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► **To cite this version:**

Khalil Aliane, Damien Minenna, Yves Elskens, Frederic Andre, Alexandre Poye. Time-Domain non-linear simulations of a 3 meter long traveling wave tube. 2021 22nd International Vacuum Electronics Conference (IVEC), IEEE, Apr 2021, Rotterdam, France. pp.1-2, 10.1109/IVEC51707.2021.9722482 . hal-04452756

**HAL Id: hal-04452756**

**<https://hal.science/hal-04452756v1>**

Submitted on 12 Feb 2024

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# Time-domain non-linear simulations of a 3 meter long traveling wave tube

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## Abstract

At previous IVEC conferences, we presented a new  $N$ -body time-domain model for simulating traveling wave tubes (TWTs), which has been applied and assessed for several industrial TWTs covering a broad range of bandwidth and power regimes. Since then, we applied this model to meters long TWTs operating far beyond the saturation point. The capacity of our algorithm DIMOHA to predict correctly non linear behaviours is assessed against measurements for a 200 MHz, 3 meter long TWT.

## Keywords

metric traveling-wave tubes TWTs; DIMOHA; simulation; time-domain; AM/AM; AM/PM; wave-particle interaction; Hamiltonian dynamics;  $N$ -body dynamics; large-signal amplifiers; non linear regime; trapping.

## INTRODUCTION

We presented previously our new time-domain Hamiltonian model for TWTs and similar vacuum structures with a periodic slow wave structure (SWS), which relies on two main features, namely a model order reduction for the electromagnetic wave representations and an  $N$ -body Hamiltonian to describe the beam-wave interaction. The order reduction enables our algorithm DIMOHA to be much faster than alternative PIC codes despite the big number involved in an  $N$ -body description.

One of DIMOHA's advantages is that, since it relies on a self-consistent Hamiltonian, it fully reproduces the physics in the SWS, including non linear phenomena, such as intermodulation, trapping etc. . . Those features were successfully assessed against measurement for several industrial TWTs. However, such devices are primarily designed for broadband or high power amplification [4], and thus do not reach far beyond saturation.

One way to assess DIMOHA's ability to investigate strong non linear behaviours is to apply it to meter long, low frequency TWTs. Though uncommon, such TWTs have been used [1, 2, 3] primarily as investigation tools for beam-plasma instabilities, since they share mathematically equivalent evolution equations. Unlike their industrial centimeter long counterparts, meter long TWTs can go deep in the non-linear regime, where several trapping oscillations are observed.

One such TWT is the San Diego university 3 meter long tube, built specifically to study the beam-plasma instability. This TWT is 3 to 4 times longer than commercial TWTs in terms of wavelengths, and contains a continuous probing system, allowing to follow the RF power all along the delay line [1, 2]. Another metric TWT is the 4 meter long tube built and developed in the PIIM laboratory at Aix-Marseille university [3], which contains 4 moving probes providing also access to the power along the TWT.

Here we compare DIMOHA's simulations of the 3 meter long San Diego TWT, studies of the 4 meter long tube are undergoing.

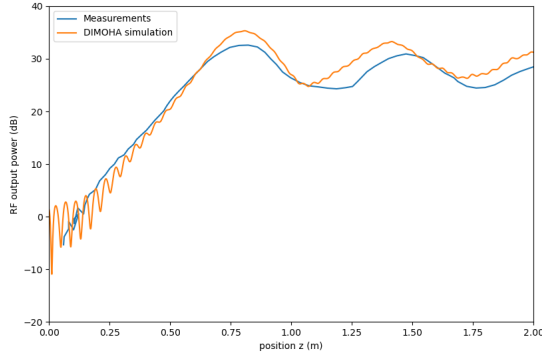
## ALGORITHM

DIMOHA is a 1-D specialized model in time domain and large-signal regime, based on an  $N$ -body (a.k.a. many body) Hamiltonian description [5, 6, 7, 8, 9, 10]. This symplectic algorithm [11] is written in modern Fortran and parallelized with the Message Passing Interface (MPI) libraries. DIMOHA bears several advantages, including a its grand versatility, as it supports any periodic slow wave structure and as it has been tested and validated for a large range of industrial TWTs of different geometries and types [12, 13], and a relatively small computing cost as well as a small number of input parameters requirement.

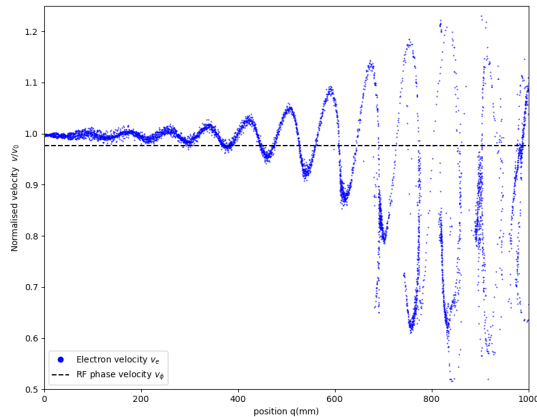
It is the discrete method used in our model that enables DIMOHA to be much faster than PIC codes : electromagnetic fields are decomposed on space cells of the size of the helix pitch (more generally, the length of the periodic structure cell). Even for a several meter long TWT, comprising thousands of pitches, we only need to adjust the numerical parameters of our algorithm, and optimise the parallelization and memory management to successfully simulate meter long TWT reasonably fast.

## VALIDATION

We use DIMOHA to simulate the electromagnetic power along the delay line in the San Diego 3 meter long TWT at 195 MHz. In figure 1, and we compare our simulation (in blue) to San Diego observations (in orange) [1, 2]. We obtain a good agreement in the linear regime. After the saturation point, discrepancies grow bigger : while we observe the same number of trapping oscillations, their measured period is a little longer than what DIMOHA predicts. This can be due to several reasons, the most likely one being an improperly adapted space charge model.



**Figure 1. Time average RF power at  $F = 195$  MHz as function of the longitudinal position inside a 3 m long TWT at time  $t = 0.7\mu\text{s}$ .**



**Figure 2. Zoom at the macro-electrons positions and velocities (blue dots), normalized by the beam velocity  $v_0$ , inside the 3 m long TWT at time  $t = 0.7\mu\text{s}$  simulated with DIMOHA at  $f = 195$  MHz. The dashed line corresponds to the phase velocity  $v_\phi/v_0$ . Electrons slower than their initial speed have lost their momenta to the benefit of the wave.**

DIMOHA also enables us to follow the electron positions and velocities at any given time of the simulation (figure 2).

## CONCLUSION

While previously tested and validated for several industrial TWTs, DIMOHA proves to be also a promising tool for more research oriented plasma-beam physics and deep non linear regime investigation. Currently, we are testing our algorithm on the PIIM laboratory homemade 4 meter long TWT.

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