Ku-Band Traveling Wave Tube

The simulation of a traveling wave tube includes many aspects of physics and therefore a broad spectrum of the solvers available in CST STUDIO SUITE™ is needed. The structure of the tube is shown in figure 1. The particle beam is created in an electron gun and enters an adjacent slow wave structure. There, the beam interacts with the helical circuit to amplify the signal fed in at the RF input coupler. At the RF output the amplified signal is obtained. Since the particles would deflect each other due to an equal sign of charge, a magnetic field is used to keep the beam focused. In order to provide such a focusing magnetic field a periodic permanent magnet (PPM) stackup is employed. Finally, when passing the RF output coupler the particles end in a collector, where their energy is recovered.

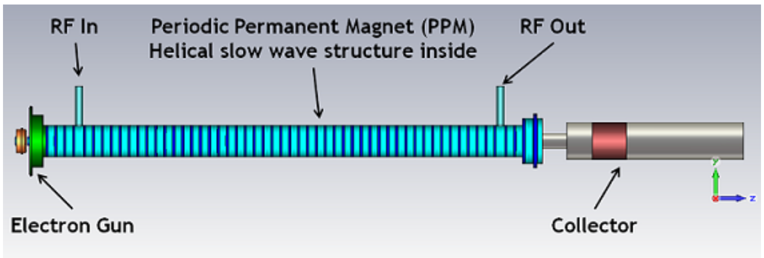

Figure 1: Traveling Wave Tube Structure

The simulation of an electron gun, where the particle beam is created, involves the evaluation of an electrostatic field in combination with particle tracking. A more detailed structure of the electron gun is shown in figure 2. The particles are emitted from the cathode towards the anode. A second electrode is used for focusing the generated electron beam.

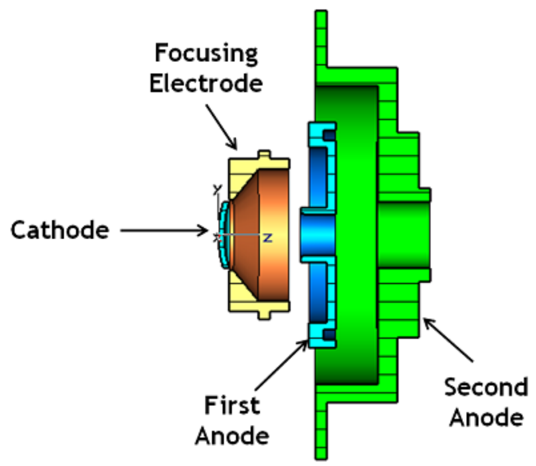

Figure 2: Structure of the electron gun.

Electric potentials are applied to generate an accelerating and simultaneously focusing electrostatic field. The electric potentials are applied in CST PS, where also later on the particles are included. The corresponding routines of CST EMS to evaluate the electrostatic field are called internally by the software. The resulting electrostatic potential is shown in figure 3.

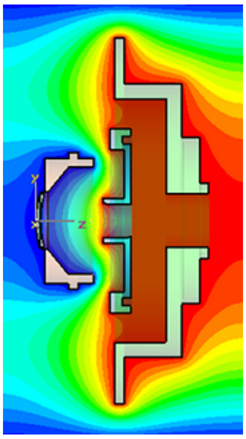

Figure 3: Electrostatic potential

The particle beam is then emitted from the cathode according to Childs Law. This represents an emission limited due to the space charge in front of the cathode. The emitted current and the particle trajectory (see figure 4) are obtained in CST PS. The color of the particle trajectories can indicate different values, as for example energy, velocity or charge of the particles. In figure 4 the color indicates the energy of the particles. This illustrates nicely that the particles start slowly (blue color), are accelerated by the electrostatic field to a final energy (red) and finally are only focused.

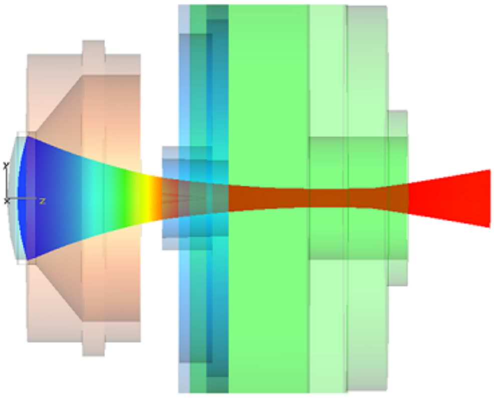

Figure 4: Particle Trajectories.

The particles will leave the electron gun and enter the slow wave structure, where they are focused by a magnetostatic field. This field is generated by means of a periodic permanent magnet (PPM) stackup, which consists of several cylindrically shaped permanent magnets. The magnets show a varying remanent magnetization along longitudinal (z) direction. They can be easily included as source in a magnetostatic simulation. The resulting z-component of the magetic field along the z-axis can be seen in figure 5 (right).

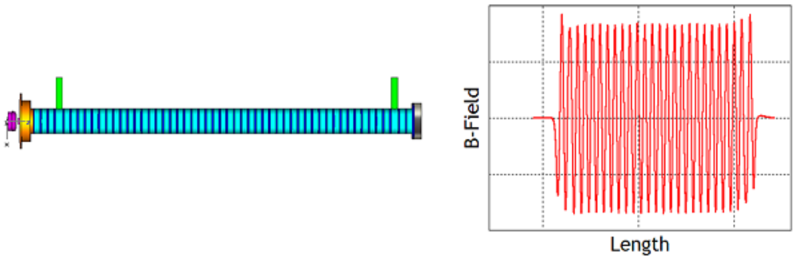

Figure 5: Periodic Permanent Magnet (PPM) structure (left) and resulting longitudinal magnetostatic field along longitudinal axis (right)

After having analyzed the electron gun and the magnetostatic field of the PPM, the next step is the design of the slow wave structure. Here a helical slow wave structure supported by dielectric rods is used (see figure 6). The dispersion diagram of the structure can be obtained by a parameter sweep in CST MWS (see also Periodic Eigenmode Simulation of a Traveling Wave Tube). Besides the dispersion diagram shown in figure 6, the parameter sweep directly gives interaction impedance and phase velocity vs. frequency. The intersection point of beam line and - diagram gives then either the operating frequency or the necessary beam voltage (see [1], Chapter 8, Figure 8.9 or 8.10).

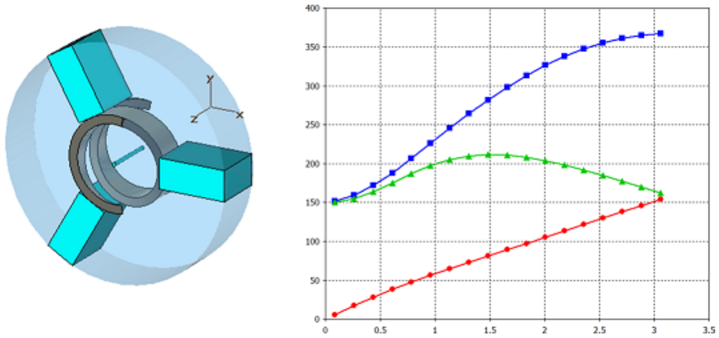

Figure 6: Dispersion diagram for forward mode (red), backward mode (green) and third mode (blue). The x-axis shows phase shift for one helix length. The y-axis is angular frequency.

In order to suppress the backward wave, often the support rods are coated with lossy material. This coating shows usually a longitudinal variation. To apply this spatial variation in the simulation, several parts of the support rods with spatially varying material properties are created with a customized VBA macro (see figure 7).

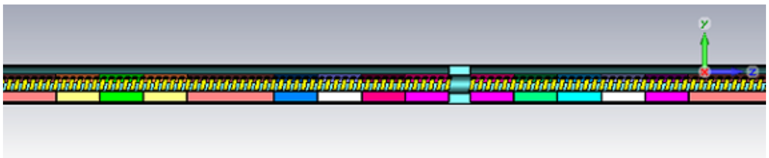

Figure 7: Spatially varying loss inside the helical circuit (varying color indicates varying loss).

After having performed the aforementioned cold test the RF amplification is simulated with the Particle-In-Cell (PIC) solver of CST PS. The resulting signals are shown in figure 8. In red is the low power RF input signal depicted. The blue curve represents the amplified RF output signals. The signals are obtained by waveguide ports embedded also in CST MWS. Their amplitude is sqr(Power) such that the power amplification can be evaluated by the signal amplitudes. The oscillation and the amplitude of the input signal (red) can hardly be seen in figure 8, since an amplification of 46.5 dB is gained.

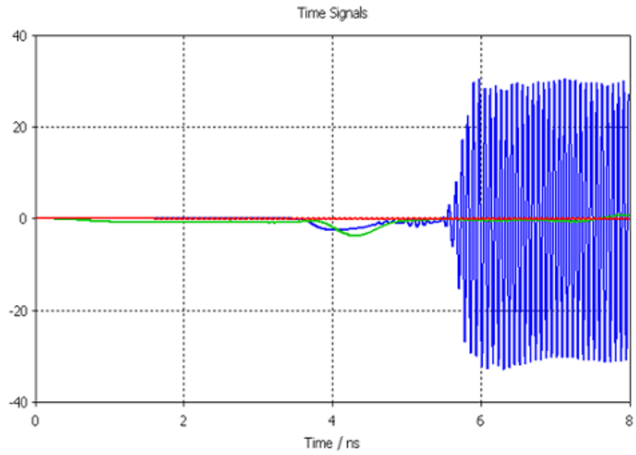

Figure 8: PIC simulation time signals: RF input (red), reflection (green), RF output (blue)

This article shows the different physical aspects of a traveling wave tube design and their usage of the broad spectrum of the CST STUDIO SUITE™. It involves the evaluation of electrostatic and magnetostatic fields (CST EMS). Particles need to be tracked through according to Lorentz Force equation to compute the DC current of the electron gun (CST PS). Possible RF interaction between the slow wave structure and beam needs to be carefully analyzed without particles in a so called cold test (CST MWS). And finally, a Particle-In-Cell (PIC) simulation with mutual coupling between fields and particles is perfomed to obtain the gain in a true transient process (CST PS).

References:

[1] J. Benford, J. A. Swegle, E. Schamiloglu, "High Power Microwaves", 2nd Edition, Taylor Francis Group, 2007