration into a true microwave source.

Cerenkov Radiation Generators

The production of microwave radiation, when an electron beam passes through or in close proximity to a dielectric medium at a velocity equal to the speed of light in the medium, is called Cerenkov radiation. The Cerenkov interaction is essentially the same slow-wave interaction characteristic of traveling-wave tubes, where the delicate slow-wave structure is replaced by a continuous solid or gas dielectric. A recent review article on the subject has summarized much of the theoretical and experimental work which has been performed in an effort to utilize Cerenkov radiation to produce high-power microwaves [4].

In this Special Topics Issue, we have two papers which discuss various aspects of utilizing the Cerenkov interaction in generating microwave radiation. The first paper, by Garate and Walsh, presents calculations which lead to optimal design parameters for a Cerenkov generator in the microwave regime. The second paper, by Lin *et al.*, includes multiparticle simulations for a Cerenkov microwave device and suggests a method of enhancing the efficiency of a given design.

Magnetrons, Klystrons, and Backward-Wave Oscillators

In our final category, we have included papers which utilize the basic concepts of several of the most well-known types of microwave tubes. However, the results presented for these devices far exceed those obtainable in currently available "off-the-shelf" versions of the same devices.

The paper by Benford *et al.* reports the results of experiments performed on a relativistic magnetron at Physics International Co. The state of the art in high-peak-power klystron technology is represented by the work of Lee *et al.* They have observed *S*-band power levels of 150 MW with efficiencies of 50 percent on an advanced klystron design in experiments at the Stanford Linear Accelerator Center. Backward-wave oscillators are the subject of the final two papers in the Special Topics Issue. The first of these is a theoretical study of the sensitivity of a backward-wave oscillator to Budker's parameter by Brandt and Uhm. In the second paper, Kehs *et al.* present the design and initial experimental results for a high-power backward-wave oscillator.

As is evident from the wide variety and impressive results of the high-power microwave generation devices discussed in this Special Topics Issue, a lot of ingenuity and hard work is paying off in significant advances to the state of the art. As long as important applications continue to be more and more demanding in their microwave power requirements, the momentum and enthusiasm in the field should continue to flourish.

Acknowledgment

I would like to thank the many authors and referees who have generously contributed much time and energy to this Special Topics Issue on High-Power Microwave Generation. In addition, I would like to acknowledge the skillful assistance of J. Camp in preparing this issue, and the Varian Microwave Tube Division for allowing me the opportunity to participate in this stimulating endeavor.

References

[1] M. Q. Tran, Guest Ed., "Gyrotrons 3," *Int. J. Electron.*, vol. 57, no. 6, pp. 786–1246, Dec. 1984.
[2] V. L. Granatstein and C. W. Robertson, Guest Eds., "Third special issue on free-electron lasers," *IEEE J. Quantum Electron.*, vol. QE-21, no. 7, pp. 804–1119, July 1985.
[3] H. Barkhausen und K. Kurz, "Die kurzesten, mit Vakuumrohren herstellbaren Wellen," *Phys. Z.*, vol. 21, pp. 1–6, Jan. 1920.
[4] J. E. Walsh, "Stimulated Cerenkov radiation," in *Advances in Electronics and Electron Physics*, vol. 58. New York: Academic, 1982, pp. 271–310.

Kevin Lee Felch, *Guest Editor*
Manager, Gyrotron Oscillator Development
Microwave Tube Division
Varian Associates, Inc.
Palo Alto, CA 94303