Enhance the Efficiency of Sheet Beam TWT with Advanced Optimization Algorithm

Zeng Liu, Jianxun Wang, Yixin Wan, Qiang Liu, and Yong Luo
School of Electronic Science and Engineering
University of Electronic Science and Technology of China
Chengdu, China

Abstract: *The sheet beam traveling-wave tube (SBTWT) with staggered double vane (SDV) structure has attracted much attention as a board band and powerful terahertz and millimeter-wave source. In this paper, the velocity taper for SDV structure is optimized with a recently proposed swarm-intelligence (SI) based optimization algorithm named dragonfly algorithm (DA) in order to enhance the beam-wave interaction efficiency in sheet beam TWT. The optimization result of this algorithm is compared with other commonly used algorithms. The taper optimized with DA is verified with CST particle in cell (PIC) simulations. The efficiency of the optimized structure has been greatly increased in both optimization and PIC simulations.*

Keywords: sheet beam; optimization algorithm; traveling-wave tube; efficiency.

Introduction

The sheet beam traveling-wave tube (SBTWT) with staggered double vane (SDV) structure has attracted much attention as a board band and powerful terahertz and millimeter-wave source in recent years [1]. This structure is commonly made of metal and has the advantages of large power capacity and high mechanical strength. Its planar structure is in favor for heat dissipation and manufacturing with micro-fabrication technologies. This kind of devices is very appropriate for high power and board band applications. However, owing to the problem of electron losing synchronization with the microwave during the process of amplification, the interaction efficiency of this kind of device is usually in a low level, which greatly limits its output power. One of the most effective ways to solve this problem is to reuse the energy of decelerated electrons with optimized velocity tapers [2]. A. Palm et al. has introduced the velocity taper into the SDV TWT by changing the dimensions of periodic structure, the efficiency has increased 55% relatively in a terahertz SDV TWT with this method [3]. In this paper, a recently proposed optimization algorithm named dragonfly algorithm (DA) is utilized to determine the length of all the periods in the SDV slow wave structure (SWS) in order to obtain a velocity taper with possibly high efficiency. DA is an advanced swarm-intelligence (SI) based optimization algorithm proposed by Mirjalili in 2016 [4]. Like other SI algorithms which are inspired by the collective intelligence of the group living creatures, the DA simulates the natural behavior of dragonflies such as alignment, cohesion and attraction of food, and updates the individuals according to this logic during the optimization [5]. The DA has the advantages of better optimization solution and less likely to be trapped in the local optimum according to the comparison result with other commonly used algorithms.

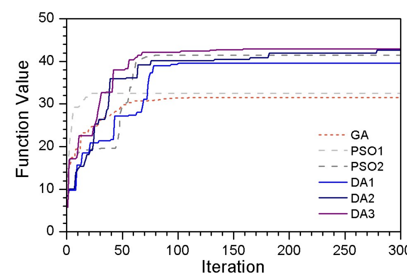

Figure 1. Comparison of optimization algorithms

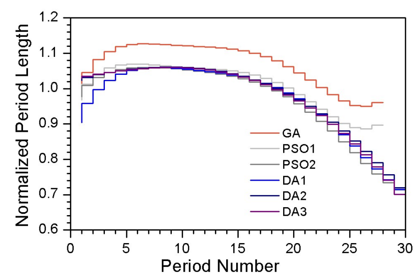

Figure 2. Velocity taper optimized with different algorithms

Comparison of optimization algorithms

The profile of the velocity taper can be optimized with the dragonfly algorithm. A nonlinear self-consist code based on the large signal theory of J. E. Rowe et al. is used to calculate the efficiency of the TWT as the fitness function. The optimization process of taper profile in DA is compared with that in genetic algorithm (GA) and particle swarm optimization (PSO) algorithm in Figure 1. The tapers optimized with these algorithms are shown in Figure 2. As shown in the Figure 1, the best optimization result of DA is better than that of the traditional GA and PSO algorithm, and DA is also unlikely to be trapped in the local optimum as the aforementioned algorithms. The results of multiple optimization using DA are all very close to the maximal value at 42.9 as shown in Figure 1. While in the optimization with GA or PSO, the problem of premature convergence is easy to occur (GA, PSO1). The DA seems to be a more proper tool to search for the optimum in this problem.

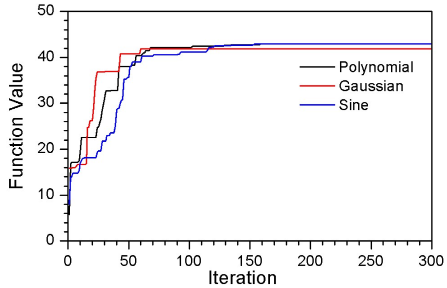

Figure 3. Optimization results of different fitting curves

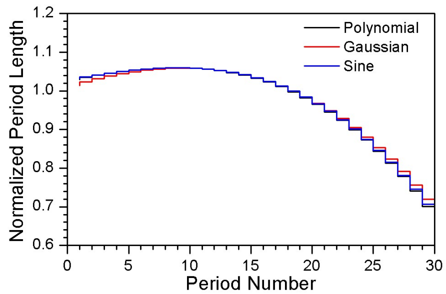

Figure 4. Taper profile optimized with different fitting curves

Comparison of different fitting curves

In the optimization, there is a 5 percent limit for gradual change between periods to prevent the serious reflection. And the taper generated in the optimization also needs to be smoothed using a curve without which the reflection will also be very serious. Because only the smoothed taper is useful in the design, the efficiency of randomly generated tapers will only be calculated after smoothed with fitting curves in this optimization. We have optimized the velocity taper fitted in different ways using DA optimization. Figure 3 is the optimization results of the tapers fitted into 5-degree polynomial curve, 2-term Gaussian curve and 2-term sine shaped curve. Although the profile curve is smoothed with different methods, the optimization program will always find a similar velocity taper profile just like the polynomial one as shown in Figure 4.

PIC simulations

The best taper profile optimized with DA is verified in CST with a 30-period and about 120 mm long model and a sheet electron beam of 26.4 kV and 1.0 A. This result is also compared with a normal structure of 30 constant periods. The efficiency of the tapered TWT has been greatly increased according to the simulation results. The efficiency at the optimization point (29GHz) has been doubled, from less than 14% in the constant-period TWT to about 30% in tapered TWT, and it can be even higher at the band edge. The comparison of efficiency in optimized TWT and uniformed-period one over the full band is shown in Figure 5 according to the PIC simulation with a constant drive of about 300W.

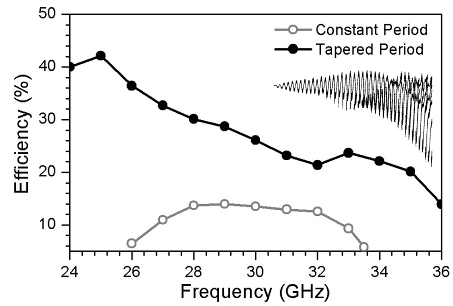

Figure 5. Efficiency over the full band from PIC simulations

Conclusion

The velocity taper with high efficiency performance for the SDV SBTWT is designed with the help of a newly proposed SI based optimization algorithm DA. The optimized structure smoothed with polynomial fitting curve has achieved a great increase in efficiency compared with the constant-period TWT according to PIC simulations.

Acknowledgment

This work is supported by National Natural Science Foundation of China (Grant No: 61671129).

References

1. Young-Min Shin, and Larry R. Barnett, "Intense wideband terahertz amplification using phase shifted periodic electron-plasmon coupling," Applied Physics Letters, vol. 92, no. 9, 2008.
2. Jeffrey D. Wilson, "Design of high-efficiency wide-bandwidth coupled-cavity traveling-wave tube phase velocity tapers with simulated annealing algorithms," IEEE Trans. Electron Devices, vol. 48, no. 1, pp. 95-100, 2001.
3. Andrew Palm, Jagadishwar Sirigiri, and Young-Min Shin, "Enhanced traveling wave amplification of co-planar slow wave structure by extended phase-matching, " Physics of Plasmas, vol. 22, no. 9, 2015
4. Seyedali Mirjalili, "Dragonfly algorithm: a new meta-heuristic optimization technique for solving single-objective, discrete, and multi-objective problems," Neural Computing and Applications, vol. 27, no. 4, pp. 1053-1073, 2016.
5. Omid Bozorg-Haddad, Advanced optimization by nature-inspired algorithms, Singapore: Springer, 2018.