3D Meander Line Slow Wave Structure for W-band TWT

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Abstract: *Planar meander lines have been recently studied in detail due to their favorable properties as slow wave structures for traveling wave tubes. However, the interaction of a cylindrical electron beam with this kind of structures is not efficient enough in order to achieve the output power levels required for space applications at W-band. A new design, suitable and optimized for the cylindrical beam geometry, is introduced in this work. Cold and large signal results are presented in the paper.*

Keywords: Traveling wave tube (TWT); Slow wave structure (SWS); Meander line; W-band.

Introduction

The exploitation of W-band for the feeder downlink (71-76 GHz) between satellites and ground stations could offer a suitable transmission window for high data transfer rate [1]. The bandwidth and transmission power required to overcome atmospheric attenuation at W-band can be provided only by TWTs. Given the infeasibility of helix-type slow wave structures at high frequencies, different full-metal topologies have been tested as alternative SWSs [2, 3].

Meander lines represent a promising alternative to the full-metal designs as they are potentially capable to provide similar gain and output power levels while offering higher interaction impedance and lower operation voltage. However, due to the intrinsic planar design of meander lines, high output levels are only obtained when the structure interacts with planar electron beam geometries, for instance sheet beams [4]. The use of sheet electron beams as particle sources in traveling wave tubes is not desirable due to the instability that the beam suffers as the electrons travel along the tube [5]. Cylindrical geometries are typically much more stable and can be easily controlled by means of conventional periodic permanent magnets, but the results for gain and output power are very discrete [6]. Even though different efforts have been made in order to increase the output levels using cylindrical electron beams [7, 8], the results are not yet satisfactory for satellite applications at W-band and better configurations are necessary.

This paper presents a three-dimensional meander line structure which has been shown to provide much better results than a planar meander line of the same characteristics. Cold and large signal simulations, and a possible fabrication process, are presented in the following sections.

Planar-3D meander

The typical planar meander line and the proposed three-dimensional (3D) meander line designs are shown in Fig. 1. The 3D structure can be understood as a projection in height of the conventional planar meander line. The beam tunnel is obtained in the centre of the metal structure.

The electric field distribution in the transmission direction for the planar and 3D meanders is plotted in Fig. 2, where a lateral cut-plane of the structures is presented. The electric field of the planar meander line is concentrated close to the metal line; this implies that a cylindrical beam with certain realistic radius traveling on top of the metal line will not interact uniformly with the electric field. It is expected that the bottom side of the cylindrical beam will present a better interaction with the electric field than the top part of the beam, thus lowering the overall efficiency. Instead, the electric field profile of the 3D meander is more suitable in order to accommodate a cylindrical beam as the whole electron beam is immersed in the electric field and a more uniform interaction should be achieved.

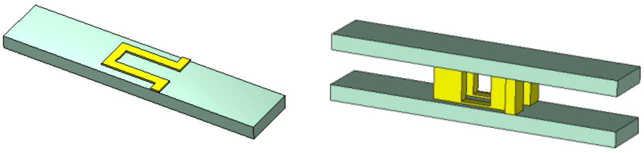

Fig. 1. Design of one period of the planar (left) and the 3D (right) meander lines.

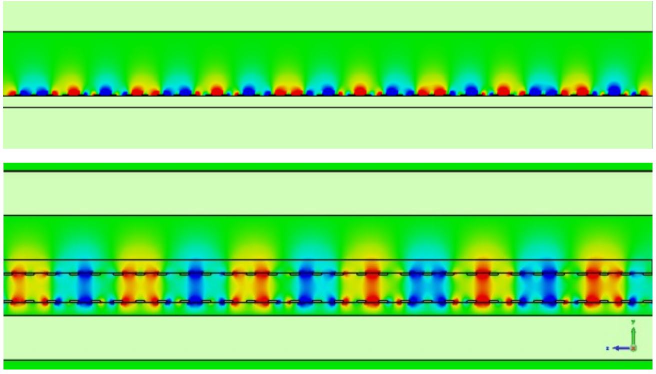

Fig. 2. Electric field profile for the full planar (top plot) and 3D (bottom plot) meander lines.

3D meander simulations

A preliminary simulation is performed in order to roughly compare the performance of the planar and 3D meander lines using the same dimensions and parameters. The results are shown in Tab. 1. As expected, considering the more favourable electric field distribution, the 3D meander slow wave structure shows much better performance than the conventional planar meander line.

Tab. 1. Results obtained after cold and large signal analysis of the planar and 3D meander line. The values show the average improvement in percentage of the 3D structure in comparison with the planar meander line.

	Interaction impedance	Gain	Output power	Electronic efficiency
Planar line	--	--	--	--
3D meander	+220%	+30%	+400%	+150%

The simulations are performed using CST Microwave Studio [9]. Alumina with relative permittivity $\varepsilon_r = 9.9$ and copper with reduced conductivity $\sigma = 2.25\text{x}10^7$ S/m are used for the substrate and metal, respectively.

The cold results for the 3D structure, computed for an operation voltage of 6.5 kV, are presented in Fig. 3. An average interaction impedance of about 13.5 Ω in the frequency range 71-76 GHz is obtained.

The coupling transition design between the 3D meander and waveguides is similar to the one for planar meanders [6]. The bottom planar meander line is extended at both ends acting as a probe for the electric field coming from and leaving the waveguide (Fig. 4). The S-parameters of the SWS with this coupler are provided in Fig. 5. Good transmission is achieved in the 71-76 GHz frequency range.

For the large signal simulations, a cylindrical electron beam with radius 80 µm and current 40 mA (current density 200 A/cm^2) is chosen. The beam is focused with 0.5 T magnetic field. An input signal of 50 mW is applied. Gain and output power at W-band are presented in Fig. 5, providing peak values close to 30 dB and 50 W, respectively.

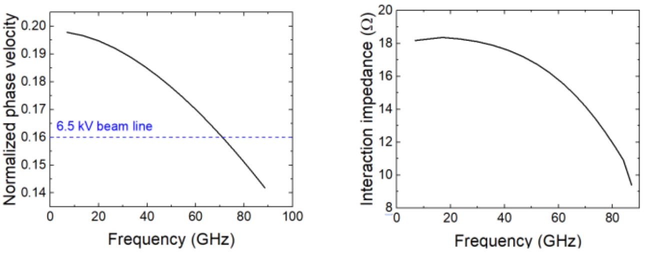

Fig. 3. Normalized phase velocity (left) and interaction impedance (right) for the 3D meander line.

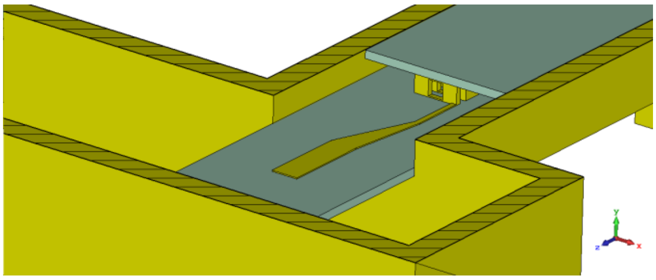

Fig. 4. Cut-plane view of the coupling transition between the meander line and the waveguide ports.

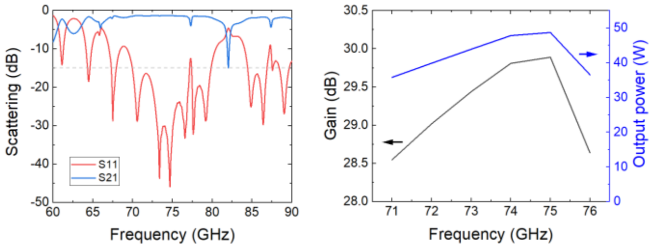

Fig. 5. Scattering parameters (left) and gain and output power (right) for the 3D meander line.

Fabrication of the 3D meander

The fabrication of a three-dimensional structure at W-band is a more demanding task in comparison with planar configurations which can be easily built using lithography. Nevertheless, a possible fabrication approach would consist of splitting the structure into two parts which could be fabricated using, for example, LIGA process: one substrate would contain the 3D part of the structure whereas on the other one, a planar meander would be grown. Fig. 6 shows schematically the design.

The final step would be to join both structures placing the planar meander on top of the other part. However, a method to bond the two parts is under investigation.

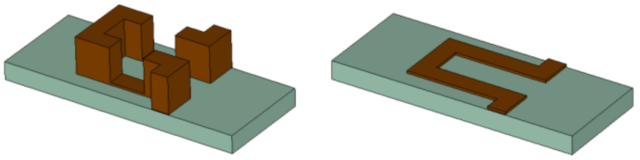

Fig. 6. Schematic of the parts of the 3D meander line.

Conclusion

A 3D meander line has been designed and compared with a conventional planar line with the same characteristics showing enhanced overall performance. The SWS is able to provide the output power level suitable for space applications at W-band with the advantages of lower operation voltage and higher interaction impedance in comparison with other full-metal SWSs. Further work will be focus on finding a suitable joining method between both parts of the structure and investigating the most suitable materials in order to facilitate the fabrication process.

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