A high-power two stage traveling-wave tube amplifier

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Results are presented on the development of a two stage high-efficiency, high-power 8.76-GHz traveling-wave tube amplifier. The work presented augments previously reported data on a single stage amplifier and presents new data on the operational characteristics of two identical amplifiers operated in series and separated from each other by a sever. Peak powers of 410 MW have been obtained over the complete pulse duration of the device, with a conversion efficiency from the electron beam to microwave energy of 45%. In all operating conditions the severed amplifier showed a “sideband”-like structure in the frequency spectrum of the microwave radiation. A similar structure was apparent at output powers in excess of 70 MW in the single stage device. The frequencies of the “sidebands” are not symmetric with respect to the center frequency. The maximum, single frequency, average output power was 210 MW corresponding to an amplifier efficiency of 24%. Simulation data is also presented that indicates that the short amplifiers used in this work exhibit significant differences in behavior from conventional low-power amplifiers.

These include finite length effects on the gain characteristics, which may account for the observed narrow bandwidth of the amplifiers and for the appearance of the sidebands.

It is also found that the bunching length for the beam may be a significant fraction of the total amplifier length.

I. INTRODUCTION

Recent experiments have demonstrated the capability of generating large microwave output powers ranging from several hundred megawatts up to 15 GW.\textsuperscript{1–9} The operating frequencies of these devices range from 1 to 30 GHz. Sources of this type may be used in a variety of applications including phased array radars and drivers for ultra-high-energy electron accelerators. Many of the applications have common requirements on the source characteristics. Of these the most important is that the sources be frequency and phase stable. Clearly, for example, a phased array radar must have a controllable phase at each antenna to direct the beam, or an accelerator stage must have correct phasing compared to that in the previous stage to continue to accelerate the electrons to higher energy. This paper reports simulation data and experimental results obtained with a severed, high-power traveling-wave tube (TWT) operating in the x band at 8.76 GHz. The experiment extends work reported earlier on a single stage amplifier operating at the same frequency.\textsuperscript{10–12} In this work we reported narrow-band, high-gain operation of single stage periodic structure TWTs with either 11 or 22 periods. The amplifier input signal came from a 250-kW magnetron and the amplifier was powered by an 850-kV, 0.8–1.6-kA electron beam. A maximum gain of 33 dB, corresponding to a total output power of 110 MW in the TM\textsubscript{01} mode was achieved at a beam current of 1.6 kA. Attempts to operate with higher gain lead to oscillation at the input frequency. The two stage device, with the stages separated by a sever, was developed to reduce substantially positive feedback from the output to the input and allow higher-gain and -output power operation. The maximum gain and total power achieved with this device were 37 dB and 410 MW, respectively, at a beam current of 975 A and diode voltage of 850 kV, of which the amplified power at the magnetron frequency was 210 MW, corresponding to a 24% conversion efficiency. The remaining power appeared in “sidebands” separated from the center frequency by about 100 MHz.

In the following sections we present a brief description of the experimental configuration followed by a review of the characteristics of the single stage TWTs. This is followed by new data on the single stage devices and a full experimental account of the operation of the severed amplifier. The results are compared with simulation data and with analytic theory. A comprehensive paper describing the analytic results is in preparation. We conclude with a discussion of the results.

II. EXPERIMENTAL CONFIGURATION AND SINGLE STAGE TWT CHARACTERISTICS

A. Experimental configuration

The high-power TWT is driven by a relativistic electron beam generated from a water-filled Blumlein transmission line. The electron beam is produced from a field-emission diode with a carbon cathode. The diode voltage is 850 kV and has a 100-ns pulse duration. The beam current has been varied between 800 and 1700 A. The electron beam is a pencil beam 6 mm in diameter and is injected into the experimental region through a central hole in an extended graphite anode plug. The beam is confined by a longitudinal magnetic field that can be varied in the range 0–14 kG. A rippled-wall waveguide forms the slow wave structure for the TWT. The structure has an average radius of 1.32 cm, a ripple depth of 8 mm, and a periodic length.