E-band Traveling Wave Tube for High Data Rate Wireless Links

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***Abstract* — E-band (71 – 76 GHz and 81 – 86 GHz) is already used for point to point links with a few Gigabit/second data rate. Front-ends are powered by solid state amplifiers with about 2 – 3 W output power. This output power values limit range and spectral efficiency and have to be compensated by high gain antennas. The availability of tens of Watt would allow higher spectral efficiency and long range, and the use of lower gain antennas for multibeam and area coverage. This paper reports the design and the initial fabrication of the first ever E-band Traveling Wave Tube (TWT) based on the double corrugated waveguide. A test short interaction structure TWT is in assembly phase as proof of concept with about 2 W output power. The final TWT is designed to provide about 70 W power and about 40 dB gain.**

I. Introduction

The E-band (71 – 76 GHz and 81 – 86 GHz) is of high commercial interest having 10 GHz band allowed for wireless communications in point to point (PtP). E-band links are commercially available with data rate of a few gigabits per second (Gb/s) depending on the atmosphere conditions. However, the relatively low power of solid state amplifiers, in the range of 1 to 3 Watt, has to be compensated by high gain antennas to achieve range and Signal-to-Noise (SNR) ratio to satisfy the link budget for the typical availability of 99.99% in the rain zone of operation [1].

High gain antennas have relatively large footprint that impacts the deployment. In addition, if tens of Gigabit per second links are needed, a cluster of front-ends has to be used with a combined large footprint that could make difficult to find a site for its installation.

The availability of higher transmission power would enhance the spectral efficiency, reduce the antenna footprint and increase the data rate, making front-ends more compact and easier to deploy.

Traveling wave tubes (TWTs) are the only devices able to provide tens of Watt at millimeter waves with compact dimensions [2, 3]. Their working mechanism is based on the transfer of energy from an electron beam traveling in high vacuum with a RF signal propagating in a guiding structure to reduce its phase velocity to achieve synchronism with the velocity of the electron of the beam.

This paper presents the first ever fabrication of a 71 – 76 GHz TWT for wireless communications based on the double corrugated waveguide [4]. The use of 3D electromagnetic simulators and high computation power provided by GPUs have substantially improved the TWT design making more accurate the simulation domain modeling the interaction mechanism [5].

However, TWTs are mechanical structures. The dimensions of the interaction structure (slow wave structure) are a function of the wavelength. The short wavelength at millimeter waves makes fabrication challenging due to the tight tolerance and the dimensions of the smallest features.

The experience acquired in the fabrication of D-band TWTs in the frame of the EPSRC DLINK project has highlighted that the most critical step is the diffusion bonding [6, 7] and the CNC machine step of the interaction circuit.

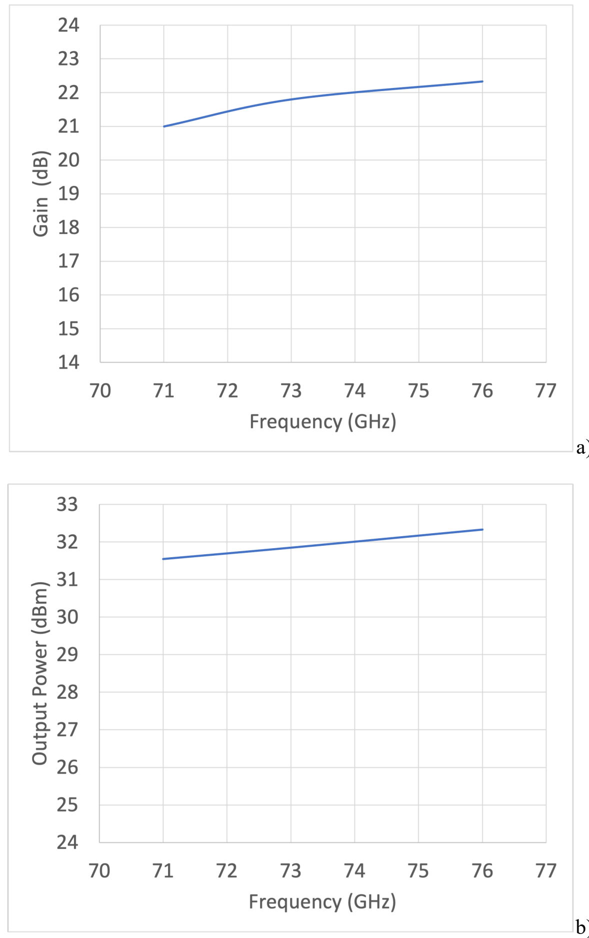

Fig.1 Simulated a) Gain and b) Output Power of the single section E-band TWT.

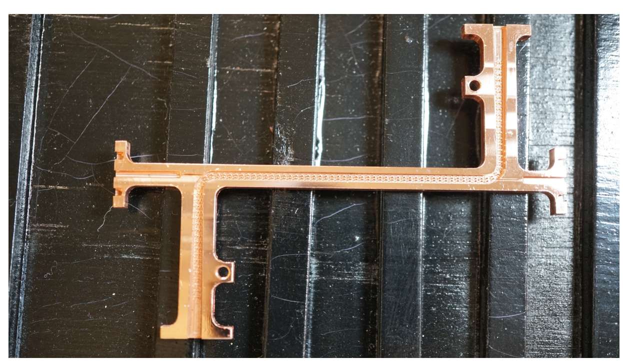

Fig. 2. Fabricated E-band Double Corrugated Waveguide – waveguide block

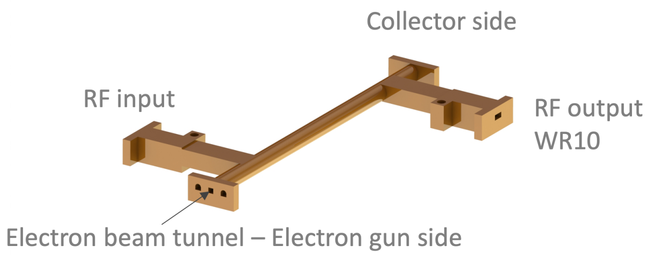

Fig.3 Final DCW circuit to be assembled with the electron gun, collector and RF windows.

The slow wave structure, for the described TWT is the double corrugated waveguide, is built in split blocks made of High Conductivity Oxygen Free (OFHC) copper. One block includes the waveguide with pillars, couplers and beam tunnel. The fabrication of this block requires high accuracy CNC milling, very small diameter tooling and longer fabrication time. The other block is a flat lid to close the waveguide. The two blocks have to be bonded with a vacuum tight sealing by diffusion bonding. After the diffusion bonding, the resulting block is machined into a cylindrical shape to support the permanent magnetic focusing system.

This machining phase is critical. If the bonding is not strong, fractures of the material and deformations that have no remedy could be present, with the results that new DCW blocks have to be fabricated with high additional costs.

II. Results

The E-band TWT specifications are 70 W output power and 40 dB gain. A double corrugated waveguide (DCW) was designed in the 71 – 76 GHz band with dispersion in synchronism with a 13.05 kV beam voltage. The specifications were satisfied in the design phase by a two-sections DCW able to provide the required gain and output power.

The first prototype of the E-band TWT was decided to be built with a single section instead of two sections to facilitate the beam alignment and test all the fabrication aspects, in preparation to the more complex two sections TWT.

A DCW with 45 periods was designed. More than 21 dB gain and about 2 W, with about 10 mW, input power, were obtained in the band as shown in Fig.1

The DCW fabrication has been performed by the new technique to overcome the fabrication risks of the typical fabrication in two squared blocks to be bonded. The DCW was built with the two blocks shaped very close to the final circuit. Fig. 2 shows the fabricated shaped block with the DCW. The detail of the pillars and couplers are visible. To note the high fabrication quality. The second block is a flat lid (not showed). To note the lateral squared profile. This permits to assess the quality of the bonding and reduce the machining effort to achieve the final shape to be assembled to the electron gun and the collector.

The two shaped blocks were bonded by diffusion bonding. A relatively short CNC machining process has been performed after the bonding for having the final shape (Fig.3). The part is machined to have a cylindrical profile to support the magnets of the periodic permanent magnetic system. In the specific case the diameter of the cylindrical section is 4 mm. Fig. 3 shows the circuit machined after diffusion bonding. Two lateral flanges will be connected to the RF windows. The beam tunnel is connected to the electron gun and collector by flanges with dowel pins for a high accuracy alignment.

The assembly of the TWT is in the final stage. After the assembly, the TWT will be baked to achieve a vacuum level better than 10^{-8} torr. When the vacuum level is established, the high voltage measurements will start.

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