Results From an X-Band Coaxial Extended Length Cavity

T. J. Davis, Member, IEEE, L. Schächter, and J. A. Nation, Fellow, IEEE

Abstract—Experiments and simulations demonstrate high-power microwave generation at 9 GHz in a coaxial geometry. The 9 cm diameter annular electron beam is propagated between inner and outer drift tube conductors, a configuration which increases the beam current and reduces the structure fields from existing high-power sources. Since the TEM mode of the coaxial guide reduces the quality factor of small-gap cavities, especially at high frequency, the interaction is provided by an extended length cavity loaded with dielectric. A single 16 cm cavity generates 200 MW of power from the 400 keV, 7 kA electron beam. Although the cavity can oscillate at a number of resonances, a single mode is selected with 10–30 kW of input power from a magnetron. A coupler samples 25 MW of the power from the interaction region, precisely measured using a single-shot calorimeter. Simulations indicate that the efficiency of the device is limited to 7% by saturation effects, and can be improved by reducing the length of the cavity.

I. INTRODUCTION

VIGOROUS effort in recent years has been applied toward the development of high peak power microwave amplifiers for particle accelerator and phased-array radar applications. Although relativistic klystrons [1, 2], gyrokystrons [3], traveling wave tubes [4] and free electron lasers [5] have extended the limits of radio frequency ( rf ) sources, no single device satisfies the stringent criteria of high frequency ( >9 GHz ) and high peak power ( >= 100 MW ) while maintaining amplitude and phase stability. The common approach in these devices is to propagate the electron beam in a single conductor waveguide, where the interaction occurs with the fundamental mode. As a consequence, the most serious limitation is the high fields imposed on the surface of the microwave structures, which often results in breakdown or pulse shortening [6] as the output power is increased. Reducing the surface fields below the threshold for field emission and breakdown is necessary to increase the peak power of any device, but is exceedingly difficult as the characteristic dimensions shrink for X and K frequency bands.

To alleviate the shortcomings of existing devices, we initiated a program to study microwave generation in a coaxial geometry. The cross section of our coaxial drift space is illustrated in Fig. 1: an annular electron beam is propagated within inner and outer drift tube conductors. By increasing the average diameter of the system, the surface fields are reduced because of the expanding volume in the microwave structures. A TM_{010} cavity in our coaxial arrangement, for instance, will reduce the maximum electric field by a factor of four over a standard pillbox TM_{010} resonator (for equivalent stored energy and gap length). In addition, the annular beam configuration allows the propagation of much higher beam currents; the beam cross sectional area increases with the average system diameter, and the limiting current is enhanced by the annular geometry. The limiting current for a thin annular beam in the coaxial drift tube may be calculated from

\[ I_{\text{limit}} = 8.5 \left( \frac{\gamma^{2/3} - 1}{\ln(r_b/r_i)} \right)^{3/2} \left( \frac{1 - \ln(r_b/r_i)}{\ln(r_b/r_o)} \right) \kA \]  

where \( \gamma \) is the injection relativistic factor, \( r_b \) is the beam radius, and \( r_i, r_o \) are the inner and outer radii of the coax, respectively. For our 9 cm average system diameter, the limiting current is 48 kA, much higher than the 2-3 kA often found in pencil beam klystrons. In many respects, the coaxial beam is similar to a high aspect ratio sheet beam [7].

Of course, as the average system diameter is increased, waveguide modes will propagate in the drift space. Although the transverse magnetic (TM) modes can be cutoff in the coaxial guide by decreasing the separation distance between drift tube conductors, the fundamental transverse electromagnetic (TEM) mode and several transverse electric (TE) modes will propagate. Control of the transmission line TEM mode remains the most difficult task in the development of a coaxial microwave amplifier. The first high-power coaxial...