Novel Double-Mode O-type Source of Coherent Subterahertz Radiation

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***Abstract* - A new type of subterahertz generator at harmonics of BWO oscillations in the mode of diffraction radiation is proposed. The nonlinear multidimensional theory of the double-mode beam-wave interaction at the harmonics of the BWO is developed. The regions of problem parameters values, corresponding to diffraction radiation excitation are defined.**

Modern progress in a nanotechnology and development of subterahertz and terahertz bands result in problem of creating effective radiation sources. One solution of this problem would be to use generators and amplifiers with a prolonged beam-wave O-type interaction on the higher frequency harmonics.

It is well known that the presence of higher frequency harmonics is caused by nonlinear interaction of electron beam with excited rf fields. However, the direct use of such regimes results in considerable technical difficulties due to exponential decrease of the high-frequency field amplitude near the surface of slow-wave periodic structure. In this regard, multistage devices schemes that combine the properties of various radiation sources: generators, amplifiers, modulators, converters, multipliers are used. Typically, the first stage in such devices is a modulator, and the second - the amplifier of the field amplitude at the selected higher harmonics. In the presence of the O-type electron device periodic structures two modes of oscillations may exist: the surface waves regime and mode of bulk waves. While the existence of surface waves all the spatial harmonics of the field are slow waves. This regime is used in such devices as BWO or TWT. While the existence of a bulk wave the one spatial harmonic of the field is fast and all the rest are surface and slow waves. This regime is realized in the orotron and diffraction radiation generator (DRG) [1], based on the Smith-Purcell effect [2]. The Smith-Purcell effect (diffraction radiation) occurs when the bunched electron beam interacts with the rf field of a slow-wave periodic structure in the bulk waves mode. Smith-Purcell effect was also observed at the time harmonics of the beam modulation frequency. Explanation of the coherent Smith-Purcell effect at the fundamental and higher harmonics of the frequency is given in [3, 4].

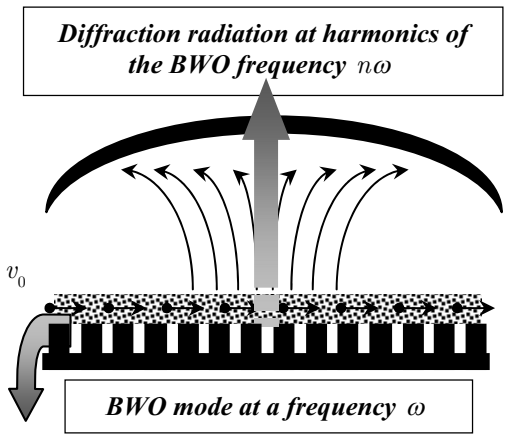

Fig. 1. Scheme of the double-mode oscillator.

It is known that the starting current to excite radiation in the BWO mode is less than in the DRG mode. Simultaneous using of the two operation modes in a single device is the perspective way for development of the novel subterahertz sources. Since the nonlinear beam-wave interaction in the BWO mode results in the forming of the harmonics set the higher harmonics of BWO can be used for the excitation of high-frequency fields in the bulk waves mode. Furthermore the positive feedback on the bulk wave is necessary to create a generator. This feedback is achieved by introducing of the additional reflector (mirror) into the device. Thus two oscillations can simultaneously exist in the electron device. First one at the fundamental frequency of the BWO oscillations, another one at the harmonica of the BWO oscillations but in the bulk waves mode owing to the coherent Smith-Purcell effect. Such a dual-frequency mode differs from the known systems because in this case there are two different output of power. Output of the BWO oscillations realizes by a surface wave. Signal at higher BWO frequency harmonica brings out by a bulk wave. Starting currents for the excitation of oscillations at BWO frequency harmonics in the conventional single mode device is significantly higher than at the fundamental harmonic. However, the presence of a BWO regime and BWO frequency harmonics in the high-frequency beam current leads to the appearance of the initial field in the device bulk waves mode. This is the original cause of the starting current decrease in subterahertz band. Scheme of the device is shown in Fig. 1.

Simulation of physical processes in the resonant O-type electron-wave system with a prolonged interaction in the two-mode two-frequency regime is performed on the base of the multidimensional self-consistent theory [5].

In general, self-consistent set of equations consists of three-dimensional equations of motion and the equations of excitation of the BWO oscillations and DRG oscillations at the BWO frequency harmonics. The spatial structure of two modes

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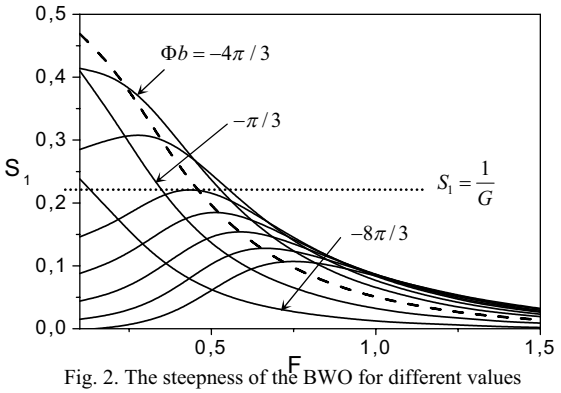

Fig. 2. The steepness of the BWO for different values of parameter Φb .

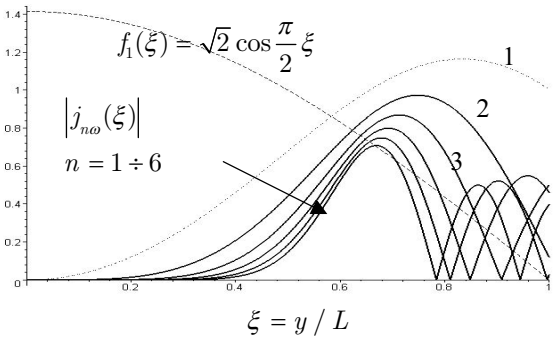

Fig. 3. Distribution of modulus of the current harmonics amplitude in the resonant BWO.

rf fields is fixed. The longitudinal electric field components of these modes are:

$$E_{BWO} = E_1 f_1(z)\Psi_1(y)\exp\left[i\left(\beta_1 z - \omega t\right)\right],$$

$$E_{DR} = E_2 f_2(z)\Psi_2(y)\exp\left[i\left(\beta_2 z - n\omega t\right)\right].$$

Here the functions $f_{1,2}(z)$ and $\Psi_{1,2}(y)$ characterize the amplitude distribution of rf field along the longitudinal and transverse coordinates respectively; $\beta_{1,2}$ – the wave numbers; $E_{1,2}$ – the amplitude of the fields in the BWO mode and the diffraction radiation mode.

One of the main characteristics of the generator is the steepness of the oscillatory characteristics [1, 2]. Fig. 2 shows such characteristic that calculated for the BWO mode in the nonlinear regime.

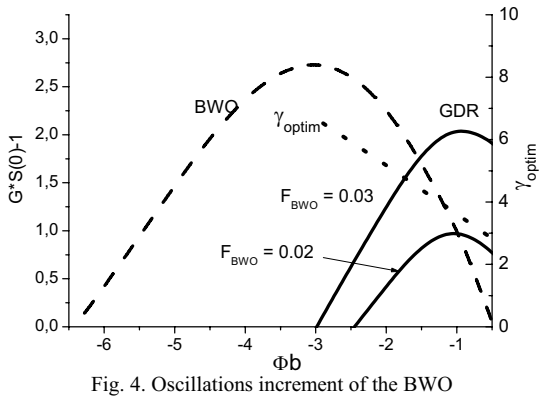

Fig. 4. Oscillations increment of the BWO and DRG for optimal phase values γ_{optim} .

The amplitude of oscillations at BWO frequency harmonics in the of diffraction radiation mode (Smith-Purcell radiation) was calculated from solution of the self-consistent system of equations in dual-mode regime. It was assumed that the amplitude of these oscillations is smaller than the BWO oscillations amplitude.

Fig. 3 shows the spatial amplitude distribution of the beam current harmonics in the resonant BWO. It is clear that the rf current amplitude varies slightly with the increase of harmonica number *n*. Therefore, it seems appropriate to use higher BWO oscillations harmonics to excite oscillations in the diffraction radiation mode.

Fig. 4 shows the increment of the oscillations amplitude growth in the DRG mode on the third harmonic of the BWO for different values of the BWO oscillations stationary amplitude as a function of the velocity mismatch parameter magnitude for optimum values of the phase difference between two modes of oscillations.

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