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Method of Parametric Characteristics for the Analysis and Simulation of Nonlinear Devices

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Abstract—A method designed for the analysis and simulation of nonlinear devices has been considered. It is called the method of parametric characteristics. Nonlinear elements are considered as parametric and their analysis is performed by using the multidimensional Laplace transform.

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Despite the widespread introduction of digital methods into all kinds of radio systems, analog components are an integral part of these systems. The account of their nonlinear properties involves the need of developing the methods for analysis and simulation of devices with nonlinearity. This problem can be split into two parts: building of the adequate mathematical models of nonlinear elements, in particular semiconductor devices, and the development of methods using such models and designed for investigating nonlinear devices. The techniques of solving the first part of the problem steadily evolve together with the advancement of semiconductor technologies. At the same time, given a large variety of the methods available for simulation and analysis of nonlinear devices (see, for example, paper [1]), only some of them are general-purpose, i.e., suitable for a wide class of radio devices and find wide application. They include: the method of numerical solution of nonlinear differential equations (used in the PSpice software package and the like); the Volterra series method (VS) that is basically analytical (applied for devices with small nonlinearity in the design environment of the Microwave office); the harmonic balance method (HB) that is referred to numerical-analytical methods and applied in the Microwave office for simulation of devices with large nonlinearity).

Nowadays the Microwave office software package is popular. It employs the last two methods depending on the degree of device nonlinearity. The VS method implies the presentation of parameters of nonlinear elements of the circuits in the form of a power series. The sufficient accuracy of such representation with a small number of the terms of the series is ensured only at small nonlinearity of the characteristics, while an attempt to increase the number of terms above 3…5 makes the expressions unacceptably cumbersome. The numerical simulation in the mode of large nonlinearity involves the use of the harmonic balance method, where the time functions are presented in the form of shortened Fourier series; next the system of algebraic equations containing coefficients of these series is solved. The method has a number of disadvantages: it yields a low accuracy of calculating the nonlinear products of minor level and often results in the convergence problems, etc.

The purpose of the study is to propose a method for simulation and analysis of nonlinear devices, where the nonlinear elements are presented as parametric components, the parameters of which change under the impact of voltages and currents. A device is also viewed as parametric, and the notions of parametric transfer characteristic and parametric pulse-response characteristic can be introduced. That is why this method has been called the method of parametric characteristics (PC).

It is well-known that the representation of the nonlinear system response in the form of the Volterra series is based on the Frechet theorem from the functional series theory [2]; that is why it allows us to obtain an analytical solution for such a system. However the Volterra series can be built only in the case, if the nonlinear relationships of parameters are presented in the form of power polynomials. In this case, the first term of the series coincides with the Duhamel's integral of the linearized system, while each higher-order term is calculated by using previous results that actually corresponds to the method of successive approximations. As the order of the terms is growing, their expressions rapidly become cumbersome, limiting the method applicability to the cases of small nonlinearity. In situations where the nonlinear relationships are specified by arbitrary functions, the implementation of the VS method involves the need of expanding the above relationships into the Taylor series that is related to the same restrictions. An alternative