DESIGN OF A 300 GHZ BROADBAND TWT COUPLER AND RF-STRUCTURE*

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Abstract

Recent LANL activities in millimeter wave structures focus on 95 and 300 GHz structures [1]. They aim at power generation from low power (100W-2kW) with a round electron beam (120kV, 0.1-1.0 A) to high power (2-100 kW) with a sheet beam structure (120 kV, 20 A). Applications cover basic research, radar and secure communications and remote sensing of biological and chemical agents. In this presentation the design of a 300-GHz RF structure with a broadband (> 6% bandwidth) power coupler is presented. The choice of two input/output waveguides, a special coupling region, and the structure parameters are presented. As a benchmark also a scaled up version at 10-GHz was designed and measured. These results will also be presented.

INTRODUCTION

We are investigating planar micro-fabricated traveling-wave tube amplifiers as sources for the generation of millimeter waves from 95 to 300 GHz. While for low energy applications narrow structures with pencil beams are proposed, for high-energy operation flat, thin sheet beams are required. For the latter, vane-loaded rectangular waveguides that operate in a slow-wave mode matched to the velocity of the electron beam are especially well suited. The 300-GHz effort initially is limited to narrow structures for pencil beams. The main emphases for this work are the study of fabrication issues and the understanding of features that allow a broadband operation (5-10% bandwidth.)

THE GEOMETRY

The design work is focused on the RF-structure. This structure is made up of the resonator, the power couplers to couple power to the structure, and the coupling regions between the RF-structure and the couplers.

The Base Geometry

The base geometry is a vane-loaded rectangular waveguide (see Fig. 1). We opted for a double-sided waveguide with vanes on the top and the bottom. The vane thickness, height and spacing are given by the desired phase velocity that has to match the energy of the electron beam. A second consideration is maximizing the achievable gain in the structure. The vane parameters that match these criteria, have been determined by simulations with the DETER code [2].
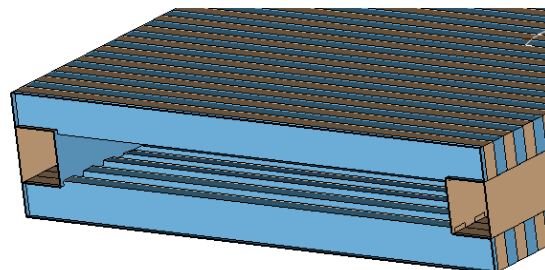

Figure 1: 3D model of the vane loaded waveguide. The top and bottom vanes can be seen inside the waveguide. The bars on the sides define the width and the proper spacing of the top and bottom halves of the resonator.

The Power Coupler

The power has to be fed to the structure off the central plane, away from the entrance path of the electron beam. We opted for two rectangular waveguides operated in a TE mode. These waves that are 180 degrees out of phase at the entrance into the structure combine into the operating TM mode. Figure 2 shows the arrangement of the couplers and the combination of the properly phased electric fields. In the central plane also the waveguide opening for the beam to enter the structure is included.
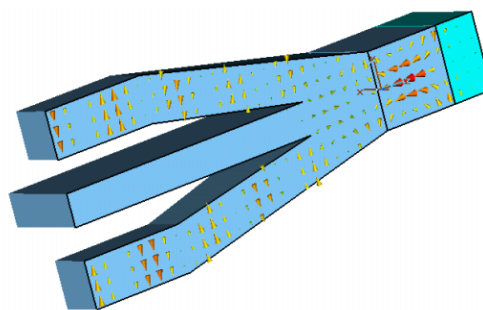

Figure 2: A cross-section through the input waveguides and their combination at the entrance of the RF-resonator are shown. For RF-considerations the inside volume, not the outside material is modeled. The cones indicate the amplitude and direction of the electric field.

The parameters for matching the coupler are the distance of the top and bottom waveguides, the length of the tapered section and a side taper that opens up the waveguide cross-sections towards the entry into the structure. An identical coupler is attached to the outlet of the structure as a load to remove the generated power.

The Coupling Region

As the vane-loaded waveguide presents a strong mismatch for the electromagnetic waves entering the RF-structure, a matching section has been incorporated into the cavity-coupler interface. The cavity starts with the unloaded dimensions of the rectangular waveguide. Tapered vanes are added with a height starting from zero and increasing to their nominal height over 14 cavity cells (see Fig. 3.) The number of coupling cells has been determined as part of the optimization of the coupler.
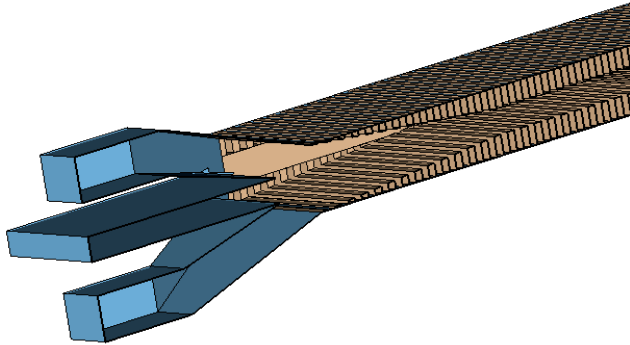
Figure 3: To reduce the mismatch from the coupler to the ridge-loaded waveguide, a matching section with increasing vane height is incorporated into the cavity/coupler arrangement.

THE OPTIMIZATION OF THE RF-PERFORMANCE

The design goal is to obtain a RF-structure wide enough to exhibit the wave propagation of an infinitely wide structure that at 300 GHz has very good RF-propagation over a bandwidth of more than 5%. While the inner dimensions are given from the previously mentioned DETER simulations, the coupling region and coupler dimensions to achieve this goal had to be found.

Figure 4: A snapshot of the traveling wave electric field fed to a structure with 30 inner cells is shown. The power is removed at the outlet by an identical coupler.

The RF-design has been done with the Microwave Studio (MWS) electromagnetic simulator [3]. Fields (Fig. 4), s-parameters (Fig. 5) and VWSR ratios (Fig. 6) have been evaluated for a wide range of parameters. The fact that no resonant peaks can be seen in the transmission curve indicates a good coupling between the couplers and the structure that provides the desired traveling wave operation. The bandwidth has been defined as the range of transmission, where the return loss is less than –10 dB. The frequency range of 294-313 GHz includes the $2\pi/3$-mode operation mode.
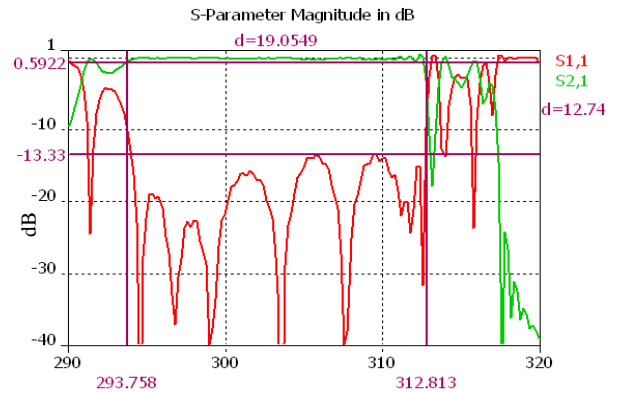
Figure 5: The s-parameters obtained by simulations with MWS show a good transmission over a range of 19 GHz, which corresponds to a bandwidth of 6.3%.
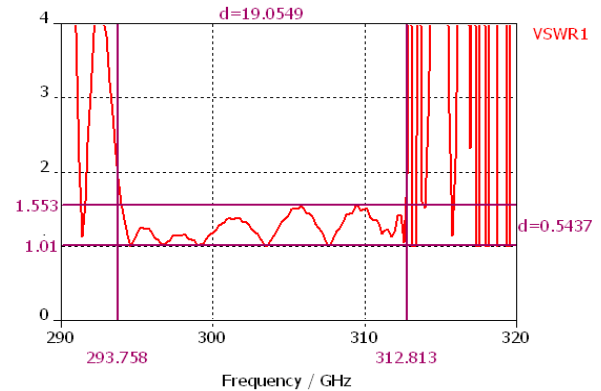
Figure 6: The VSWR ratio over the bandwidth is around 1.5 or better.

The final structure with input and output coupler is shown in figure 7. The dimensions are given in Table 1.
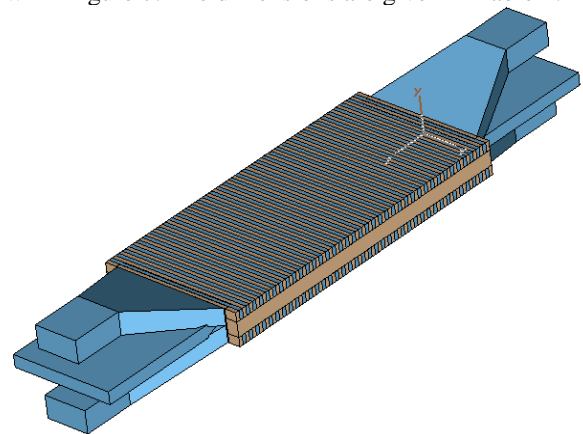
Figure 7: The final geometry of the optimized 300-GHz resonator with input and output couplers.

Table 1: Geometric parameters of the cavity and couplers

Quantity	Value [mm]	Comments
Waveguide height	0.6334	Resonator
Waveguide width	2.187342	Resonator
Vane height	0.1979	

Vane thickness	0.07765	
Aperture height	0.2376	
Cell length	0.07765	
Period	0.1553	
Waveguide width	0.864	Coupler (WR3)
Waveguide height	0.432	Coupler (WR3)
Waveguide separation	1.30	Coupler
Taper length	1.65	Coupler
Taper width	2.187342	Coupler
Beam guide height	0.2376	
Beam guide width	2.187342	
Coupling cells	14	14 at each end

ERROR STUDIES

As this was the first structure of its kind we have designed, we needed to study the effects of geometry variations. Discussions with industry indicated that over-tight tolerances would significantly increase the cost of fabrication. Too generous tolerances would significantly deteriorate the performance of the structure. Simulations showed that the overall performance was insensitive to achievable radii due to the wire EDM (electrical discharge machining) fabrication process. Surface positions required an accuracy of a few mils (0.03-0.07 mm). The most critical features were the coupling taper, whose volume is important to achieve the required bandwidth, and the orientation of the vanes perpendicular to the beam direction. The maximum RF-phase difference of 180±10 degrees between the two waveguides in each coupler is easily achievable.

10-GHZ COLD MODEL

As a proof-of-principle of the coupling scheme a 10 GHz cold model has been designed and built. A direct scaling from the 300 GHz model was not possible, as the WR90 waveguide available for 10-GHz operation has a different aspect ratio than the WR3 waveguide. The cold model has been designed for a bandwidth of > 6% around 10 GHz. It has been build by machining from aluminum. Figure 8 shows the two halves of this model. It has been built in two lengths with 11 and with 31 nominal inner cells. Both models have 14 coupling cells at each end. The measurements show that the coupling scheme with the two waveguides is working. The bandwidth of the coupling has been confirmed. However, the measured s-parameter curve is shifted lower by 500 MHz compared to the simulations and the transmission curve is not as flat as the simulated curve (see Fig. 9.) Tolerance studies show that only the overall height and tip-to-tip distance of the vanes can explain this shift. Measurements of the assembled structure are still under way.
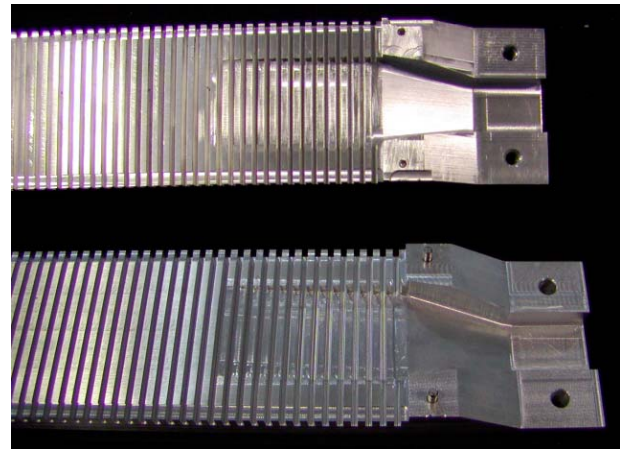

Figure 8: This photo shows the top and bottom half of the aluminum cold model. The material forming the coupler taper and the coupling cells can be seen.
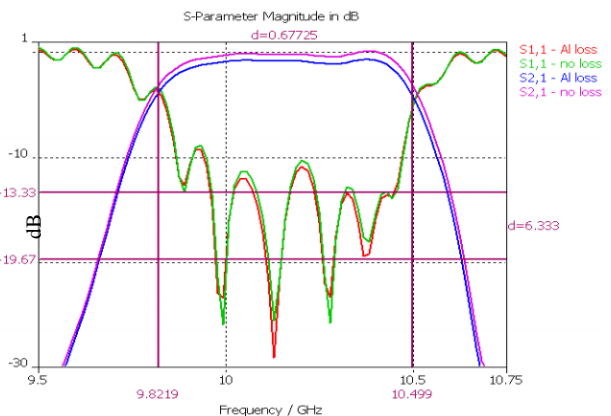

Figure 9: The s-parameter curves compare the simulated transmission and reflection for an ideal material and for aluminum. The measured reduction in transmission due to the losses in aluminum agrees very well with these simulations.

CONCLUSION

A cavity/coupler system for a 300-GHz TWT structure has been designed. The coupling principle for the broadband coupler has been confirmed in a cold model. Interaction with industry is under way to build and measure this structure.

REFERENCES

[1] B.E. Carlsten et al., ''MM-Wave Sheet-Beam Traveling-Wave Tube Development at Los Alamos'', 31st IEEE International Conference on Plasma Science, Baltimore, MD, June 2004.

[2] B.E. Carlsten, ''Modal Analysis and Gain Calculations for a Sheet Electron Beam in a Ridged Waveguide Slow-Wave Structure'', Physics of Plasmas, **9**, 5088 (2002).

[3] MWS Userguide, CST GmbH, Darmstadt, Germany, http://www.cst.de/