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Terahertz TWT on a Rectangular Waveguide Folded in a Circular Spiral

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Abstract: The most promising in the THz range is traveling-wave tubes (TWTs) and backward-wave tubes (BWTs) on a serpentine-curved (zigzag-rolled) rectangular waveguide. They are implemented in the THz range (220 GHz), although their characteristics are far from satisfactory due to the strict restriction on the tape electron beam width, that does not allow reaching the summarizing beam current optimum level. To replace the zigzag convoluted waveguide with the spiraled for the TWT and BWT on a curved rectangular waveguide is the best way to remove the ribbon beam width restriction. In the early TWT and BWT design a waveguide planar spiral was also flat in the upper and lower parts connected by vertical idle (without beam) transitions. Proposed design can be significantly improved both in relation to the electron interaction process with the waveguide field and in relation to the TWT-BWT manufacturing technology if instead of a planar waveguide spiral, a circular one is used. The article proposes the TWT designing a terahertz rectangular waveguide folded as a circular spiral. The design differs from the previously proposed TWT with a planar-spiral waveguide by the improved interaction conditions between the electron beam and the waveguide field, as well as the manufacturing technology simplification for terahertz range. Based on numerical simulation, it is shown that proposed TWT achieves G_H= 42 ÷ 48dB saturation gain in the 220 GHz range with the waveguide turn number n = 40 ÷ 50. The proposed TWT design on a rectangular waveguide folded in a circular spiral is more technologically advanced than the TWT on a planar-spiral waveguide. In the most necessary 220 GHz range the efficiency is very high and can provide the need for amplifiers and generators in this and other ranges. We also note that the TWT on a spirally folded waveguide can operate in the BWT mode and, moreover, simultaneously in the TWT and BWT modes. The latter is possible in modes close to linear one. The TWT magnetic system of the type described above can be implemented in the form of a permanent magnet with pluses on the TWT end parts. The proposed TWT characteristics can be significantly improved by optimizing the waveguide helical winding pitch. Exactly as it is achieved with using the spiral wire deceleration system. The efficiency of such optimized TWT reaches 70% efficiency.

Keywords: Terahertz TWT, Circular-Spiral Form of Waveguide, Ring-Shaped Electron Beam, 220 GHz, Gain

1. Introduction

The problem of exploring the terahertz frequency range (0.1-10 THz) is one of the most important and serious in microwave electronics and radio physics. This problem has two sides. On the one hand, without mastering the terahertz range, progress in the creation of high technologies in many branches of science and technology is impossible. These include: the creation of ultra-high-speed (5G) and secure communication systems, systems for remote recognition of chemicals (spectroscopy in the terahertz range), replacing X-rays with non-ionizing T-rays in medicine (tomography; for example) and in security scanners, location in military systems destination. In many other areas, T-rays can radically solve complex problems. On the other hand, the terahertz range refers to the "technological gap" (THz Gap) that separates electronics from photonics. There are no effective

devices for microwave electronics, there are no optical generators or amplifiers (the photon energy is too low). This range, in principle, can be covered by free electron lasers (FEL), but they require using accelerators such as a microtron, cyclotron, or betatron, and their efficiency is low.

The most promising in the THz range turned out to be traveling-wave tubes (TWT) and backward-wave tubes (BWTs) on a serpentine bent (folded zigzag) rectangular waveguide. They are implemented [1-4] in the THz range (220 GHz), although their characteristics are far from satisfactory because of the strict limitation on the width of the ribbon electron beam, which does not allow achieving the optimal level of the total beam current.

A radial solution that removes the restriction to the ribbon beam width for TWT and BWT on a curved rectangular waveguide was proposed in [5-9]: replace the zigzag folded waveguide with a spirally folded one. Then the ribbon beam width is not limited in principle. In [5-9], in TWT and BWT design uses a planar waveguide spiral, flat in the upper and lower parts, connected by vertical idle (no beam) transitions. This design can be significantly improved both with respect to the process of electron interaction with the waveguide field and with respect to simplification of the TWT-BWT

fabrication technology if a circular spiral is used instead of a planar waveguide spiral.

This article is devoted to the design description and TWT characteristics on a rectangular waveguide folded in a circular spiral.

2. TWT Design

The design of the TWT is shown in Figure 1. Here: 1, 2 - respectively, the outer and inner sleeves, which are manufactured separately, and then welded with a vacuum-tight seam; 3 - circular electron gun forming a thin circular (cross-sectional) electron flow; 4 - power inputs for the electron gun; 5 - input insulators, if the lamp housing 1, 2 is at a higher potential; 6 - input waveguide (as a continuation of the working part of the spirally bolded waveguide 7); 7 - spirally bolded (rolled) rectangular waveguide on the H_{10} mode (the electric field E_z is normal to the wide wall of the waveguide); 8 - output waveguide; 9 - ring flight slot for the electron flow; 10 - ring electron collector; 11 - collector input; 12 – input insulator (the collector can be at a reduced potential relative to the TWT housing 1, 2).
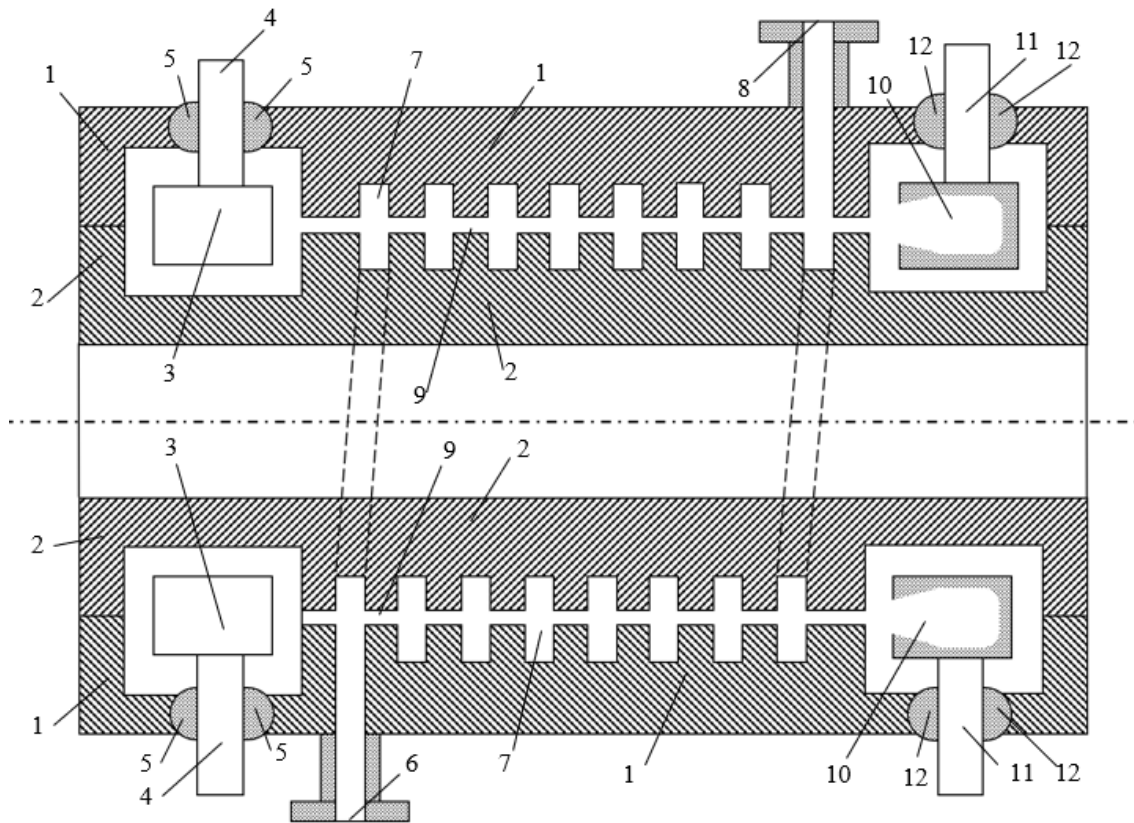

Figure 1. Terahertz TWT scheme on a rectangular waveguide folded in a circular spiral.

This TWT design allows a simplified manufacturing process using modern technologies. Sleeve 1, 2 are manufactured separately. The spiral waveguide grooves ("halves" of the waveguide) can be formed by X-ray lenses fabricated by LIGA technology which allows to withstand

very high manufacturing precision. Then, after mounting on the sleeve 1 of the electron gun and the collector, they are soldered forming a TWT unit.

Note that bushings 1, 2 are not necessarily metal, they can also be plastic with subsequent metallization of the working

surfaces (silver or copper sputtering).

The poles of the focusing magnet located at the end walls of the TWT body are not shown.

3. Calculation Results

After The model of the TWT interaction process on a spirally folded rectangular waveguide for both a planar spiral and a circular one is identical, since in both cases the electroninteraction of each flow element is similar to one another. Therefore, the calculation used the model developed in [5-9]., and more general ones presented in [10-15].

The calculations are carried out using the universal program "Cheren-S" from code "CEDR" [8], based on the models from works [10-15]. The condition of non-excitation of counterpropagating waves in a spirally folded waveguide are also used: $l/L_w = m$ (L_w – the wavelength in the waveguide, l— the length of the waveguide turn along the central line, m – an integer).

The characteristics of the motion and electron grouping, the excitation of the field in a given TWT with discrete interaction as well as amplitude and frequency characteristics have an ordinary character, they are well known [10-15] and are not presented here.

The calculation for f = 220 GHz gave the following results:

The radius of the ring beam r_0 = 5mm;

Beam current II_0 = 0.5A, V_0 = 16kV;

Input power Pin = 0.01W.

waveguide section: a=1.22 mm (along the axis r), b=0.35 mm (along the axis z)

waveguide helix pitch h=1.08 mm

electron beam thickness D=0.18 mm

slot width d=0.25 mm

For a given input power and beam current, the following results were obtained: for the number of turns of the waveguide n = 40, the gain Gs in saturation is 42 dB; at n=50, Gs = 48 dB.

Dependence of Gs on the beam current at Pin = 0.01W, n = 48: I_0 = 0.2A - Gs = 35dB; I_0 = 0.5A - Gs = 45 dB; I_0= 0.7A - Gs = 50 dB.

Thus, the calculations confirm the high efficiency of the terahertz TWT on a rectangular waveguide folded in a circular spiral.

4. Conclusion

The proposed design of a TWT on a rectangular waveguide folded in a circular spiral is more technologically advanced than a TWT on a planar-spiral waveguide. Its efficiency in the most demanded range of 220 GHz (here transparency windows in the atmosphere) is very high and can provide the needs of amplifiers and oscillators in this and other ranges. Note also that a TWT on a spirally folded waveguide can operate in the BWT mode [10-15] and, moreover, simultaneously in the TWT and BWT modes [10-15]. The latter is possible in modes close to linear one. The TWT magnetic system of the type described above can be implemented in the form of a permanent magnet with pluses on the TWT end parts. The proposed TWT characteristics can be significantly improved by optimizing the waveguide helical winding pitch. Exactly as it is achieved with using the spiral wire deceleration system. As shown in [12-14], the efficiency of such optimized TWT reaches 70% efficiency.

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