Development of a 220 GHz 50 W Sheet Beam Travelling Wave Tube Amplifier

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Abstract: *We report on progress in developing a travelling wave tube amplifier with significant gain and power at 220 GHz. This paper provides an overview of the program, describing fabrication and test of slow-wave structures with bandwidths exceeding 50 GHz centered at 220 GHz, the production of a sheet electron beam, development of a solid state preamplifier delivering 50 mW to the tube with > 17 dB of gain and beam-wave simulation of the entire circuit leading to expected output powers of over 50 W. Two further papers from the group are also submitted to IVEC: from UC Davis describing the interaction structure fabrication and hot test, and from CPI describing the sheet electron beam, TWT design and beam – wave simulations. The tube is currently under test and results will be reported in this paper.*

Keywords: travelling wave tube; sheet electron beam; millimeter wave; slow wave structure, interaction structure, mm-wave waveguide.

Introduction

We are developing a sheet beam traveling wave tube for upper mm-wave operation that is small, compact and rugged. This paper is an overview of the development program, and will focus on three areas: the fabrication of the staggered vane interaction structure, the sheet electron beam, and simulations of the beam-wave interaction and the expected power output of the device.

Slow Wave Interaction Structure

The slow wave structure is based on a waveguide with two interdigitated sets of vanes which provide passband greater than 50 GHz around the operating frequency of 220 GHz. Critically this creates a symmetric longitudinal electric field that constructively interacts with an electron beam, and the dimension can be matched to a sheet electron beam [1].
Figure 1 below shows the internal structure of the slow wave device in both cross-section and 3D model, together with a scanning electron micrograph of half of the device directly machined into copper using a nano-CNC machine tool with a 100 μm diameter end mill.

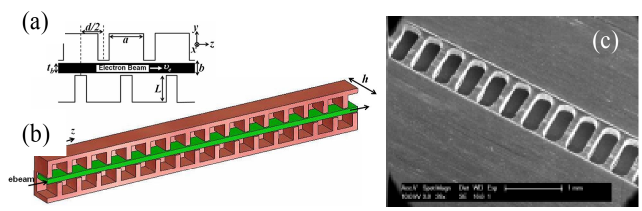

Figure 1. (a) The staggered vane interaction structure (b) 3D model of the structure, a 20 kV 7:1 aspect ratio sheet electron beam is shown in green. (c) Scanning electron micrograph of half of the structure directly machined into copper

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The periodicity of the staggered vane structure is 467 μm, with 115 μm thick vanes, with a beam tunnel of 150 by 770 μm, designed to accommodate a 7:1 aspect ratio sheet electron beam. The interaction circuit is split into two consecutive sections, an initial 30 period section to cause beam bunching and a second 50 period section to produce high power RF. Only the beam propagates through to the second section, the forward propagating RF power from the first section, and any backward propagating RF from the second are fed into waveguide sections with sintered Aluminum Nitride to provide > 40 dB attenuation.

Sheet Electron Beam

The gun is designed with an elliptical cathode placed at the center of a machined focus electrode with different curvature along each axes of the ellipse. The beam compresses further along the short axis than the long axis, giving the required aspect ratio. A 20 kV 250 mA beam of dimensions 700 x 100 μm is produced by a combination of electrostatic focusing and an immersed magnetic field with a defined field profile peaking at 6.2 kG. Modeling of the structure with the MICHELLE code shows an expected beam transmission efficiency of over 95%.

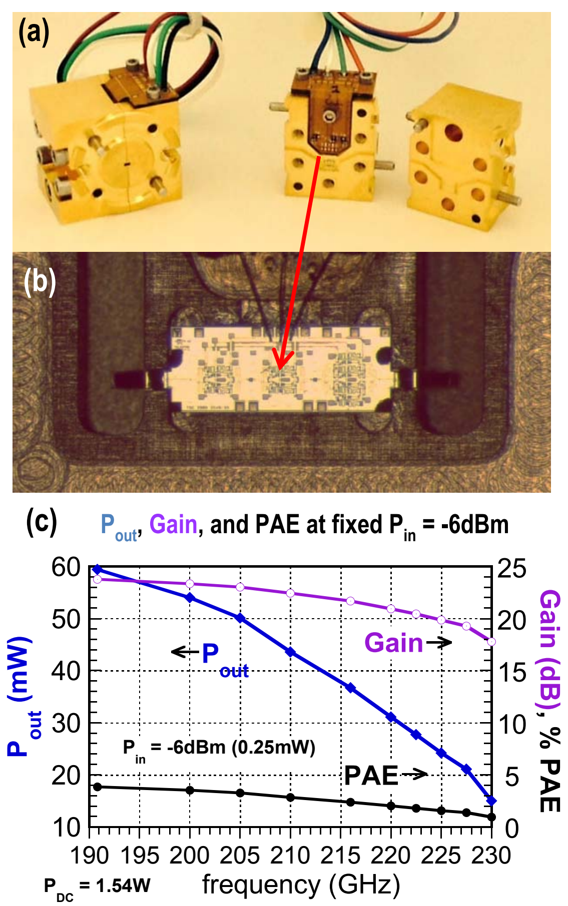

Figure 2. (a) Packaged waveguide block (b) Optical micrograph of a three stage amplifier with integrated TE probe input and output. (c) RF power test results: 30 mW at 220 GHz, with 22 dB of gain.

Solid State Preamplifier

We have designed, fabricated and tested 220 GHz preamplifiers using 250 nm InP heterojunction bipolar transistors. Input and output is via integrated TE probes in the package waveguides. Packaged three stage amplifiers show > 22 dB gain at 220 GHz, providing 30 mW output with a 0.25 mW input signal, and a bandwidth of > 30 GHz. Figure 2 above shows an optical micrograph of a packaged three stage amplifier and RF power test data.

TWT Power Output

Simulation of the beam-wave interaction using the MAGIC-3D code, assuming a 50 mW 220 GHz input, with the full thermal beam modeled by MICHELLE, shows a stable output of 74 W.

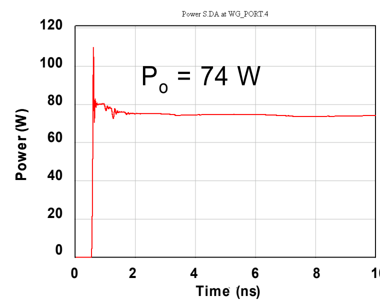

Figure 3. Simulated power output versus time at 220 GHz, assuming 50 mW input and thermal sheet beam

The TWT can produce over 140 W when saturated. Figure 4 below shows the output power as a function of input drive at 220 GHz. This tube is currently under test, the latest test results will be reported at the conference.

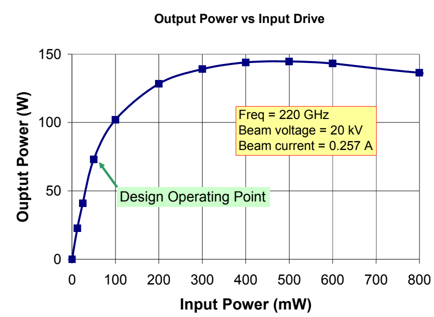

Figure 4. Output power as a function of input drive.

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Reference

1. Young-Min Shin and Larry R. Barnett, Appl. Phys. Lett., Vol. 92, 091501, 2008