23. At a fixed efficiency of 30% for converting beam power to microwave power, operating at a current that is 80% of the space-charge-limiting value, plot the microwave output power at 2 MV as a function of wall radius (assuming a 2-mm standoff between the thin annular beam and the wall). Take account of space-charge depression of the beam energy.

24. To get higher beam power at fixed voltage, one must raise the current. Given that the beam must have some separation from the wall, it seems that one must increase the radius of the drift tube. From the standpoint of basic klystron operating principles, what problem does this raise?

25. To continue to raise beam currents while maintaining cutoff between cavities, the triaxial klystron, with a center conductor in the drift tube, has been proposed. We want to know the cutoff frequencies for the triaxial waveguide configuration. To avoid the headaches of cylindrical geometry and Bessel functions, consider the case where the cylindrical geometry is almost planar, when the inner conductor is close to the outer. (a) Derive the normal modes and dispersion relation for the three classes of waves in a planar waveguide with infinite parallel-plate conductors separated by a distance d: transverse electromagnetic (TEM), transverse electric (TE), and transverse magnetic (TM). (b) Comment qualitatively on the difficulties posed by the TEM waves. If you can, offer a comment about the probability that these waves will couple to a beam and drive axial density perturbations.

26. In the reltron, the modulation cavity fill time delays microwave onset. We define this time as the period from the start of the electron beam to the time when the microwave signal reaches its full-power flattop. In Figure 9.29, estimate the cavity Q and the reduction in energy efficiency that this effect causes.

27. Derive the expression for the space-charge-limiting current in the triaxial klystron given in Equations 9.35 and 9.36.

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10

Vircators, Gyrotrons and Electron Cyclotron Masers, and Free-Electron Lasers

10.1 Introduction

This chapter is devoted to a somewhat briefer treatment of three classes of narrowband microwave sources that are unrelated in their underlying operating principles: virtual cathode oscillators, gyrotrons and electron cyclotron masers, and free-electron lasers. The reason for collecting these microwave sources in a single chapter is that at this time we regard these three classes of narrowband sources as somehow less significant in the field of high power microwaves (HPM) than the sources of Chapters 7 to 9. Let us consider each separately and state the reasons for our admittedly subjective judgment, which varies with the source, recognizing that the significance of any one of them could change with shifts in the technology or application needs.

Virtual cathode oscillators are enjoying something of a renaissance at this time, and developments with two variants in particular — tunable vircators and coaxial vircators — may yet overcome two problems that have plagued devices of this type: low efficiency and sensitivity to gap closure in the high-current, explosive emission diodes that are so often used with sources of this type. Nevertheless, despite their efficiency problems, these sources are attractive in applications requiring a simple source configuration — vircators many times employ no applied magnetic field and no slow-wave structure — and low device impedance, which permits high power operation at low voltage or optimizes coupling with low-impedance power sources such as explosive generators, which are a compact, energy-rich power source.

Gyrotrons are an extraordinarily mature source for high-average-power application at the several-megawatt level to the problem of heating magnetic fusion plasmas at electron cyclotron resonance frequencies of 100 GHz or more (see Chapter 3). In fact, gyrotrons join klystrons as the only sources that are produced to continuously generate power levels at 1 MW or above. Another variant of this class of *electron cyclotron masers*, the *gyroklystron*, has been investigated as an alternative to klystrons for power levels around 100 MW and frequencies in the X-band and above. Another variant, the *cyclotron*