Design and fabrication of a D-Band Traveling Wave Tube for millimeter wave communications

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Abstract— **The design and fabrication aspects of a novel D-band (141 GHz-148.5 GHz) Traveling Wave Tube (TWT) for enabling the first point to multipoint front end at D-band, objective of European Commission H2020 ULTRAWAVE is presented. The ULTRAWAVE system will provide unprecedented wireless area capacity over wide area sectors, with radius up to 500 - 600 m for the future 5G high density small cell deployment. The design and fabrication processes adopted for the TWT are focused to find new low cost solutions for TWTs at millimetre waves to satisfy the requirements of the wireless market. The proposed TWT will provide more than 10 W saturated output power for achieving more than 100 Gb/s/km2 of area capacity over 600 meters radius wide angle sector, with 99.99% availability in ITU zone K.**

I. INTRODUCTION

The European Commission H2020 ULTRAWAVE, "Ultra-capacity wireless layer beyond 100 GHz based on millimeter wave Traveling Wave Tubes" [1, 2] project aims at the exploitation of the D-band (141 GHz-148.5 GHz), and G-band (275 GHz - 305 GHz), to provide unprecedented wireless data rate over wide area sectors, with radius up to 500 - 600 m, for future 5G high density small cell deployment [3]. The challenge is the availability of relatively high transmission power, at Watt level to compensate the low gain antenna, typical of point to multipoint distribution, used to illuminate a wide angle sector and the high atmosphere and rain attenuation for assuring the requested 99.99% availability in ITU zone K. The link budget for a D-band sector with the size above mentioned estimates a saturated power in the range of 10 W to provide a Signal-to-Noise ratio supporting at least 16QAM, and potentially 64QAM. The used of high modulation order will assure more than 20 Gb/s data rate over 7.5 GHz bandwidth. No solid-state power amplifier is presently available to provide this power level. The maximum power reported in literature at D-band is about 20 dBm. Traveling Wave tubes (TWTs) are the only solution above 100 GHz for multi-Watt transmission power, due to their inherent higher power-bandwidth product [4-7].

The TWT, is a vacuum electron device, typically used at microwave frequencies in satellite communications and other niche applications. ULTRAWAVE is the first project that will used TWTs as enabling devices above 100 GHz. Presently, only a few laboratory prototypes of D-band TWT are reported in literature. TWTs are based on a slow wave structure (SWS) that it is a waveguide with specific topology to reduce the speed of the waves close to the speed of the electrons of the beam (typically below 0.3 *c*, where c is the speed of light). The size of the SWS is a function of the wavelength. The short wavelength at D-band poses substantial fabrication challenges due to the small dimensions needed, determined by the WR-5 flanges (1.2954 x 0.6477 mm). In this abstract, a novel TWT power amplifier for D-band point to multipoint front ends will be described.

II. TWT DESIGN AND FABRICATION.

A TWT includes an electron gun, the interaction section (slow wave structure) where the amplification is obtained by partially transfer of the electron beam energy to the RF input signal, the collector that collects the electrons at the end of the tube and the magnetic focusing system that keep the electron beam confined. The main challenge at D-band are the small dimensions of the RF circuits due to the short wavelength. The double corrugated waveguide (DCW) is used as full metal slow wave structure due to the relatively easy fabrication by conventional CNC milling and low sensitivity to tolerances [8].

The DCW was designed to support the interaction with a cylindrical electron beam with low voltage (<13kV) and current

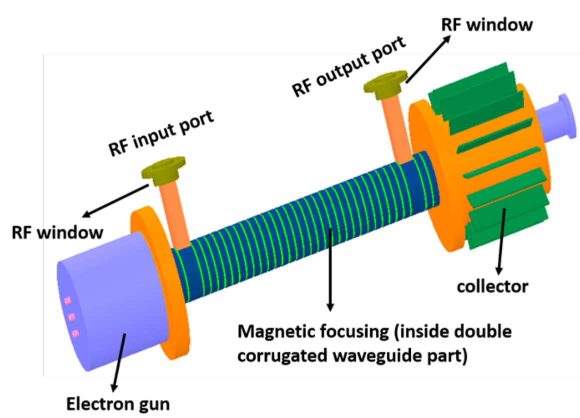

Fig. 1. TWT Schematic

(50 mA) [9]. The beam parameters were chosen to use a low

cost compact power supply. The dimensions were optimized to obtain a dispersion curve assuring a wide synchronism range over 20 GHz bandwidth including the 141 - 148.5 GHz operation band. An interaction impedance of about 1.5 Ω has been obtained. It permits a good beam - RF interaction. The design and the technical solutions have been optimized for reducing the total cost of the TWT and enabling high volume production, fundamental feature for the wireless network market. Fig. 1 shows the rendering of the D-Band TWT.

An extensive simulation campaign by 3-dimensional time domain simulations (CST Microwave Studio) confirmed very good S_{11} and the relatively low losses over the full bandwidth. The input and output ports will be vacuum sealed by a RF window in Alumina. It has been designed with return loss better than 15 dB.

A Pierce type electron gun has been designed using CST particle tracking solver. A magnetic focusing system based on (periodic permanent magnets) PPM structure has been built to provide 0.6 T magnetic field.

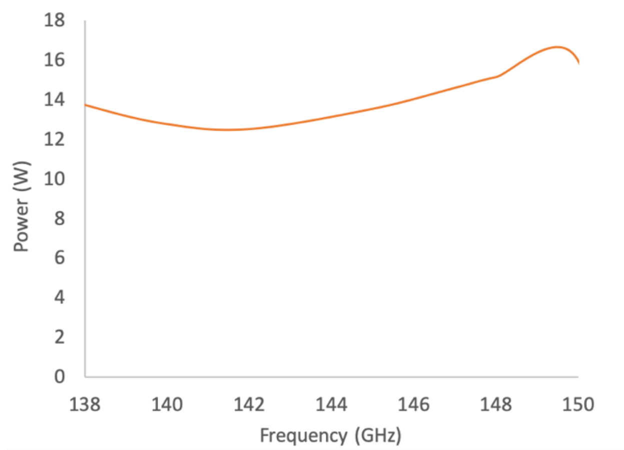

Fig. 2 TWT saturated output power

A simple single stage depressed collector has been designed and fabricated with good efficiency and zero back-streaming. Radial cooling fins are used for forced air convection cooling.

Due to the high gain, the TWT requires two sections of DCW separated by a sever to prevent oscillations. About 35 dB gain and more than12 W output power were achieved with 4 mW input power over the full band. (Fig. 2). This performance satisfies the specification for the link budget. The SWS is fabricated by using High Conductivity Oxygen Free (HCOF) copper. The fabrication needs tolerance better than 5 microns.

The design and fabrication of all the parts of the D-band TWT has been completed (Fig. 3 detail of the electron gun). The DCW is in fabrication, but a test section has been successfully measured.

Before the fabrication and the assembly of the TWT, a beam tester, similar to the TWT but without RF input/output ports, will be built to calibrate the beam transmission.

Conclusions

The first European D-band Traveling Wave Tube for millimeter wave high capacity backhaul networks has been designed. The fabrication of all the parts is completed and the assembly is in final stage.

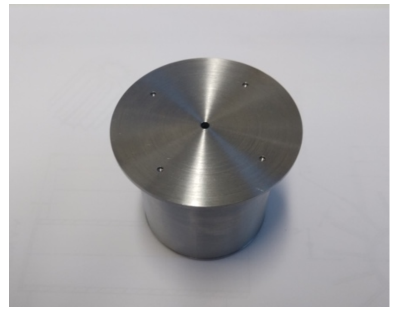
Fig. 3. Detail of the electron gun

The numerous challenges due to the novelty of the topology and the dimensions related to the wavelength have been overcome with different fabrication and assembly processes.

The first test in is progress.

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