A High-Power Wideband Traveling-Wave Tube with Stepwise Changes in the Diameter of the Drift Channel

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Abstract—Results of the design of a high-power wideband (in the band 8–18 GHz) traveling-wave tube (TWT) with stepwise changes in the diameter of the drift channel are presented. The TWT is stable against self-excitation by a backward wave at high values of the accelerating voltage. It is shown that the output section of the device can be increased by a factor of 1.5 and the operating current can be raised by a factor of 1.3. These increases are attained owing to the 1.27-GHz diversity of the \( \pi \)-type frequencies of sections with different values of the channel diameter and owing to growth of the starting current corresponding to self-excitation by the backward wave. Application of the TWT with the interaction space that has steps of the channel diameter improved the electron efficiency by a factor of 1.2 and increased the output power by a factor of 1.6.

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INTRODUCTION

Suppression of self-excitation by a backward wave is an important problem in high-power high-voltage wideband traveling-wave tubes (TWTs) with a voltage of more than 13 kV across the slow-wave structure (SWS). In order to reach high efficiency, the output section should be sufficiently long; however, the length is limited by the possible initiation of generation. Usage of irregularities (for example, deep jumps of the SWS step or isochronism) leads to reduction of the bandwidth of amplified signals [1]. In addition, irregularities may initiate the TWT self-excitation by a backward wave in the presence of an RF signal [2]. The possibility of generation in a TWT by a backward wave in the presence of the input signal was first reported in [3], where it was shown that generation may arise because of slowing of the electron velocity in the output section of the tube. The slowing is caused by interaction of electrons with the electromagnetic wave. Papers [4, 5] were the first to show that generation can be attributed to both a decrease in the electron velocity and an increase that occurs in the beam radius at the end of the interaction space owing to dynamic defocusing.

As was mentioned in [6, 7], a change in the channel diameter along the length of the interaction space is the main way to avoid self-excitation by the backward wave. However, these studies do not explain how to change a channel: Should it be increased or decreased? Paper [8], giving the abstract of paper [9], distorts meaning of the latter. Paper [9] refers to known studies and states that the phase velocity should be decreased according to a linear law in order to suppress oscillations excited by a backward wave. This paper does not contain a word about the decrease of the helix diameter, although in [8], this phenomenon is ascribed to [9]. Patent [10] proposes to smoothly increase the drift channel toward the end of the interaction space in order to decrease the beam interception by the SWS and increase the efficiency (owing to isochronism, which is realized in that case). Patent [11] suggests introduction of at least two sections with different inner diameters of the SWS and a smooth transition between them. However, the patent does not stipulate which section goes first: the section with the smaller diameter or the section with the larger diameter. In order to simplify the production technique of the device, it is proposed in [11] to keep constant the outer diameter of the SWS along the full length by means of polishing the helix turns to the outer diameter.

As far as the authors were concerned, there was no available information on the existence of a TWT with a changing diameter of the drift channel. Therefore, the purpose of the current paper is the study of the design and the performance of a TWT with stepwise changes of the channel diameter and comparison of the performance of this TWT with the performance of a device with a constant channel diameter.

1. STARTING CURRENTS OF SELF-EXCITATION BY A BACKWARD WAVE IN TWTs WITH AND WITHOUT STEPWISE CHANGES IN THE CHANNEL DIAMETER

A TWT with stepwise changes in the channel diameter was manufactured on the basis of a device without such steps. A similar device has been studied in [1, 4, 5]. However, as was mentioned in [5], the length of the device SWS used in calculations was increased slightly in order to make the calculated starting currents closer to the real ones. The difference of the lengths, amount-
The calculations have shown that, in the case of the values of the channel diameters differing by 10%, the π-type frequency that corresponds to intersections of curves 3 and 4 is shifted by 1.27 GHz relative to the π-type frequency that corresponds to intersection of curves 2 and 1. The difference between the frequencies is 5.9% of the mean frequency of self-excitation at the minus first spatial harmonic (i.e., by the backward wave).2 If the channel becomes smaller, the π-type frequency increases and shifts away from the upper limit of the operating band. This shift, as well as the frequency difference, contributes to an increase in stability against self-excitation. In this case, it is possible to avoid an undesirable (from the viewpoint of TWT excitation in the presence of an RF signal) decrease in the phase velocity. The phase velocity can even be slightly increased with a change in the channel diameter via selection of an appropriate step of the SWS. At the same time, it can be seen from comparison of intersection points of curves 1 and 2 with intersection points of curves 5 and 6 that, while a positive jump of 6% (a decrease of the pitch value) decreases the phase velocity, it leaves the π-type frequency practically unchanged. (The frequency changes only by 0.04 GHz.) Perhaps, this fact explains why a jump in the SWS pitch of up to 6% is inefficient for suppression of self-excitation by a backward wave in the presence of an RF signal, as has been shown in [1].

Starting currents of self-excitation by a backward wave in a TWT with stepwise changes of the channel diameter were calculated with software described in [15]. An increase that occurs in the beam radius owing to dynamic defocusing was taken into account. The calculations have shown that two sections whose channels differ by 10% cannot be excited as a whole (since the self-excitation frequencies are different) but can be excited only separately. Owing to this fact, it became possible to lengthen the output section of the device with steps of the channel diameter by 1.55 times relative to the length of the output section of the prototype. This lengthening was reached through a shift of the output absorber towards the input of the tube. In this case, the total length of the SWS remained unchanged. The distance from the end of the SWS to the point of the stepwise change of the channel diameter was 37.3% of the total length of the output section. Simultaneously, the step of the SWS was decreased in order to obtain close values of slowing factors in sections with different channels. In this case, reflections from the step decrease. In effect, a small negative step of the phase velocity was introduced 1.9% at the lower frequency and –0.8% at the higher frequency because of frequency pushing or, in other words, the dependence of the self-excitation frequency on the beam current [14].

1 The calculation was performed with the program described in [13].

2 The frequency of self-excitation by the backward wave may be slightly different from the π-type frequency because of frequency pushing or, in other words, the dependence of the self-excitation frequency on the beam current [14].