MATHEMATICAL MODELLING AND DESIGN OF MULTIPLE-VALUED LOGIC ELEMENTS OF DIGITAL TELECOMMUNICATIONS NETWORKS

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Abstract — The study tackles the issues of multiple-valued elements design, based on the nonlinear resonant circuits (NRC) as a decision of a parametrical optimization problem. We illustrate that the use of nonlinear resonant circuit is one of the most perspective variants of multiple-valued logic elements implementation.

МАТЕМАТИЧЕСКОЕ МОДЕЛИРОВАНИЕ И ПРОЕКТИРОВАНИЕ ЭЛЕМЕНТОВ МНОГОЗНАЧНОЙ ЛОГИКИ ЦИФРОВЫХ СЕТЕЙ ТЕЛЕКОММУНИКАЦИИ

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Аннотация — Рассматриваются вопросы проектирования многозначных элементов на основе нелинейных резонансных цепей как решение задачи параметрической оптимизации. Одним из перспективных вариантов реализации элементов многозначной логики является использование нелинейных резонансных цепей.

I. Introduction

The non-linear vibratory systems take an important place in different areas of engineering. They are the components of many radio electronic, mechanical, optical devices.

The special place among them is taken by high-Q vibratory systems (oscillation elements, driving generators, pendulous systems etc.), the mathematical modelling of which entails considerable difficulties. It is caused by the fact that the study of such systems by the numerical methods requires considerable temporary costs even for modern computers, but the accuracy and convergence of the process are not guaranteed. Besides, in many cases in a non-linear vibratory system, there are two kinds of processes – slow and fast (for example, processes in a feedback circuit and in an oscillating circuit [1]). In simulation of such systems, there are difficulties with selection of a numerical integration step in research of dynamic behaviors, and there is no possibility of using qualitative analysis methods of behavior of systems on a phase plane.

The numerically – analytical computer approach proposed by the authors, allows carrying out approximated analytical methods of the solution of non-linear differential equations to be used at an analytical stage of simulation [2] and numerical methods of non-linear algebraic and differential equations solution at a numerical stage.

Optimization problems of parameters of devices concern also a numerical stage, of the non-linear vibratory systems (for example, [1—3]) are a basis of them.

II. Mathematical Models

NRC is described by non-linear differential equations of a sufficiently complex form containing small non-linear elements with derivatives not only of the first order, but also of higher orders. In case of availability of a feedback in NRC the differential equation of the first order, depicting a feedback circuit, is added. In case of a frequent-harmonic multi stable element (FHSE) the equation of such system can be presented as

$$\frac{d^2\upsilon}{dt^2}+\varpi^2\upsilon=-\{\frac{\lambda}{1+\lambda}\upsilon\frac{d^2\upsilon}{dt^2}+ +\frac{h}{1+\lambda}(1+h\lambda-\lambda\xi\upsilon+\frac{\lambda}{h}\frac{d\upsilon}{dt})\frac{d\upsilon}{dt}+ +\frac{\varpi^2\upsilon^2}{2}\}+\phi(t); \qquad (1)$$

$$\frac{db}{dt}=-\frac{b}{R_f C_f}+\frac{F(a)(b-1)+\left(b+{}^{\varphi_k}\!/\!_{\varphi_k}{}'\right)}{R_i C_f}\alpha_0, \qquad (2)$$

where $\alpha_0=\frac{\sin\theta-\theta\cos\theta}{\pi(1-\cos\theta)}$ (θ is an angle of cutoff in diode detecting); υ is normalized charge on non-linear capacity of p-n-junction; $b={}^{E}\!/\!_{\varphi_k}$ is a normalized voltage of auto shift; $h={}^{R}\!/\!_{L}$ is an equivalent attenuation; $\lambda={}^{C_1}\!/\!_{C_k}<<1; C_1, L, R$ are parameters of a oscillation elements; φ_k is a contact difference of potentials; Ri is an internal resistance of p-n-junction; $\varphi_k{}'$ is a factor connected with approximation of VAC p-n-junction; F(a) is the function determining a value amplitude of an unlocking half-wave of a voltage on p-n- junction.

The equation (1) describes a property of non-linear oscillatory circuit, and equation (2) – feedback circuit. FHSE power supply voltage represents a sequence of rectangular pulses of large relative pulse duration. The frequency element is sequentially adjusted to harmonic components of supply voltage in feeding control pulses to feedback circuit. Earlier it was supposed, that the

2014 24th Int. Crimean Conference “Microwave & Telecommunication Technology” (CriMiCo’2014). 7—13 September, Sevastopol, Crimea, Russia
 ISBN: 978-966-335-412-5. IEEE Catalog Number: CFP14788

FHSE non-linear circuit has a high Q-factor and in its passband only one harmonic component of a spectrum of supply voltage sets into its passband, on which one it is aligned. In the described FHSE mathematical model some spectral components of supply voltage getting the circuit passband are taken into account and it increases its accuracy in comparison with a model taking into account one component.

Thus, the equation (1) is the equation of the oscillator, which is under the effect of the small nonlinear exerting force representing a single frequency signal with slowly (in comparison with a frequency of an external force) varying amplitude and a phase.

For the solution of non-linear differential second-order equations with small nonlinearity the application of the Krylov-Bogoljubov-Mitropol'sky asymptotic method is possible [1, 2, 4—7]. Applicability of this method is defined by the presence of the periodic solution of NRC equations in which the basic harmonic close to natural frequency of system can be singled out.

As it is known, in construction of the asymptotic approximated solutions on a method of Krylov-Bogoljubov-Mitropol'sky, integrating one second-order equation is reduced to integrating two equations of the first-order (so-called shortened equations), which in many cases can not be integrated in elementary functions. It is necessary to search for their decisions by means of numerical methods. Using the numerical methods one can directly integrate, the input equation of the second order however it is a composite problem requiring very much time and frequently difficult to perform in connection with a possibility of accumulation of a large systematic error. It is especially noticeable that these difficulties show in simulation of high-Q NRC. Numerical integrating of equations of the first order solved by a method of Krylov-Bogoljubov-Mitropol'sky, does not represent difficulties in connection with that in these equations variables are amplitude and a phase, instead of the oscillating function υ. For receipt of a full picture of the process here, it is enough to calculate a small amount of points located on rather "smooth" curve, that essentially simplifies numerical integration while in integration of the second order equation it is necessary to determine not the envelope, but directly a high-frequency signal itself.

It is no less important that the solution of NRC equations the method by Krylov-Bogoljubov-Mitropol'sky is obtained allowing to apply qualitative methods of the vibration theory. Having chosen as phase variables an amplitude and a phase of fluctuations NRC, behaviour on a phase plane can be studied by construction and the analysis of phase portraits at various values of parameters. Such approach allows to establish the presence and to define coordinates in phase space of stable and unstable points of balance to find areas of existence of the non-stationary phenomena in NRC, and thus to define values of parameters of the circuit, at which in it useful (and undesirable) effects exist. At only numerical approach, frequently, it may be required unacceptably much time for realization of the appropriate calculations by practically full exhaustive search of all allowable values of the circuit parameters. Besides, it is difficult to prove stability or instability of the mode defined because of the numerical solution.

Let us consider the behavior of the studied scheme in a phase space. Fig. 1 shows the phase portraits for two stable states cross-section of a phase volume for two values of auto shifting voltage. From the analysis of these figures it follows that in each of cases the scheme is characterized by the availability of a stably limit cycle, all phase path approach to it. The motion of a representing point on a limit cycle corresponds to slow variation of amplitude a and oscillation ϑ phase in each stable state.

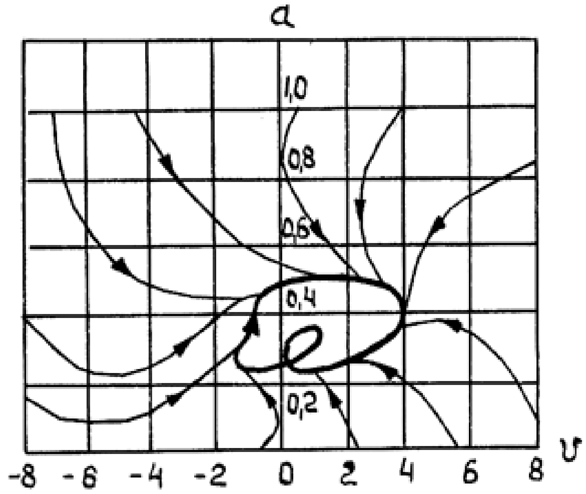

Fig. 1. Phase portrait for E = 0.88 V.

Рис. 1. Фазовый портрет для E = 0,88 V

III. Conclusion

In the conclusion it should be noted, that the described approach is applicable to non-linear vibratory systems of the different nature. The used Krylov-Bogoljubov-Mitropol'sky method of the solution of non-linear differential equations with a small parameter is sufficiently multi purpose, since in many cases the equation of a non-linear vibratory system can be reduced to the form allowing applying this method.

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2014 24th Int. Crimean Conference "Microwave & Telecommunication Technology" (CriMiCo'2014). 7—13 September, Sevastopol, Crimea, Russia
© 2014: CriMiCo'2014 Organizing Committee; CrSTC. ISBN: 978-966-335-412-5. IEEE Catalog Number: CFP14788