# Design Considerations of a 10 GHz helix TWT

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## Abstract

This paper discusses the design considerations of a 10 GHz helix traveling wave tube using commercial electromagnetic simulation software CST-PIC/MWS. The dispersion characteristics of the TWT have been analyzed by modeling of a single turn electron-free slice in eigenmode solver. The return loss optimization of the input-output couplers is performed by using of transient solver. The complete model has been simulated and analyzed in particle-in-cell solver and the results are presented.

## 1. Introduction

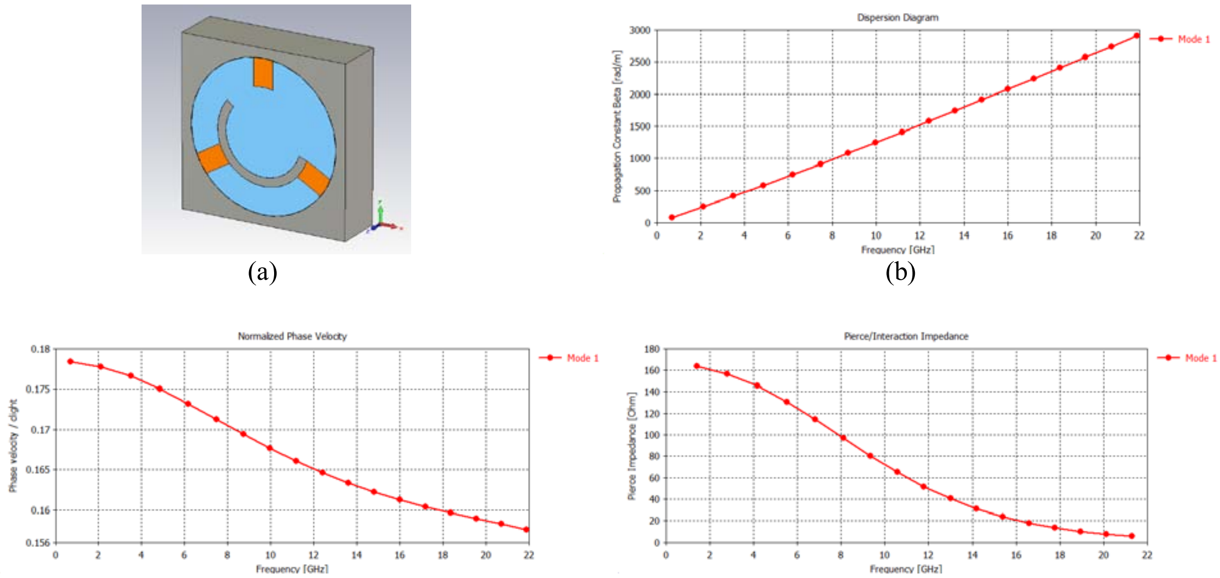
The traveling wave tube (TWT) having helical slow wave structure (SWS) is widespread used in radar and space communication satellites due to its RF performances [1, 2]. The TWT consists of input/output couplers, helical slow wave structure, support rods, electron gun and a collector embedded in a vacuum barrel. It works briefly on the principle of efficiently continuous interaction of the traveling electromagnetic wave and the electron beam to serve as a RF power amplifier. For efficient interaction it is required to have nearly synchronism between the electron beam and RF wave. In other words bunching in the electron beam have to occur in decelerating phase that implies that the speed of electron beam is slightly more than the axial phase velocity on supporting SWS structure. During the interaction the electron beam is giving its energy to the wave and that causes retardation in the beam speed. That can shift the electron bunch to the accelerating phase resulting energy transfer from the wave to the electron beam. A tapered helix can resynchronize the process results an increase in the interaction length to improve the gain of TWT [3, 4].

Helical SWS's are attractive for wideband applications on account of its dispersion characteristics. Reflections at the couplers of the TWT are always present over a bandwidth owing to the mismatch in the SWS. Depending on the strength of the mismatch it can cause oscillations in the amplified output signal [5, 6]. Usually using severed SWS's in combination with attenuators near the sever ends is an option to avoid these oscillations [7].

In recent years developments in three-dimensional commercial electromagnetic simulators make it possible to model a comprehensive TWT to simulate its dispersion characteristics as well as electron wave interactions to analyze the amplification process. In this paper we present the design and simulation of a X band helical SWS TWT operating at 10 GHz center frequency. The dispersion characteristics of the TWT have been analyzed by modeling of a single turn electron-free slice in CST Micro Wave Studio (MWS) eigenmode solver. The return loss optimization of the input-output couplers is analyzed in MWS transient solver. The complete amplification process including the electron beam and wave interaction has been simulated and analyzed in particle-in-cell (PIC) solver.

## 2. Design of the TWT

The design parameters to operate at 10 GHz frequency is firstly determined assuming the non-dispersive helical SWS to slow down the axial speed of RF wave to the speed of electron beam emitted from the cathode of the TWT. The radius of the tape helix is adjusted to satisfy $\beta a \approx 1$ condition, where $\beta$ is the axial phase constant of the wave and $a$ is the radius of the helix, to obtain an efficient interaction [8]. Since SWS is a periodic constant pitch helix it is reduced to a single pitch model to treat it as a resonator. Then a phase shift is imposed between the input and output planes, both ends of the slice, to calculate the corresponding eigen frequency. That is performed in MWS eigenmode solver by using of periodic boundary conditions. According to the results the parameters are adjusted to obtain a tradeoff between a minimum dispersion to increase the operational bandwidth and a maximum interaction impedance to increase the gain. Figure 1.a shows a general view of the simulated single turn slice having an inner helix radius of 0.812 mm, pitch of 1.05 mm, width of tape 0.597 mm, thickness of tape 0.18 mm, width of support rod of 0.42 mm and the barrel inner radius of 1.57 mm. In Figure 1.b-c respectively, the phase constant, normalized phase velocity and the interaction impedance is depicted with respect to the frequency.

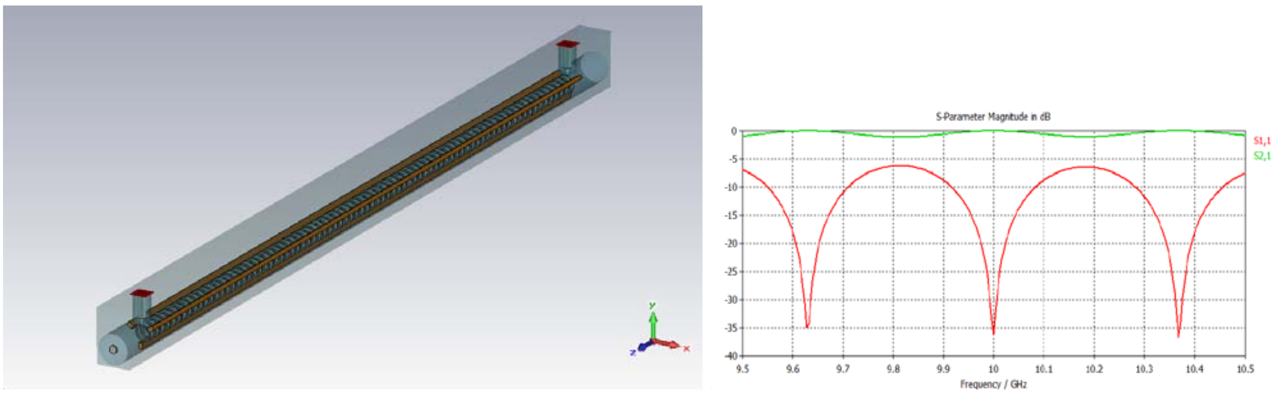



(a) (b)

(c) (d)

Figure 1: General view of slice model (a), propagation constant (b), phase velocity (c) and interaction impedance (d)

After determining the cold test parameters the TWT is designed. A general view of an 80 turn TWT is shown in Figure 2.a. The cathode radius determining the electron beam radius is chosen as the half of inner helix radius and the distance between the cathode and the SWS is chosen as five pitch length. The dielectric constant of 5.1 is chosen for support rods. The parameters as the tape width and thickness are adjusted to obtain a minimum return loss at the ports at 10 GHz center frequency. The results obtained from MWS transient analysis is shown in Figure 2.b. The input and output ports are matched to yield a 50 Ω impedance.

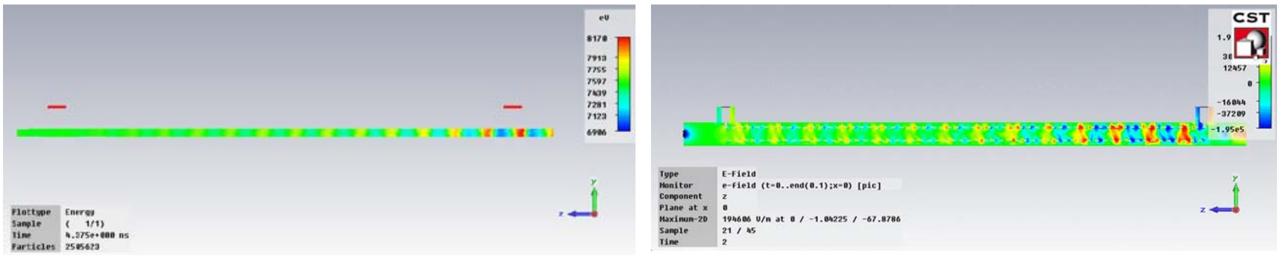



(a) (b)

Figure 2: General view (a) and S-parameters (b) of the TWT

## 3. Hot Simulation Results

The electron beam and RF wave interaction is simulated in PIC solver. At the input port of the TWT a 10 GHz sinusoidal signal with unit amplitude is excited. To align the electrons along the axial length a predefined magnetic field is determined. The current of the electron beam is chosen as 0.14 A. In Figure 3.a-b the electron bunching and axial electrical field is given, respectively. The amplification along the length of the TWT is clearly observed. Finally in Figure 4 the excited signal at the input (red), the return signal at the input (green) and the amplified output signal (blue) is shown. At the output there is about 24 dB gain. Since we did not design a measure for the returned signal at the ports after a while the returned signal is also amplified and cause oscillations. The gain of the TWT can be increased by using of a tapered pitch.



(a) (b)

Figure 3: Electron bunching (a) and axial electric field amplification (b) of the TWT

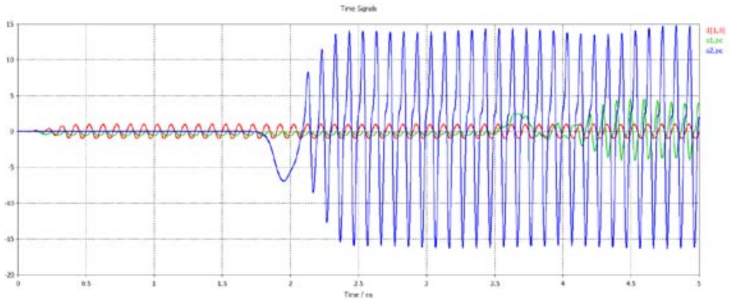


Figure 4: Input and output signals of the TWT

## 4. Conclusion

The design considerations of a X band helical TWT is presented by using of CST-PIC/MWS. The cold test characteristics are analyzed by modeling of a single turn slice. The input-output couplers are adjusted to have a minimum return loss. The hot simulation of the TWT has been performed and results are presented.

## 5. Acknowledgments

The presented TWT simulations are performed by using of CST PIC/MWS at the department of electrical and electronics engineering in Yeditepe University.

## 7. References

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