A Fast Model of a 1-D Nonlinear Beam-Wave Interaction for a 225 GHz TWT

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***Abstract*—A code for a fast 1-dimensional model is under development for the simulation for the beam-wave interaction in the traveling wave tube amplifier (TWTA). The code is based on a Lagrangian algorithm. The input parameters are modified to extend the code validity to structures different from angularly symmetric structures. The preliminary results for the output power and gain for the double corrugated waveguide (DCW) TWT at 225 GHz are compared with particle in cell (PIC) simulations.**

I. Introduction

Amplification at terahertz (THz) frequencies is challenging, but of great importance. The applications of the Thz regime has been shown to be wide, with uses in high speed data transfer, high resolution imaging, or astromony [1] to name only a few.

TWTAs operate by propagating a signal along a proper waveguide. This waveguide slows the wave's phase velocity to just less than that of electrons in an electron beam at a defined voltage. Energy is transferred to the signal from the beam via beam-wave interaction, amplifying the signal. Traditionally, helices are used as the slow-wave structure (SWS) by which the signal would propagate. At the THz regime, the required size of the helix is too small to be fabricated. Novel structures must be designed and realized, such as the double corrugated waveguide (DCW) [2], [3] . Proper simulation tools are required for the accurate evaluation of the performance.

Presently, advanced full 3D electromagnetic simulators are used in this process, but a very long simulation time is required due to the computation complexity. Consequently, a fast method, as the Lagrangian simulator, for simulating THz structures would be very effective for expediting the design process whilst still maintaining accuracy.

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In the following, the preliminary results to validate a Lagrangian simulator to non-angularly symmetric structure is described.

II. Theory

A Lagrangian formulation of the interaction and force equations is used to describe the beam-wave interaction occuring in the operation of the TWTA. The code follows individual charge groups along the tube, whose positions relative to each other are calculated by the analysis of each charge groups phase position relative to the rf wave propagating along the slow wave structure. This allows for the understanding of the nonlinear behaviour of the interaction [4], [5].

$$\frac{d\vec{v}}{dt} = - \mid \eta \mid \left[\vec{E} + \vec{v} \times \vec{B}\right] \tag{1}$$

The set of equation comprises of two circuit equations, a force equation describing the force the charge groups experience due to the wave and space charge, and a velocity-phase equations. The circuit equations are second order ordinary differential equations (ODEs) describing the normalised wave amplitude and the phase angle between the wave and the electron beam, and are derived from a one-dimensional lossy transmission line equation. The force equation is derived from the Lorentz force equation, shown in Eqn. 1. The velocity phase equation is derived from the definition of the phase lag of the rf wave relative to a hypothetical wave travelling at initial charge group velocity [4], [6].

III. Code Development

The simulator has been written in MATLAB [7]. The number of calculation planes, or iterations, is calculated by using the structures length divided by a pre-defined integration step. Due to the stiffness of the equations used, a small integration step is required for a stable output.

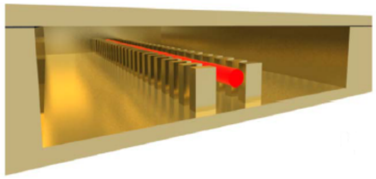

Fig. 1. Double corrugated waveguide, DCW [2]

The calculation is treated as an initial value problem. The initial conditions are the normalized amplitude of the wave, the phase angle between the wave and the electron beam, their rates of change with respect to their axial position, and the normalised axial velocity and phase position of each charge group. The initial phases are spread evenly over one rf cycle, and the initial velocities are all normalised to zero. The first iteration solves the equations based on these initial conditions, and uses the solutions as the initial conditions for the next iteration. The algorithm continues until the defined number of calculation planes has been met.

When compared to the helical waveguide, the DCW has very different E_z field component distribution. The topology of the DCW supports an electromagnetic wave that is not angularly symmetric. The helix, however, supports an angularly symmetric field propagating in a cylindrical beam tunnel with a given radius. Due to the code being based upon equations supporting angularly symmmetrical fields it is necessary to modify some of the physical values to obtain valid result for the DCW. It has been found that the values to modify that provide the best agreement are the interaction impedance and the losses. The interaction impedance and the losses are both defined by the topology of the waveguide and the metal used in its construction. The beam tunnel radius is defined as the distance from the center of the beam to the corrugation wall. The adopted values for the test DCW structure in [3] are shown in Table I.

TABLE I
MODIFIED VALUES

Simulation	Z_0/Ω	Loss/db/period
Fast 1-D	2	0.0185
MAGIC3D and CST	1	0.05

A. Results

The code has been applied to simulate the performance of the 90-period DCW-TWT at 225 GHz in [3]. The original simulation was performed by MAGIC3D particle in cell simulator. This simulation took about 70 hours. [2], [3], [8], [9].

The 1-D code used the values of interaction impedance and losses in Table I. Fig.2 and Fig. 3 show the gain and output power as a function of axial distance along the tube as caluclated by the 1-D code. The comparison the power along the tube simulated by MAGIC3D (Fig. 4) shows a good agreement. A gain of about 12 dB was found, which is also consistent with both the MAGIC3D simulation and the CST-

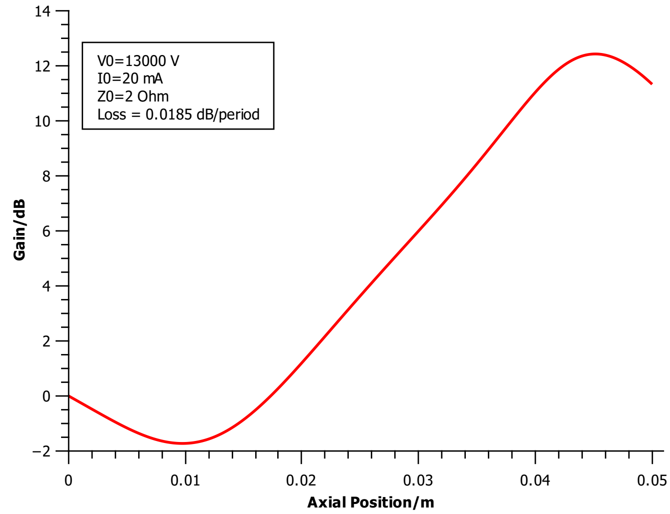

Fig. 2. Gain at 50mW input power calculated by 1-D code

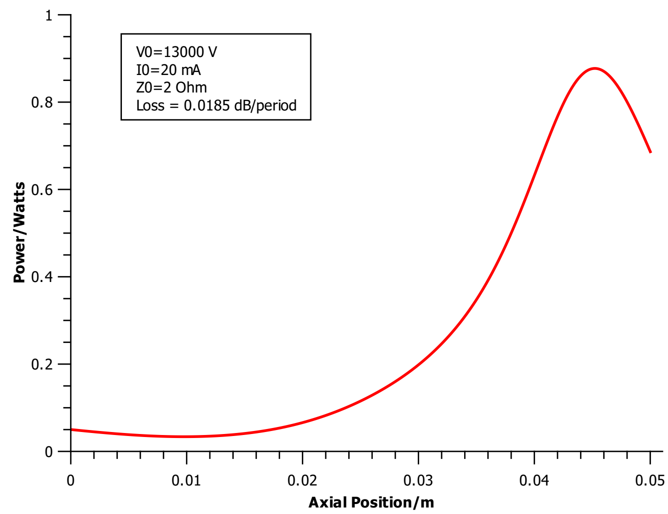

Fig. 3. Output power at 50mW input power calculated by 1-D code

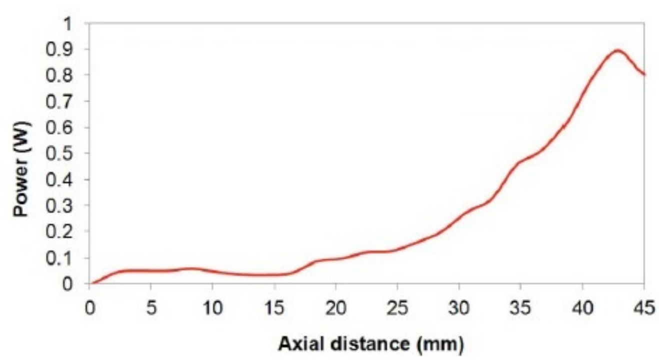

Fig. 4. Output power at 50mW input power calculated by MAGIC3D [3]

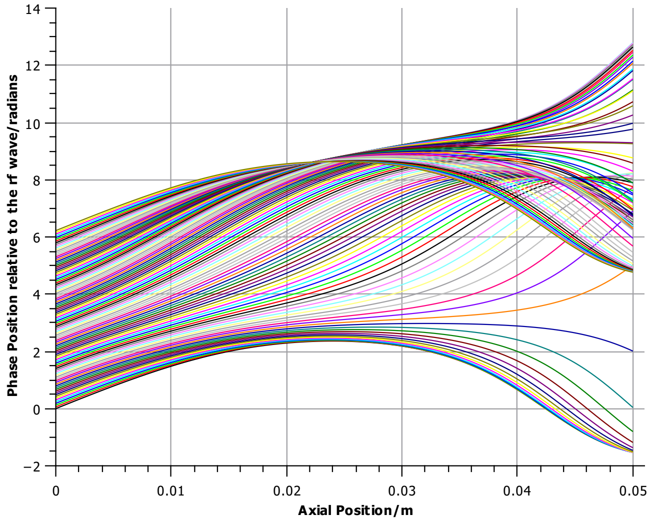

Fig. 5. Phase as a function of axial distance

PS simulation [3].

Fig. 5 shows the phase position of each charge group relative to the phase of the rf signal as a function of axial distance.

IV. Conclusion

A first approach to a 1-D fast simulator for non-angularly symmetric SWS has been presented. It has been shown that, with modification of cold parameters, the code outputs a power and gain in agreement with that of the full 3D electromagnetic simulators with very short computation time. The code was validated with data for a DCW TWT at 225 GHz.

Acknowledgment

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