On a D-band Traveling Wave Tube for Wireless Links

[1]Rupa Basu, [1]Laxma R. Billa, [1]Jeevan M. Rao, [1]Nicholas Renninson, [1]Benjamin Rodgers, [2]Quang Trung Le, [1]Rosa Letizia, [1]Claudio Paoloni
[1]Engineering Department, Lancaster University, Lancaster, UK
[2] HF Systems Engineering GmbH, Kassel 34123, Germany

Abstract: *The D-band (141 - 178 GHz), due to relatively low attenuation and about 27 GHz available bandwidth, is attractive for point to multipoint backhaul. However, solid state power amplifiers at those frequencies do not have sufficient power to assure a long propagation range with 99.99% availability. This paper will describe the design and fabrication of a novel D-band traveling wave tube power amplifier to enable the first point to multipoint wireless system at D-band. The design approach is for potentially large scale production. For the first time, a new topology of double corrugated waveguide, used as slow wave structure, has been fabricated and measured at D-band. The D-band TWT provides about 35 dB gain and more than 12 W output power.*

Introduction

One of the main obstacles to the deployment of high density small cell for new high capacity 5G networks is the backhaul, that has to provide high capacity to a high number of base stations. Fiber is the ideal medium, but in many cases its deployment is, due to environmental constraints, or too expensive or not feasible**.** The most attractive solution is high capacity wireless links exploiting the wide and unused spectrum above 90 GHz. Data rate at level of tens of Gb/s has been demonstrated up to 400 GHz at laboratory level in point to point configuration [1]. However, point to point links are not suitable when high density of links is needed due to cost of equipment and large footprint of the cluster of antennas, that make difficult the deployment. Point to multipoint distribution, based on a transmission hub illuminating a wide area, by a low gain (16 – 20 dBi), wide aperture antenna, where a number of terminals are arbitrary distributed, is demonstrated as a more cost effective solution. The D-band (141 – 178 GHz) with about 27 GHz available, is suitable for multigigabit/sec point to multipoint backhaul [2]. However, above 90 GHz, the high atmosphere and rain attenuation pose a challenge for the transmission power that, to compensate the low gain antenna, needs to be at multi-Watt level. Presently, the best solid-state technology, e.g. InP can provide about 15 – 20 dBm at D-band. The only solution for multi-watt transmission power at D-band is a traveling wave tube (TWT). So far only a few prototypes have been reported at D-band [3]

In this paper, it will be presented aspects of design, simulations and preliminary fabrication of a novel TWT for enabling the first ever realized D-band (141 – 148.5 GHz) point to multipoint system for high capacity backhaul networks [2]. The simple structure of the double corrugated waveguide makes the proposed TWT suitable for large scale production.

TWT Design and fabrication

Design and fabrication challenges: The challenges for the fabrication of a 140 GHz TWT are to achieve sufficient accuracy for the small size of parts (down to 100 microns), to build an electron optics to generate an electron beam with a few tens of microns radius, an accurate alignment and vacuum tight behaviors.

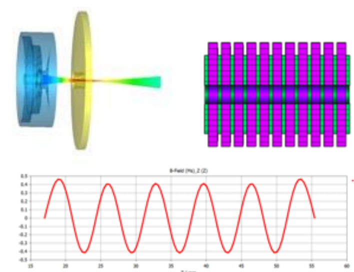
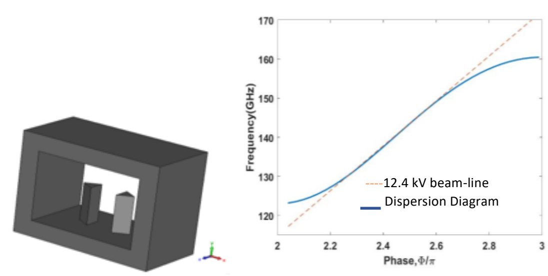


Figure 1. Electron gun and PPM simulation

Electron gun and PPM: The electron gun was designed to produce an electron beam with 12.4 kV voltage and 60 mA current. The radius of the beam is 80 microns. The electron gun simulation by CST-MWS is shown in Fig. 1. A 0.4 T periodic permanent magnetic (PPM) focusing system is used to confine the beam with the given diameter.

Design of Double Corrugated Waveguide SWS: A modified double corrugated waveguide [4, 5] is used with pillars with triangular cross-section instead of square section (Fig.2a). The use of triangular pillar almost doubles the interaction impedance (about 2 Ω). The DCW was designed to provide a wide synchronization region with the electron beam to cover the 141 – 148.5 GHz bandwidth. Fig. 2b shows the dispersion curve with superimposed the 12.4 kV beamline. It is noteworthy the wide band of synchronism.

A full simulation of the D-band SWS circuit was performed. It consists of two sections (for a total of 170 periods), separated



a)

Figure 2. a) DCW and b) dispersion curve with superimposed beam line.

by a sever. The sever is waveguide with the size of beam tunnel without corrugations and below cutoff, to isolate the two sections electromagnetically. Two idle ports with lossy materials are used to absorb the signal. A reduced copper conductivity σ_{Cu} = 2.9×10^7 S/m is used in the simulation to include the surface roughness effect.

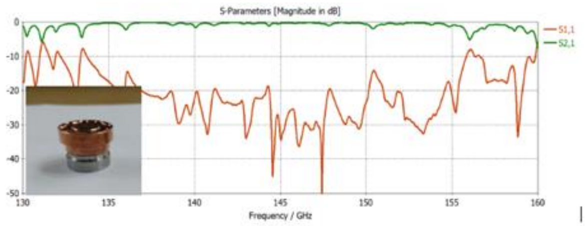


Figure 3. Window simulation (inset: assembly)

Each section has a gain of about 18 dB. The large signal simulations are performed by CST-Particle Studio. The input power is 4 mW. The output power is better than 12W over the operation bandwidth (141 – 148.5 GHz) with a gain better than 35 dB.

RF windows: The RF window design is based on a simple pillbox topology (Fig. 3) with a small cavity to match the interface air-Alumina. It consists of two copper sections that hold the Alumina layer. The two parts are then brazed to be vacuum tight. Fig. 4 shows the excellent S-parameter in band.

Fabrication and measurements of the DCW: The fabrication of the DCW is done in two parts. One part includes the waveguide and the pillars. It is the most difficult to machine. Tolerance better than 5 microns are needed to avoid performance degradations, achieved by small diameter toolings and high spindle speed above 30000 rpm. The second part is a flat closing lid. This structure makes the assembly easy and eventual misalignment can be corrected in the milling phase. Oxygen Free High Conductivity (OFHC) copper was used. The surface finishing of the metal walls of the DCW has to be kept below 100 nm to avoid high losses.

A DCW with 30 periods, to test the fabrication and the electrical behavior, was first produced (Fig.4a). It is notable that the S_{21} measurements of the fabricated DCW are better than the simulation (Fig. 4b), demonstrating the excellent fabrication quality. The full circuit with two sections and the sever was then fabricated and machined to produce the barrel (Fig. 4c).

Beam tester: A beam tester is presently in the calibration phase. The gun and the collector (one stage for simplicity) are the same of the final TWT (Fig.5). All the parts of the TWT are ready. As soon as the beam tester provide the correct beam transmission, the TWT will be assembled and tested.

Conclusions

Aspects of the design and fabrication of a novel D-band (141 – 148.5) TWT for enabling the first high capacity wireless network in point to multipoint is described. The TWT is in the final assembly phase. It is expected to present the working D-band TWT at IVEC 2020.

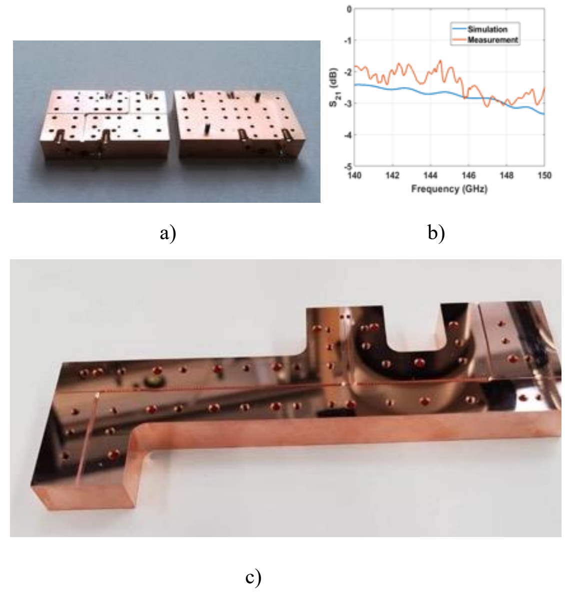


Figure 4. a) Fabricated test DCW, b) S21measurements, c) full circuit

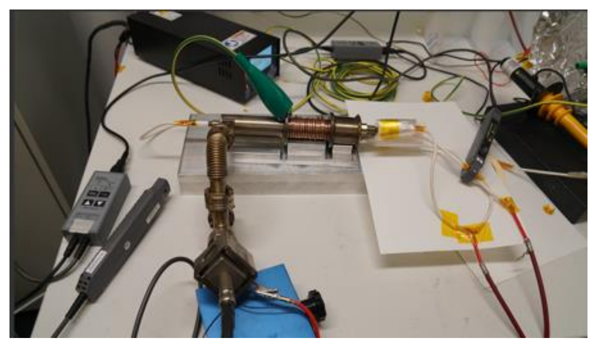


Figure 5. Beam tester

Acknowledgment

The work has received funding from the European Union's Horizon 2020 research and innovation programs under grant agreement no 762119.

References

[1] Dhillon, S. S., et al. "The 2017 terahertz science and technology roadmap." Journal of Physics D: Applied Physics 50, no. 4 (2017): 043001.

[2] http://www.ultrawave2020.eu

[3] M. Mineo and C. Paoloni, "Double-Corrugated Rectangular Waveguide Slow-Wave Structure for Terahertz Vacuum Devices," *IEEE Trans. on Electron Devices*, vol. 57, no. 11, pp. 3169–3175, Nov. 2010.

[4] R.Basu, L. R. Billa, R. Letizia, C. Paoloni, "Design of D-band Double Corrugated Waveguide TWT for Wireless Communications ", *Proc. IEEE 20th Int. Vac. Electron. Conf.*, Busan, South Kores, April. 2019.