A COMPARATIVE STUDY OF HIGH POWER, MULTISTAGE, X-BAND TWT AMPLIFIERS*

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Abstract

Our previous work on high-power efficient X-Band TWT amplifiers has used a two stage device with bunching produced in a greater than light phase velocity region, immediately followed by a short low phase velocity output structure. The device is driven by a 7mm diameter 750 kV, 450A pencil electron beam. The structure, which has a 4 GHz bandwidth in the bunching section, produces an amplified output with a power in the range 20-60 MW. At higher output powers pulse shortening develops. **A** serious candidate for the pulse shortening is excitation of the HEM_{11} mode in the structure. This mode overlaps the frequency domain of the desired TM_{01} mode. We have designed and tested new amplifier structures in which the separation of these modes is substantially increased. The performance of the new amplifier(s) will be compared with that of the older device, and the relevance of the hybrid modes to pulse shortening assessed.

1. INTRODUCTION

In this paper we describe the results from three sets of experiments on the development of High-Power X Band, TWT amplifiers. Two experimental amplifiers have been used in this work, one having a 4 GHz and the other a 2 GHz, passband in the TM_{01} mode in the 'bunching' section. A distinguishing feature of the two amplifiers is the relative location of the lower branch of the HEM_{11} mode therein. In the first device the two modes overlap, whereas in the second there is no frequency overlap. The dispersion relations are shown in figure 1.

The 4 GHz bandwidth amplifier has been studied in 2 modes of operation, namely with an immersed diode and secondly with beam compression. Operation with beam compression limited the useful beam current to about 200 A.

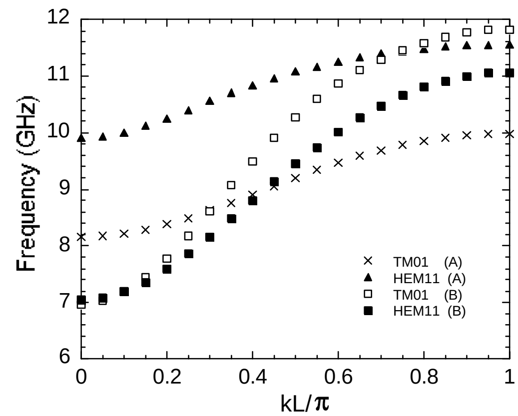

Fig 1 Dispersion relation of the two lowest modes

2. EXPERIMENTAL ARRANGEMENT

We show in figure 2 a schematic of the experimental arrangement. In both cases the rf input is fed into the amplifier via a tuneable sidearm arrangement. The amplifier has two stages, namely a short ~12 cm dielectric (Boron Nitride) stage in which the input power is absorbed, but not amplified. This stage is followed by a non-uniform disk loaded amplifier having two parts [1], a bunching section, in which the cold wave phase velocity may be as high as 1.05 c, followed by a short low phase velocity section used as the 'output'. The dielectric section and the disk loaded regions are separated by a SiC sever. A similar absorber follows the output section, which may or may not use a TM-TEM coaxial mode converter. The converter eliminates re-acceleration of the beam electrons in the amplified rf wave and increases the rf conversion efficiency. It has been described elsewhere [2]. For the experiments in which the beam is compressed during generation an additional SiC absorber was added prior to the dielectric buffer amplifier. This minimised reflections and is important in high gain (~48 dB) operation

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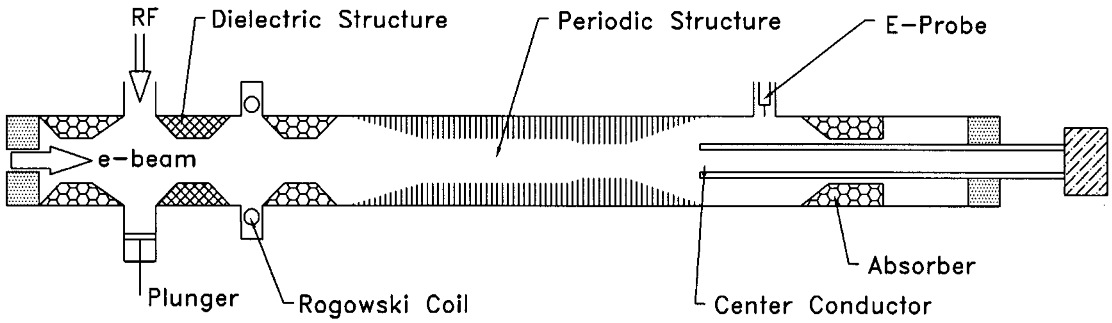

Fig 2. Schematic of experimental arrangement

We show in Table 1, the structure dimensions for the two amplifiers investigated. The buncher and output sections were, in both cases separated from each other by a tapered transition extending over several cells. The cells had a periodic length of 0.75 cm. of which 0.15 cm comprised the disk width. The disk loaded amplifier sections were terminated at each end in gradual tapers to the outside diameter of the cylindrical guide.

	Structure A. Narrow Band	Structure B. Broad Band
Buncher Rin	8 mm	11.75 mm
Rout	14.8 mm	17.13 mm
# Cells	24	45
Output Rin	8.0 mm	10.75 mm
Rout	15.2 mm	17.13 mm
# Cells	7	7

Table 1. Structure dimensions

3 EXPERIMENTAL RESULTS

Experiments were conducted using structure B with the beam generated from a cathode immersed in a 10 kG axial guide magnetic field. The beam amplitude and its profile in time were insensitive to the magnetic field strength. The beam current varied between 450 and 500A. Part way through the work a new gun geometry was employed which required that the beam be radially compressed by a factor of two prior to injection. Both amplifiers were tested in this configuration. In this regime the beam current profile was very sensitive to the magnetic field strength. The experiments were carried out at 5 kG where the beam current was almost constant in time. The beam current in these experiments was about 160-200 A. In both sets of experiments the beam energy was between 700 and 750 keV and the beam diameter was 7 mm.

3.1 Immersed Cathode Experiments: We have separately tested the 'buncher' and the combined 'buncher-output' amplifiers. The output power of the buncher was about 10 MW and continued for the full beam pulse duration. With the complete system we obtained an output peak power of up to 60 MW. At this level pulse shortening of the microwave output developed and the output pulse width decreased until at about 150 MW the microwave pulse width had dropped to about 10 ns. On investigation we found that the process was accompanied by a loss of the electron beam. At microwave peak powers of greater than 60 MW beam current loss occurs even at the input to the amplifier. At this power level the rf conversion efficiency is about 20%. It is clear that beam loss is associated with high power operation.

3.2 Compressed Flow Experiments: We report first results obtained with both of the structures.

In structure A we have obtained rf amplification with no evidence of pulse shortening from 9.03 –9.48 GHz. Output powers of up to 55 MW with a **~1** kW rf input were obtained. A rf power conversion efficiency of up to 45% was obtained. The amplifier gain ranges from 38–48 dB as one sweeps through the frequency range. In these experiments the output mode converter was not used.

Similar experiments were carried out using the broader band structure B. Again the current was limited to about 200 A and with a 5kG axial magnetic field. With this structure the output power ranged from 6 MW at ~9GHz to about ~50 MW at 9.5 GHz. Once again there was no evidence of beam or rf pulse shortening. Since this amplifier has a lower interaction impedance its length was longer and the input power was increased to 13 kW. We have also run this amplifier with the coaxial mode converter obtaining a power output of up to 75 MW at a power conversion efficiency of ~55 %.

We show typical waveforms in figure 3 for the 'broadband' amplifier, and summarize the performance of both of the amplifiers in fig 4. We plot, as a function of the input wave frequency, the gains for both devices. In all cases the amplified output frequency exactly corresponds to the input frequency.

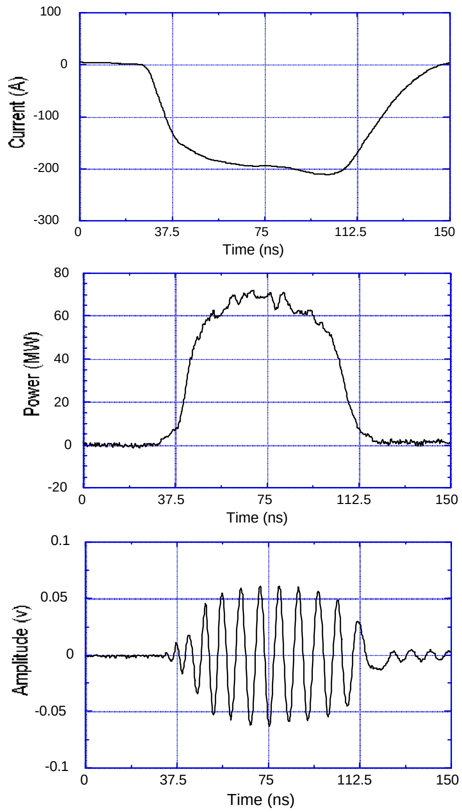

Fig 3. Typical beam current, rf envelop and heterodyne output for amplifier B

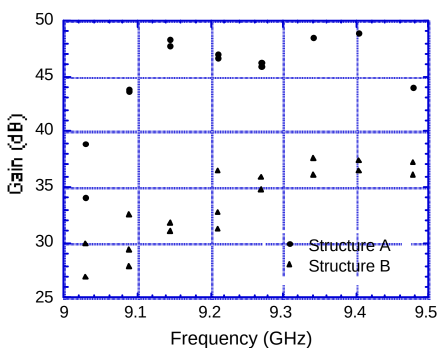

Fig 4. Gain versus frequency for both amplifiers.

4. DISCUSSION OF RESULTS

The results obtained using the immersed cathode configuration strongly suggested that the beam was lost due to the development of the HEM modes in the long uniform amplifier [4]. These results lead to the study reported in reference 3 and the related experimental attempt to suppress these modes using a Shintake cavity [5] to damp the unwanted modes. We have no direct observation of HEM mode interaction at present, and a more detailed search is presently in progress.

The results reported in the compressed flow experiments show no evidence of hybrid mode excitation, nor is there any pulse shortening. At present it is not clear if the difference between the two regimes reported above is due to differences in the beam current levels, or to some other process. The efficiency reported, especially in the experiment using the coaxial output extraction (~55%), is high and comparable to that predicted by PIC codes. The good performance of the larger diameter amplifier B is particularly encouraging for large bore TWT amplifiers, since the HEM_{11} and the TM_{01} modes overlap.

5. CONCLUSIONS

We have investigated microwave amplification in two non-uniform TWT's. In the case of the larger bore structure with high beam currents (Structure B) there was a loss of beam current, which was microwave power level dependent. This limited the amplifier power conversion efficiency to about 20%. In the lower current experiments and with both structures the beam current was limited to ~200 A. Output powers of up to 55MW with a gain of 48 dB were obtained. The efficiency in both structures reached 45% and peaked at 55%, with the higher figure arising from the use of the coaxial mode converter/beam dump.

The high output power full pulse width operation in structure B is interesting as it suggests that high frequency amplifiers (~35 GHz) might be built using large bore structures.

6. Acknowledgment

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7. References

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