# Progress on a 71 – 76 GHz folded waveguide TWT for satellite communications

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***Abstract*—A high frequency folded waveguide travelling wave tube (TWT) has been designed to test this delay line technology for applications in satellite communications. Simulations predict an output power ~100 W over the frequency range of 71 – 76 GHz can be achieved for an input power of ~9 mW (40 dB gain) using such a folded waveguide. Measurements of the vacuum windows brazed into their jackets indicate better than 17 dB return loss over the required frequency range. The collector will be single stage depressed and the cooling solution has been tested using a thermal source.**

***Keywords*—Folded waveguide TWT, slow-wave structure, window, collector, W-band, satellite communications.**

## I. INTRODUCTION

Progress on a project to design, fabricate and test a 71-76 GHz, ~100 W, 40 dB gain, TWT to prove key technology for future satellite communications is reported [1]. A folded waveguide design was selected to meet these requirements. Dispersion curve analysis has been carried out to predict the dimensions required for the folded waveguide slow-wave structure and analysis has been undertaken to predict the length required to realise the required gain. The design has also been further refined through numerical simulation.

The dispersion relationship was verified in cold test measurements on two test structures. These components, and the components for the hot test structure are fabricated in GLIDCOP [2] using precision CNC milling. GLIDCOP is a high performance copper alloy containing fine particles of aluminium oxide.

A high frequency vacuum window has been designed derived from the approach proposed by Cook et al [3] for use at 200 GHz. A window based on this design has been built and tested on a Vector Network Analyser (VNA) and achieved return loss of better than 17 dB over the required frequency range.

The spent beam will be received on a single stage depressed collector. The collector has been fabricated with relatively thin copper walls of thickness of several mm which will be water cooled during high average power tests. The collector cooling solution was tested with a thermal power source, comparable to the expected spent beam power, and found to provide adequate thermal regulation.

This paper details progress to date, outlining the simulations, measurements and development of the design of the folded waveguide TWT, including the design, simulation and test of a window, capable of operating at 71-76 GHz, collector and the delay line.

## II. SWS DESIGN

Analysis of the dispersion curve, interaction impedance and a determination of gain was initially carried out for a folded waveguide TWT operating between 71-76 GHz and at an electron beam voltage ~15 kV. The dispersion curve was calculated using equations (1) & (2) for the delay line and the electron beam respectively:

$$\left({}^{f}/_{f_c}\right)^2 = 1 + \left({}^{a}/_{L}\right)^2 \left[\left({}^{\phi}/_{\pi}\right)^2 - (n+1)\right]^2 \tag{1}$$

$$ {}^{f_b}/_{f_c} = \left[{}^{a v_z}/_{p\pi c}\right]\phi \tag{2}$$

where $f$ = frequency, $f_c$ = cut-off frequency, $f_b$ = beam frequency, $\phi$ = phase change, $L$ = wave path length, $p$ = beam path length, $n$ = number of space harmonic, $a$ = long waveguide dimension, $v_z$ = beam velocity, $c$ = speed of light, see Figure 1 [4].

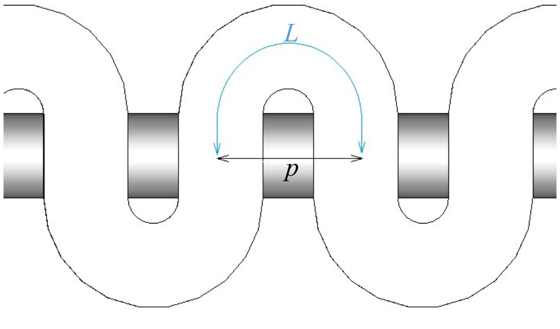

Figure 1: Schematic lay out of folded waveguide. Also indicated are some of the parameters used to determine the dispersion curve.

The interaction impedance and hence the length of the amplifier required to provide a gain of 40 dB were calculated using the approaches described in [4,5].

Further studies of critical factors such as multipacting, thermal/ mechanical loading of the structure have also been carried out, and no significant negative impact on performance is expected.

## III. COLD-TEST MEASUREMENTS

To support the design process and to verify that a) the structure achieved the required dispersion behavior and b) the techniques to be used to machine the surface were adequate, various test vehicles were designed and fabricated in GLIDCOP.

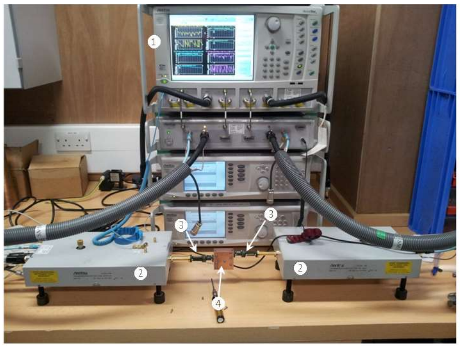

Figure 2: A test vehicle being measured by a VNA. Here: 1 = VNA, 2 = external modules, 3 = WR10 - WR12 waveguide tapers, 4 = test vehicle

The fabrication method for both the cold test components and the hot test parts is a spilt block approach using precision micro-milling to introduce the delay line and taper transitions. The cold test measurements on the test components, shown in Figure 2, gave reasonable agreement with the expected dispersion.

Good amplitude agreement was obtained between the simulation and measurement if the simulations assumed a wall conductivity about half that of pure copper.

## IV. PREDICTED AMPLIFIER PERFORMANCE

Computer simulations were used to refine the structure, optimizing the TWT delay line geometry to achieve the desired performance parameters with a specified electron beam voltage and current. Output power was found to vary from ~160 W, at lower frequencies, to ~90 W at higher frequencies. Saturated gain was seen to occur at ~9 mW of input power for the middle of the band, and initial electronic power conversion efficiencies, i.e. without the use of a depressed collector, have been estimated to be ~8 %. The spent beam energy is always above 10 kV so during the long pulse/high average power tests the collector will be resistively depressed to 10 kV, enhancing the tube efficiency and mitigating the power load to the collector to a level tolerable by the collector. Thermal transport analysis was used to design a cooling solution which has been tested with a thermal analogue to the beam power load. The collector temperature was shown to remain below 45 $^{o}$C at the maximum expected power load (the measurement point for this test lay along a thermal path from the heat source to the cooling surface with a greater thermal resistance to the cooling surface than will be the case for the real collector/heat source configuration).

## V. WINDOW DESIGN

A high frequency vacuum window has been designed and optimsed by numerical simulations. The window comprises an alumina dielectric contained within a rectangular/cylindrical/ rectangular waveguide arrangement [3], Alumina was chosen as this dielectric is readily available and has good EM / thermal / mechanical properties. The simulation predicted an optimum form for the window structure taking account of fillets required for brazing of the components. The assembled window has return losses better than 17 dB, over the frequency range of interest.

## VI. CONCLUSIONS

The design of a folded waveguide TWT for the 71 – 76 GHz range has been completed. Predicted gain is 40 dB, with an output power close to 100 W. Electromagnetic test structures have been fabricated in GLIDCOP using CNC machining. Good agreement was achieved between simulations and VNA measurements. Low loss alumina vacuum window and single stage depressed collector designs have also been developed and been subject to experimental testing.

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