Long–Pulse, High–Power, X-Band Relativistic Traveling–Wave Tube Amplifier

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Abstract

A high–power X–band traveling–wave tube (TWT) amplifier has been designed. A disk–loaded circular waveguide is used as the slow wave structure (SWS) for wave interaction with a 450 kV, 80 A solid electron beam. From Pierce theory, the predicted gain at 9.7 GHz is 1.94 dB/cm with an instantaneous bandwidth of 5% and a phase advance of $\pi/2$ for the TM_{01} mode. Cold dispersion measurements show good agreement with the simulation.

Introduction

There has been considerable attention in recent years toward high power microwave devices for applications ranging from heating of fusion plasmas, to drivers for new generation of high energy electron accelerators and radar systems. In the X–band regime, high power TWT experiments have been successful in acquiring large instantaneous bandwidth[1] and producing high power[2]. For our current project, the X–band TWT amplifier is designed for 20 MW peak power, at 9.6 GHz, an instantaneous bandwidth of 5%, and a saturated gain of 30 dB. The electron beam used will have a 2.5 μs (1μs flat top) pulse length, 450 kV beam voltage and 80 A beam current. Since the energy per pulse is much greater than in previous experiments, study of interest will include phenomena such as power saturation and sideband effect.

In the following sections we present a description of the experimental design followed by results of simulation and cold–test measurements.

Experimental Configuration

A high–voltage 2.5 μs (1 μs flat–top) pulse modulator provides the accelerating potential (450 kV) to the Pierce type thermionic electron gun which has a measured perveance of 0.27 μP, resulting in a beam current of 80 A. After being focused by a magnetic field with a maximum intensity of 3 kG, the solid electron beam has a radius of 4 mm with minimal scalloping.

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As shown in Fig. 1, the amplifier has three sections: the beam–injection and signal–input section, the slow wave interaction section, and the output section. The input signal comes from a 10 kW magnetron. The input coupler is of the type commonly used for high power TWTs[3]. The coupling from TE_{10} mode in the feed rectangular guide to TM_{01} mode in the tube is provided by a sidewall coupler placed in the first cell. A movable stub tuner along the SWS axis serves to match the microwaves into the structure and also allows an optimal coupling over a wide bandwidth.

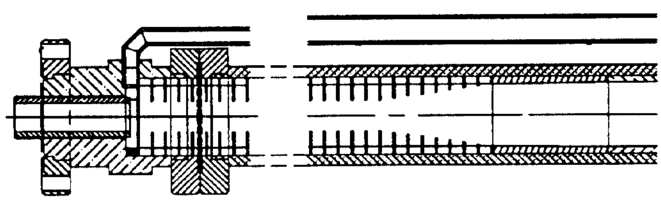

Figure 1: Design of 9.6 GHz Relativistic TWT

Disk–loaded waveguide is used as a slow wave circuit. Two different structures have been designed, one with waveguide radius b = 14.5 mm and disk radius a = 8.0 mm (designated the R8 structure), the other one with b = 13.9 mm and a = 7.0 mm (designated the R7 structure). Both structures have a periodic length of L = 6.0 mm and a disk thickness of d = 0.8 mm. The number of periodic cells can be varied from 32 to 64. In order to minimize reflections from the output sections, a tapered disk–loaded section is placed between the SWS and a smooth cylindrical waveguide. The linear tapering of the disks inner radius occurs over two guide wavelengths. Finally the smooth cylindrical waveguide leads to a conical taper with an output window.

Simulation Results

The dispersion relation of the slow wave structure is calculated using the URMEL code. The two structures were investigated.

The TM_{01} dispersion curves for these two structures are given in Fig.2. Both curves intersect the 450 kV beam line near $\pi/2$ point at 9.6 GHz.

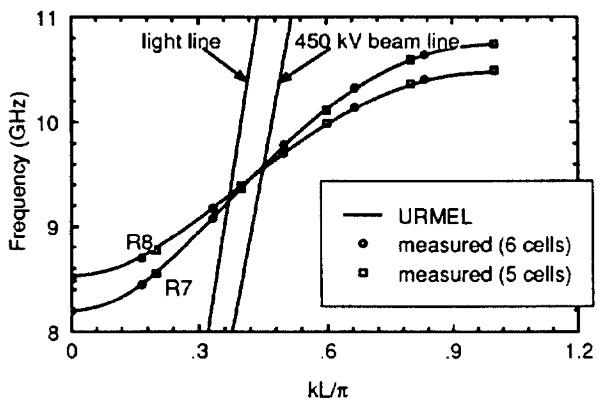

Figure 2: The dispersion curves for the disk–loaded structures.

URMEL is also used to obtain the coupling impedance, which is defined as $Z_c = E_{z0}^2/2k_{||}^2 P$, where E_{z0} is the first space harmonic electric field amplitude of the synchronous component of the E field, $k_{||}$ is the parallel wave number, and P is the power flow in the structure. The calculated coupling impedance as a function of frequency for the R8 structure is shown in Fig. 3.

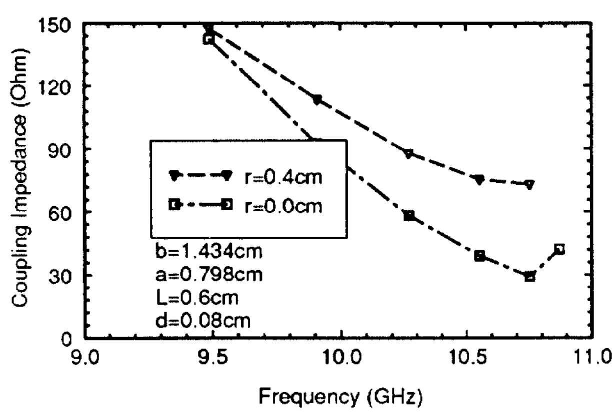

Figure 3: Coupling impedance versus frequency at two different radial positions r = 0.0 mm and r = 4.0 mm obtained from URMEL.

According to Pierce theory[4], when the Pierce space charge parameter QC is negligible, the TWT maximum gain can be written as,

$$G[dB] = -9.54 + 47.3CN \qquad (1)$$

where N is the amplifier length in number of guide wavelengths and the Pierce gain parameter C is given by

$$C = [\frac{Z_c}{Z_b}\frac{1}{2\gamma(\gamma+1)}]^{1/3} \qquad (2)$$

where $Z_b = V_b/I_b$ is the beam impedance, and γ is the relativistic factor of the beam particle. From the values of coupling impedance Z_c obtained above, the calculated gain at 9.7 GHz for the R7 and R8 structures is 1.94 dB/cm and 1.59 dB/cm, respectively. The total gain for 32 periodic cells of R7 structure is shown as a function of frequency in Fig. 4. It can be seen that the maximum gain is 30 dB with an instantaneous bandwidth of 500 MHz.

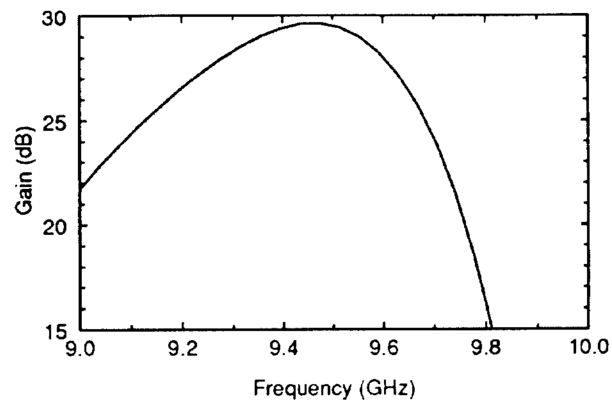

Figure 4: Total gain for 32 cells of the R7 structure as a function of frequency.

Cold–Test Results

The disk–loaded structures have been cold–tested with an HP8510 network analyzer by measuring the resonant frequencies of the standing waves in a section of the SWS structure composed by five and six cells[5]. The experimental setup for this measurement is shown in Fig.5. The measured resonant frequencies agree extremely well with the dispersion relation calculated from URMEL, as shown in Fig. 2.

The input coupler has also been cold–tested. The result shows that coupling with less than -10 dB return loss can be achieved with the designed coupler over a frequency range of 9.2 GHz to 9.8 GHz (See Fig.6). In order to avoid self oscillation of the tube for high gain operation, the implementation of distributed losses and severs is foreseen.

Conclusion

The design of an X–band traveling–wave tube amplifier has been completed. The structure will be powered by a long–pulsed, high energy electron beam. Simulation indicates a gain of 1.94 dB/cm dB for the structure with an instantaneous bandwidth of 5%. Cold dispersion measurements show good agreement with the simulation. Design of broader instantaneous bandwidth structures as well as theoretical studies of the linear and nonlinear regime using field theory are under way.

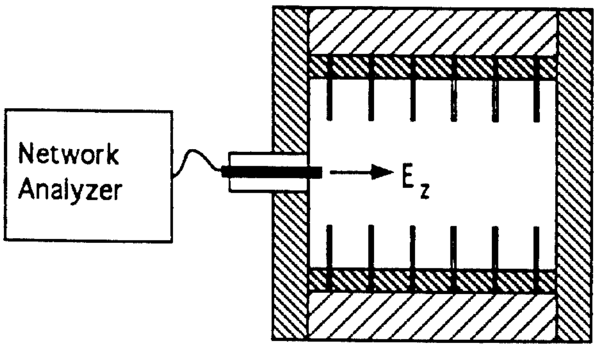

Figure 5: Setup for Cold Test Measurement of the SWS

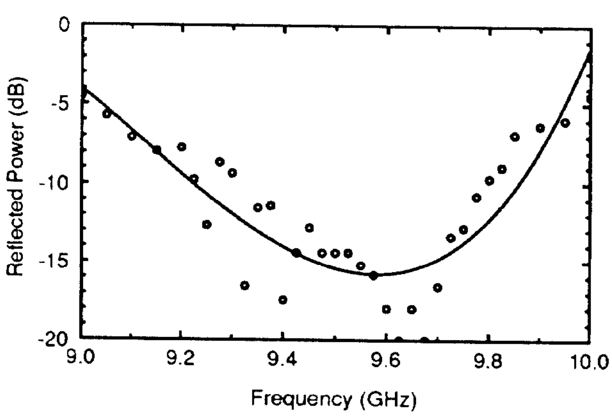

Figure 6: Ratio of reflected power to incident power in dB for TWT input coupler, showing a good match over the frequency range of interest.

Acknowledgments

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