A Traveling Wave Tube for 92 – 95 GHz band wireless applications

Claudio Paoloni[1], Frédéric André[2], Sophie Kohler[2], Viktor Krozer[3],
Quang Trung Le[4], Rosa Letizia[1], Ahmed Sabaawi[1], Giacomo Ulisse[3], Ralph Zimmerman[4]

[1]Lancaster University, Lancaster LA1 4YW, UK
[2]Thales Electron Devices, Velizy 78140, France
[3]Goethe University of Frankfurt, Frankfurt 60323, Germany
[4]HF Systems Engineering GmbH, Kassel 34123, Germany

***Abstract*— The Horizon 2020 TWEETHER project is proposing for the first time a millimeter wave traveling wave tube (TWT) as enabling device for a new generation of high data rate wireless networks for point to multipoint. The W-band is an unused portion of the spectrum comprised in the range 92 – 95 GHz that offers multigigabit data rate. The distribution of the signal over a wide area and the strong atmospheric attenuation, in case of rain, require a high transmission power, estimated in tens of Watt, to assure adequate transmission range. This power level is not available from the solid state technology at millimeter wave frequencies. A TWT, as enabling device, has been designed and is presently in fabrication phase to provide 40 W saturated output power in the W-band. High performance, low cost and long lifetime TWT are the main constraints to satisfy the wireless market needs.**

I. INTRODUCTION

MILLIMETER waves are still substantially unexploited for wireless communications. On the contrary of the congested sub-6 GHz band that cannot support further traffic increase, a number of wide sub-bands (Q-band, V-band, E-band and W-band), able to support multigigabit data transmission [1] are available in the range 30 – 100 GHz. Unfortunately, this region of the spectrum suffers an increasing attenuation in comparison to microwave, very severe in case of rain for range above a few hundreds of meters.

Millimeter wave wireless systems for Point to Point links are already available. They are based on solid state amplifiers which provide limited power at millimeter waves, typically below 1 Watt. However, the use of very high gain antennas (above 30dBi) permits to overcome the high atmospheric attenuation.

New generation networks will be based on high density small cell distribution, to serve a smaller number of users for base station. This has to be enabled by a cost effective backhaul approach. Point to point links are not convenient to feed high density cell deployment due to the need of one transmitter per cell. An effective backhaul requires a distribution of the signal on a wide sector to feed a high number of terminals with a single transmission hub. At microwave frequencies this is easily achieved by a low gain antenna to cover a wide sector supported by a high gain amplifier. The challenge is to adopt the same approach at millimeter wave. If a transmission in a sector of at least of 1 km radius and angle wider than 30° is assumed, a low gain antenna with 16 -19 dBi gain is required. An estimated transmission power level in the order of tens of Watts is needed, not achievable with the available solid state technology.

The EU Horizon 2020 project, TWEETHER [2], is demonstrating a new approach for providing high capacity distribution by point to multipoint at W-band (92 – 95 GHz) enabled by a novel W-band Traveling Wave Tube (TWT) [3].

The TWT is a vacuum electron amplifier able to provide high gain and output power on a wide frequency band. The working mechanisms is based on the interaction of an energetic electron beam with a radiofrequency field propagating in a delay line for synchronizing the phase velocity of the wave with the speed of the electrons [4]. This process permits the transfer of energy from the electron beam to the propagating field.

The main challenge at W-band is to design and realize a TWT with low cost, adequate performance, high reliability and life-time and of easy fabrication and assembly [4 - 5]. The specifications for the TWT are 40 W saturated power and 40 dB gain. The small wavelength poses tight constraints on the choice of the delay line. The folded waveguide (FWG) (Fig.1) is chosen for the relatively easy fabrication and wide band performance. The dimensions of the parts require an accurate design and optimization to comply with the capability of the fabrication process. The design requires very demanding and time consuming particle in cell simulations. Presently, the TWT is at the fabrication stage.

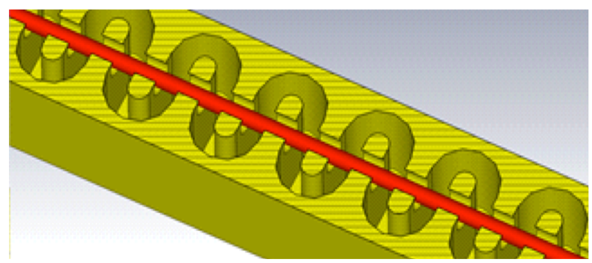

Fig. 1. 3D Schematic view of the folded waveguide with the electron beam (red cylinder).

II. DESIGN AND SIMULATION

A FGW, in copper, has been designed to support the interaction with an electron beam with 16 kV voltage and 70 mA current. The electron gun is based on a conventional Pierce gun to generate a cylindrical electron beam with 200 microns diameter. The electron beam parameters were chosen for assuring a high efficiency, relatively easy beam alignment and small power supply dimensions. A relatively low magnetic focusing field in the order of 0.3 T is applied. The cathode current density has been chosen in order to achieve a lifetime of the TWT of at least 5 years.

Fig. 2 shows the simulation of the electron trajectory along the TWT and the excellent beam confinement.

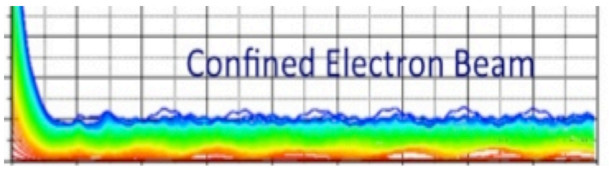

Fig. 2. Beam optics simulations.

The TWT is designed with two sections separated by a sever to avoid the risk of oscillations. The total number of period is 90 for a length shorter than 20 cm. The input and output port of the FWG are matched to WR10 flanges.

The most demanding design task is the simulation of the interaction beam – radiofrequency field by using 3D particle in cell (PIC) codes. Two different PIC codes were used, MAGIC3D and CST - Particle studio, to validate the simulation results. The correct estimate of the copper conductivity is fundamental for the accuracy of the results. The conductivity mostly depends on the surface roughness obtained in the fabrication process. Two different reduced values of copper conductivity ($\sigma = 3.6\ 10^7$ S/m and $\sigma = 2.9\ 10^7$ S/m) with respect to the theoretical value were used to evaluate the performance of the TWT for different surface finishing of the metal structure.

Fig.3 shows the comparison of the gain simulated by CST-PS with the two different copper conductivities. A flat gain higher than 40 dB is achieved in both the cases in the 92-95 GHz frequency band. It can be noted that the variation of the copper conductivity does not affect significantly the performance the TWT.

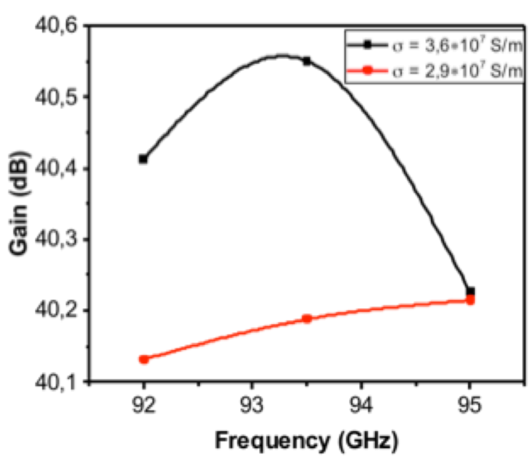

Fig. 3. Gain with two different copper conductivities.

Fig.4 shows the power growth in the FWG as a function of the length, simulated by MAGIC3D.

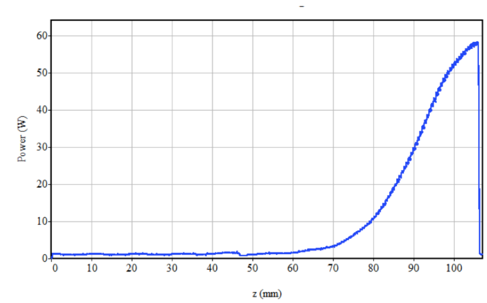

Fig. 4. Power as a function of the length from MAGIC 3D

III. Fabrication

The fabrication of the folded waveguide is performed by high precision CNC milling. A picture of a fabricated test section of the FWG is shown in Fig. 5. Optical analysis was performed on the realized parts to measure the repeatability

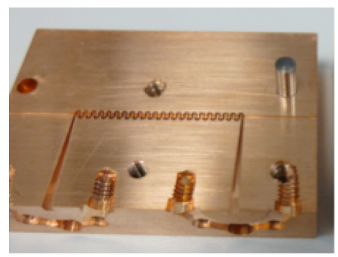

Fig. 5. Test Folded waveguide fabricated in copper by CNC milling.

and reliability of the fabrication process. A high quality fabrication was obtained after an accurate calibration process of the machining.

IV. Conclusions

A W-band TWT amplifier to enabling a new wireless network approach for high capacity and distribution is in advanced fabrication status. The challenging small dimensions and the need of easy assembly have required solutions at the state of the art.

V. Acknoledgments

The project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement no 644678.

References

[1] C. Colombo; M. Cirigliano "Next-generation access network: A wireless network using E-band Radio frequency (71–86 Ghz) to provide wideband connectivity," in *Bell Labs Technical Journal* , vol.16, no.1, pp.187-205, June 2011.

[2] TWEETHER website [Online]. Available: http://www.tweether.eu

[3] C. Paoloni, F. André, F. Magne, M. Rocchi, M. Marilier, R. Letizia, R. Zimmerman,V. Krozer, A. Ramirez; R.Vilar, "Millimeter Wave Wireless System Based on Point to Multi- point Transmissions", EUCNC 2016, Athens, Greece.

[4] J. H. Booske, et al. "Vacuum electronic high power terahertz sources," *IEEE Trans. Terahertz Sci. Technol.*, pp. 54–75, Sep. 2011.

[5] S. R. Kumar, et al. "Design of Folded Waveguide Slow-Wave Structure for W-Band TWT." *IEEE Trans. on Plasma Science,* pp. 3430-3436, Oct. 2014.