Progress with DIMOHA for fast time-domain simulations of traveling-wave tubes

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***Abstract*—We presented at previous IVEC conferences a new model for traveling-wave tubes (TWTs). Since then, we used this model to build the DIMOHA algorithm as an alternative to current particle-in-cell (PIC) and frequency domain codes. Its validity is assessed against these codes and against measurements from several TWTs. We present simulations for an 80 watts TWT in Q band presently in development. An industrial version of DIMOHA is under construction for the design and characterization of TWTs.**

***Index Terms*—traveling-wave tubes TWTs, DIMOHA, simulation, AM/AM, AM/PM, nonlinear signals, time-domain, wave-particle interaction, Hamiltonian dynamics, N-body dynamics, large-signal amplifiers.**

I. Introduction

Nowadays, to simulate the wave-particle interaction occurring in the slow-wave structures (SWSs) of traveling-wave tubes (TWTs) [1], one can rely on two main options : specialized frequency codes or particle-in-cell (PIC) codes in time-domain. We choose a third option based on our discrete model with hamiltonian approach (DIMOHA). The two salient features of this model are that it relies on model order reduction (MOR) to represent electro-magnetic waves and that its physics is expressed by a Hamiltonian function. MOR allows huge reduction in the number of degrees of freedom describing the waves compared to PIC models. The Hamiltonian formalism results in a so called symplectic time integrator that preserves important qualitative features of the physics at play. The simulation code derived from this approach is very fast compared to PIC codes and possibly more accurate than specialized frequency models, but also has some limitation. To assess these claims, we engaged into the simulation of actual TWTs and compared the different codes and the measurements. Results from this endeavor will be presented.

II. Algorithm

DIMOHA is a specialized model in time-domain and large-signal regime based on an N-body (a.k.a. many body) hamiltonian description [2], [3], [4], [5], [6], [7]. The symplectic algorithm [8] we built is developed jointly between Thales AVS/MIS, Aix-Marseille Université–CNRS and the Centre National d'Études Spatiales in France. It is written in modern Fortran and parallelized with the Message Passing Interface (MPI) libraries. DIMOHA bears several advantages : 1) it allows arbitrary waveform (not just field envelope), including continuous waveform (CW), multiple carriers, or digital modulations (e.g. phase-shift keying); 2) the algorithm is much faster than PIC codes, thanks to a field discretization allowing a drastic degrees-of-freedom reduction, along with a robust symplectic integrator; 3) it supports any periodic slow wave structure (SWS) design such as a helix or folded waveguides, including structures with pitch tapering; 4) it reproduces harmonic generation, reflection, oscillation, and distortion phenomena; 5) it handles nonlinear dynamics, including intermodulations, trapping, and chaos; and 6) the number of input parameters required is low (listed in Table I), so that DIMOHA is easy to use.

III. Validation

The validity of the discrete model was analytically assessed [9] by comparing it with Pierce's four-waves theory in frequency-domain. Several works in time-domain were performed to validate our algorithm. We performed [2] a numerical comparison against MVTRAD (a frequency code developed by Thales) for a fictitious (lossless) TWT. We already compared [8] DIMOHA against measurements from a 150W Ku TWT (a commercial helix TWT with tapered pitch) and against PIC codes for folded waveguide TWTs.

Since then, simulations of folded waveguide TWTs were improved. We compared [10] DIMOHA against PIC codes CST-PS and MAGIC3D for a 94 GHz folded waveguide TWT. Currently, we are testing our algorithm against measurements from helix TWTs at 14W in X-band, 170W in Ka-Band and 80W in Q-band (see Fig. 1). Multiple reflections, possibly causing oscillations, are being investigated (see Fig. 2).

Finally, we are performing simulations of a 4 meters long TWT. This is the experimental device of the PIIM laboratory at Aix-Marseille University–CNRS used to investigate turbulence and chaos in plasmas.

IV. Conclusion

DIMOHA is a promising tool that bears several advantages for both industrial and research activities. It also provides a new approach to analyze telecommunications signals for operators. Currently, a version is under industrialisation (with a

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TABLE I
INPUTS AND OUTPUTS OF DIMOHA FROM REF. [8]

	Inputs
Tube (per cell):	Pitch d, dispersion relation $\omega(\beta)$, impedance $Z_c(\beta)$ and attenuations α_n
Beam (cathode):	Current I_0 and potential V_0, beam diameter b
Signal:	Injected 1D electric field in time at the tube inlet
	Simulation parameters
t_{max}	Duration of the interaction
Δt	Time step size
δ	Initial spacing between macro-electrons
N_{os}	Number of mesh points per cell
N_{ph}	Range of coupling between cells
	Outputs
1D electric field in time inside the tube	
1D distribution function of electrons (positions, velocities)	

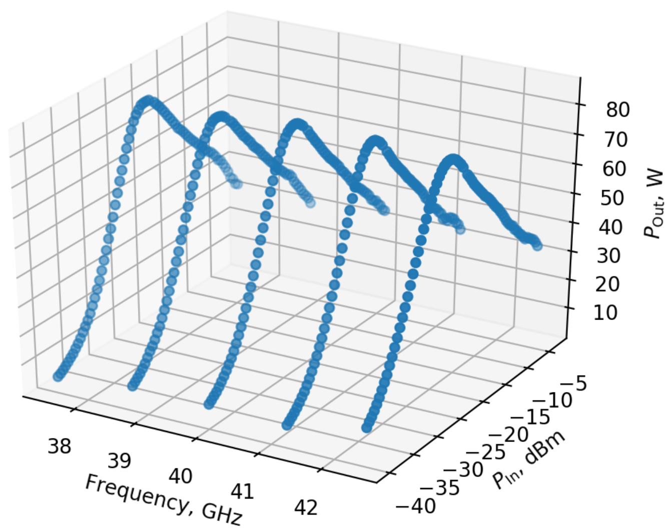

Fig. 1. Simulations of the output power at various input powers and frequencies for an 80W Q-band tapered helix TWT [11] with DIMOHA. It took 22 minutes per point with 16 processors for a numerical resolution of ± 0.005 W. On a small computer with 4 processors, it took 16 minutes per point for a resolution of ± 0.25 W.

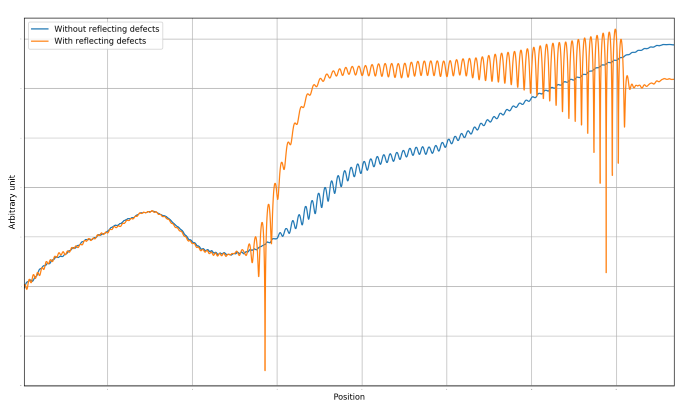

Fig. 2. 50 ns long simulation of the electric field amplitude along the tube axis for the 80W Q-band tapered helix TWT. For the orange curve, we added two reflecting defects, one after the local attenuator (VSWR of 1.05) and one at the helix output end (VSWR >2).

graphical user interface) to be implemented as a new numerical solution for TWT design. In this respect, the large range of tested tubes helps us to burn-in DIMOHA. New features are under consideration, like 2.5-D, 3-D and frequency-domain versions.

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