Spectral Models of Klystrons and Travelling-Wave Tubes

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Abstract: *An attempt is made to expand the spectral approach, implemented only for the M-type devices yet, onto O-type devices such as one-beam klystrons and travelling-wave tubes. The general features of the new spectral models are described. The used algorithms of simulation are quoted.*

Keywords: O-type device; numerical simulation; nonstationary model; signal spectrum; frequency continuum.

Introduction

Theoretical analysis of nonmonochromatic signals amplification by electron beams in guiding electrodynamic systems (ESs) is becoming increasingly more urgent. This analysis is necessary for guaranteeing electromagnetic compatibility of radioelectronic devices, developing digital high-speed high-power transmitters with vacuum final amplifiers [1], *etc*. Special attention must be focused on the amplification of wideband and ultrawideband electromagnetic pulses, which are becoming increasingly more important in radar and data-transmission systems.

The traditional methods of simulation of nonharmonic processes in microwave electronics that are referred to as the multifrequency approaches do not provide for adequate solution of the above problem. Such models involve discrete spectra of signals, and the frequencies of harmonics taken into account should be determined beforehand. An increase in the number of these harmonics requires additional computational resources.

An alternative, spectral approach to simulation of microwave devices is described in [2]. The inverse Fourier transform is applied to an input signal specified in the frequency domain. The transmission of the synthesized nonharmonic wave through an ES is simulated with allowance for the nonlinear interaction of the wave and the electron beam. The spectral analysis is applied to a time domain sample of the output signal in order to obtain the frequency representation of the one. This approach allows numerical simulation of amplification of nonmonochromatic signals in the ESs of various microwave devices, and frequency continuum can be investigated. However, that has been implemented only for M-type devices yet [3].

Preliminary results of the spectral approach implementation in the models of O-type devices (one-beam klystrons and travelling-wave tubes) are described in this paper. Note that the models are in the stage of development yet; therefore some algorithms might be improved in the future.

General Description of the Spectral Models

A spectral model of a vacuum microwave amplifier is defined as a nonstationary model that correctly takes into account the interaction between all temporal harmonics of the electromagnetic potential of an ES and the electron beam in the frequency continuum and is combined with algorithms for spectral synthesis of input signals and for spectral analysis of output parameters [4].

The main approximations and assumptions of the both transient models (for a klystron and a TWT) are as follows:

i). Full 3D simulation is used except for the electron beam space charge potential that is calculated using 2D (r,z) approximation;

ii). No relativistic effects are taken into account (this is not quite suitable for klystrons, but this assumption may be eliminated in the future);

iii). The delay line of the TWT is regular in the axial direction (not tapered). However, the cavities of the klystron might be various and be placed at different distances;

iv). The motion of electrons in the gun and the collector spaces is not simulated. Instead, input characteristics of the injected beam can be set arbitrarily. In particular, the thermal dispersion of the initial velocities is taken into account.

The Beam Dynamics

A non-relativistic equation of the particle motion is solved in the rectangular coordinates (to avoid the singularity nearby the tube axis). The Runge-Kutta method of fourth order is used. The “Polynomials with smoothing” (PWS) method [5] is used as an intermediary between the rectangular Lagrange coordinates of the particles and the cylindrical Euler coordinates of the electromagnetic potentials.

As a sample of the particle dynamic simulations, Fig. 1 shows the beam grouping by a harmonic input signal in a 27 kW 550 MHz klystron. In Fig. 2, the beam profile for the Northrop-Grumman TWT [6] is shown for a harmonic signal with the output power of 200 W at 4 GHz. About 10^5 particles were used in the both calculations.

The Electromagnetic Potential

Computation of the electromagnetic potentials of RF circuits is the only but essential difference between the models of one-beam klystron and TWT. The discrete approximation with the expansion of the potential in the normal modes of cavities [4] is used in the first case. Solving the system of ordinary differential excitation equations is performed with the fourth-order Adams-Bashforth method. The continuous approximation with the decomposition of the potential in the regular modes of ES [4] is suitable for the TWT model. Method of solving the partial differential excitation equation for this case is described in [7] and [8].

Potential of the electron beam space charge is found by solving the Poisson equation with the homogeneous boundary conditions on the drift tube or on the helix (as in [9]). Decomposition of the potential in the azimuthally invariable normal modes of a metal tube [Bessel functions of zero order J_0 and harmonic functions in (r,z) directions respectively] is used.

Spectral Analysis of Output Signals

The spectral and the harmonic analyses are used together in the spectral models, as a rule. The first is understood as obtaining a power spectral density (PSD) as a function of the frequency. The second is interpreted usually as evaluation of amplitudes and frequencies of separate harmonic components. Both the methods supplement each other from the point of view of the information value.

The modified covariance method is used for the spectral analysis. The Prony decomposition in undamped complex exponents is our base for the harmonic analysis. Both the method have been elaborated to increase their robustness with low-noise samples and to enlarge a highest model order [10].

Conclusion

New spectral models of one-beam klystrons and TWTs are described in general. They are designed for the evaluations of spectral characteristics of wideband signals amplified by those devices. The frequency resolution of the models, as expected, must be much more than for the similar models of M-type devices, due to less processor time consumption while klystron and TWT numerical simulations ensuring possibility to make up relatively larger time samples.

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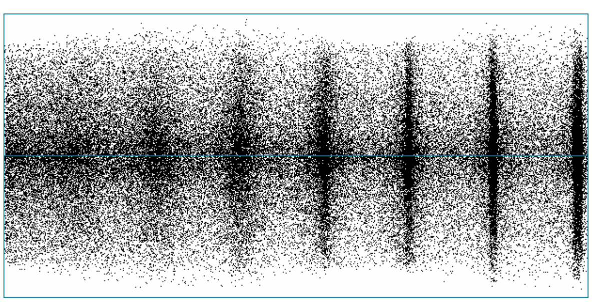

Figure 1

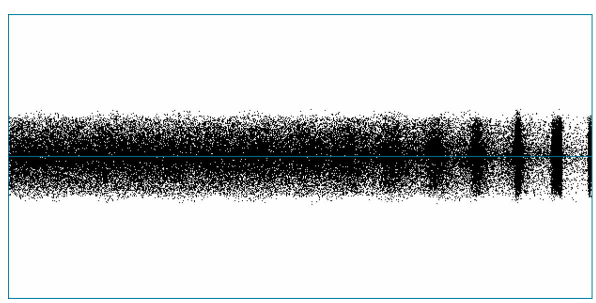

Figure 2