Using VSim to Explore the Design of a Plasma-filled W-Band TWT

Andy Yue, Ph.D.

How can I use VSim to design and model complex electron devices that involve unconventional physics such as plasma processes? And why do I want to choose VSim over other products?

Andy Yue, Ph.D.

- Born in 1994; Ph.D. in May 2021
- Ph.D. Specialization: Vacuum Electron Device Simulation and Analysis
- Completed Ph.D. research by using VSim; Joined Tech-X in June 2021

- Other Educations:
  - Mathematics (BS)
  - Financial Economics (BS)
  - Physics and Philosophy (BA, Double Majors)

Notes:

- The TWT simulation project to be discussed is part of Dr. Vishant's research, who is a client of Tech-X and granted limited permission for this presentation

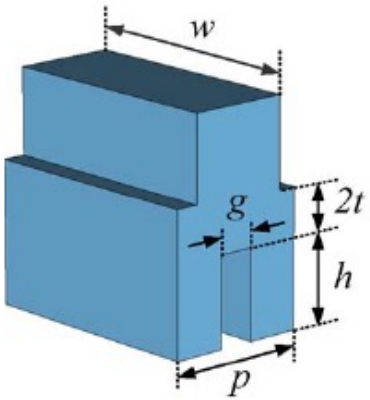
- Simulation results to be presented are not optimized since the simulation is part of an ongoing research

Topics

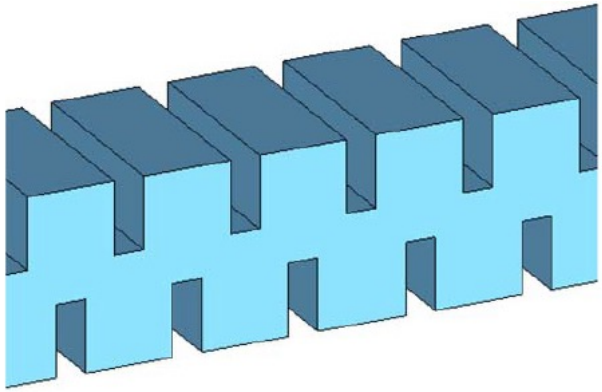
- Geometry Building
- Mode Analysis
- Velocity Modulation
- Setting Up the Plasma Process
- Conclusion

Basic Device Descriptions

- W-Band (i.e., 75-110 GHz)
- Staggered double-vane structure
- Originally published by Lai et. al. (DOI:10.1109/TED.2011.2174458)



$p = 1.066\text{mm}$
$w = 1.786\text{mm}$
$h = 0.658\text{mm}$
$g = 0.269\text{mm}$
$2t = 0.350\text{mm}$



Top: single-element 3-D schematic of the SWS with geometric parameters (Lai et. Al)

Left: Three-dimensional model of the staggered double-vane structure (Lai et. al.)

Geometry Building (Single Cell)

Mode Analysis Based on a Single Element

- Exciting the structure with a current source that contains multiple frequencies
- Periodic boundary condition
- Allow the simulation to run sufficiently long (depending on the frequency range)
- Mode of the structure can be extracted by using the VSim analyzer “extractModesViaOperator”

Mode Analysis Based on a Single Element

Mode	f_r (Hz)	f_i (Hz)	lam_vac (m)	cont	rel-err	abs-err
26	7.136546e+10	2.603145e+09	4.200806e-03	1.49e-02	1.71e-02	2.55e-04
27	7.136546e+10	-2.603145e+09	4.200806e-03	1.49e-02	1.71e-02	2.55e-04
28	7.787369e+10	-0.000000e+00	3.849727e-03	1.05e-02	1.25e-02	1.31e-04
29	8.027317e+10	-0.000000e+00	3.734653e-03	9.80e-03	2.13e-02	2.09e-04
30	8.177028e+10	3.242553e+09	3.666276e-03	1.07e-02	2.20e-02	2.35e-04
31	8.177028e+10	-3.242553e+09	3.666276e-03	1.07e-02	2.20e-02	2.35e-04
32	8.429217e+10	3.760028e-05	3.556587e-03	9.10e-03	2.17e-02	1.98e-04
33	8.883166e+10	2.771594e+09	3.374838e-03	8.65e-03	1.58e-02	1.36e-04
34	8.883166e+10	-2.771594e+09	3.374838e-03	8.65e-03	1.58e-02	1.36e-04
35	9.107102e+10	-0.000000e+00	3.291853e-03	5.38e-03	1.05e-02	5.66e-05
36	9.563160e+10	1.880014e-05	3.134868e-03	7.79e-03	7.52e-03	5.85e-05
37	1.032050e+11	-0.000000e+00	2.904825e-03	4.92e-03	8.19e-03	4.03e-05
38	1.046169e+11	-1.542107e+09	2.865621e-03	1.06e-02	3.95e-03	4.21e-05
39	1.046169e+11	1.542107e+09	2.865621e-03	1.06e-02	3.95e-03	4.21e-05
40	1.108858e+11	3.760028e-05	2.703614e-03	9.59e-03	5.32e-03	5.10e-05
41	1.151045e+11	1.880014e-05	2.604524e-03	9.84e-03	6.07e-03	5.97e-05
42	1.155944e+11	-4.175604e+09	2.593485e-03	8.97e-03	7.99e-03	7.17e-05
43	1.155944e+11	4.175604e+09	2.593485e-03	8.97e-03	7.99e-03	7.17e-05
44	1.168055e+11	-3.760028e-05	2.566595e-03	1.77e-02	2.08e-03	3.68e-05
45	1.242065e+11	3.760028e-05	2.413661e-03	5.78e-03	6.80e-03	3.93e-05
46	1.254397e+11	1.880014e-05	2.389933e-03	8.08e-03	4.37e-03	3.53e-05

"Extracting degenerate modes and frequencies from time-domain simulations with filter-diagonalization" by Werner and Cary (https://doi.org/10.1016/j.jcp.2008.01.040)

Velocity Modulation

- Setting up the input signal
- Setting up a wave absorber at the output
- Setting up the electron beam
- Adding the magnetic field
- Adding diagnostics

Velocity Modulation

Setting Up the Plasma Process

- Setting up a neutral fluid that fills the slow wave structure
- Setting up secondary electrons
- Setting up the impact ionization process
- Setting up ion sinks
- Remove the external magnetic field

Setting Up the Plasma Process

What's Next?

- Using VSim to optimize the technical parameters
- Simulating the skin depth effect by using the "computeCavityG" analyzer

Why Use VSim

- VSim enables unified simulation of EM, particles, and plasma processes within the same model
- VSim's GUI enables rapid modeling of complex devices, which allows engineers to spend less time learning the software and more time optimizing their designs
- VSim's "radical transparency" enables scientists to tackle the most advanced problems