Sideband development in a high-power traveling-wave tube microwave amplifier

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The work presented describes the characteristics of single stage and severed high-efficiency, high-power traveling-wave tube amplifiers operating in X band at 8.76 GHz. Average amplified output powers of 210 MW have been achieved at 24% efficiency. At high output power levels (> 100 MW) sidebands develop increasing the average radiated power to over 400 MW with a microwave conversion efficiency of over 45%. In single frequency operation phase stability to within ±8° has been demonstrated.

A considerable effort has been mounted in recent years towards the development of ultrahigh power microwave sources for new generations of electron accelerators and for phased array radar applications. Several experimental groups have reported very high microwave powers (in some cases in excess of 1 GW)2-5 at frequencies ranging from about 1 to 35 GHz. For some high-power applications the radiation must be monochromatic and have a fixed, controllable phase relationship to the radiation from other sources.6,10,11 One approach to achieving this goal is to drive a series of amplifiers from a single master oscillator. In this letter we report on the design, implementation, and operational characteristics of high-power traveling-wave tube amplifiers.

The microwave amplifiers are powered by an electron beam generated using a Blumlein transmission line to produce an 850 kV, 1 kA, 100 ns, pencil beam from a field emission diode. The beam is injected into a uniform guide through a transition section into a rippled wall traveling-wave tube (TWT) structure, which is designed to couple a forward wave in the TM01 mode to a space charge wave on the beam. Details of the amplifier configuration, and results from the single stage device have been previously published.5 The output section of the amplifier feeds a long conical horn antenna with a 25-cm-diam output window. The microwave input is provided from a tunable magnetron operating in X band at power levels of order 100 kW. Measurements are made by sampling the microwave signal transmitted through the output horn.

In high-gain operation a two-stage amplifier is used in which two identical 22-period amplifiers are operated in series and driven by the same electron beam. The amplifiers are isolated from each other by a carbon section (a sever) operated below cutoff for the TM wave. The energy of the electromagnetic wave grown in the first amplifier is absorbed in the resistive walls of the sever, but the space charge wave supported by the electron beam can propagate through to the second amplifier section with minimal loss. The sever also drastically reduces the feedback from the output section to the input and thus prevents oscillation due to positive feedback. When the beam enters the second amplifier section the structure radiation field is coupled to the slow space charge wave on the bunched electron beam and further amplification of bulk waves occurs.

For convenience we summarize some of the previously obtained results from the single stage device. More detail may be found in Ref. 5. The single stage amplifiers show a narrow passband with 3 dB bandwidth of between 20 and 30 MHz. The gain increases monotonically with beam current up to a peak current of 1.6 kA. Maximum gains of 33 dB with output powers of 100 MW and an energy conversion efficiency of 11% have been achieved. Microwave pulse durations are equal to the pulse power driver duration and are independent of the applied magnetic field strength. At beam currents in excess of 1.6 kA, the single stage device begins to oscillate due to positive feedback through the slow wave structure. Higher gain operation without oscillation was achieved by use of a sever to reduce the positive feedback. Before describing the severed amplifier characteristics we report a measurement of the phase stability of the single stage device using a phase discriminator. In Fig. 1 we show the measured phase stability of the single stage amplifier during the output pulse. The beginning and end of the microwave power pulse are shown by arrows on the figure. The amplified signal is phase stable during the beam pulse to within the ±8° accuracy for the diagnostic. At the end of the pulse the large oscillations occur as the radiated power becomes small. As the beam current is increased above 1150 A in the single stage device, sidebands develop and carry an increasing fraction of the radiated power. The phase stability measurements

FIG. 1. Phase stability measurement of single-stage amplifier. The arrows indicate the beginning and end of the microwave power pulse. The signals have been windowed to only allow phase angle determination during the main microwave pulse.