MICROWAVE CHAOTIC OSCILLATORS WITH CONTROLLED BANDWIDTH

Nikolay A. Maximov, Andrey I. Panas

Institute of RadioEngineering and Electronics, Russian Academy of Sciences,
Mokhovaya St. 11, GSP-3, 103907, Moscow, Russia,
E-mail: chaos@mail.cplire.ru

Abstract – **An approach to design of chaotic oscillators with controlled bandwidth in different frequency bands is proposed. One of possible mathematical models of the oscillator and simulation results are considered. Implementations of microwave chaotic oscillators and experimental results are demonstrated**.

Index terms – **Dynamic chaos, chaotic oscillator, frequency-selective circuit, microstrip line, wideband chaotic oscillations.**

I. Introduction

Chaotic oscillators play an important role of chaotic sources in various chaos applications. To be used in these applications, chaotic oscillators should have a number of features, among them the ability to generate oscillations in various frequency bands, possibility to control bandwidth of generated signals, reproducibility of basic characteristics, reliability, dimension, etc.

To provide these features, a number of fundamental and technological problems must be solved. It should be noted that the problems are more complicated in microwave range.

In this report, we propose a new approach to design of chaotic oscillators with controlled bandwidth in different frequency bands. The approach is based on principles of scale invariance and structure hierarchy.

II. Oscillator structure

A harmonic oscillator whose dynamic is described by a second-order ordinary differential equation (i.e., a system with one degree of freedom) can be used as the base. In this case, chaotic oscillations cannot exist. We refer to this oscillator as active one. Oscillators based on Wien-bridge, RC-oscillators, three-point oscillators and others can play the role of the active oscillator.

A passive oscillator is the second element of the structure. It can contain both linear and nonlinear reactive elements and it has frequency-selective response in the corresponding frequency range. As is known, to provide chaotic oscillations, oscillating system must have one and half degree of freedom as minimum. But in practice this is insufficient (as a rule). Therefore in general we shall imply that passive oscillator is a resonant circuit consisting of several simpler oscillating systems, whose number of freedom degrees essentially exceeds 2. In particular this pertains to distributed systems exploited in microwaves.

The third element of the structure is the connection between active and passive oscillators, providing their self-consistent interaction. Block diagram of the described structure is given in Fig.1.

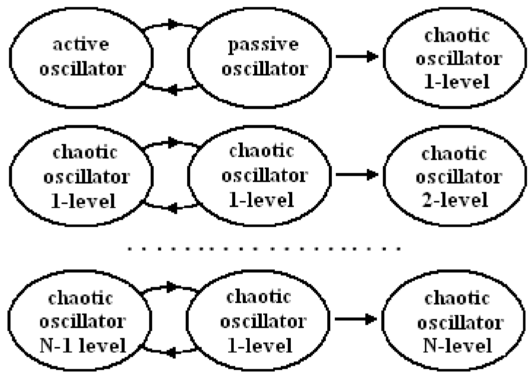


Fig. 1. Structure of the chaotic oscillator

Power spectrum of chaotic oscillations, arising in this system, is restricted to the bandwidth of resonant response of the passive oscillator. Similar oscillator structure is given in [5] where a mathematical model of an oscillator having a passive oscillator in the form of an oscillating circuit with varactor diode is described and results of experiments with a microwave chaotic oscillator are given.

III. Simulation

To verify the approach in simulation, consider a concrete structure of oscillator. Let a three-point oscillator be the active oscillator (Fig. 2a), whereas a frequency-selective circuit (FSC) composed of a chain of several parallel-serial RLC-circuits (version 1 or 2, Fig. 2b) may be taken as the passive oscillator. The FSC represents a bandpass filter (BPF), which may be considered as a low frequency model of microstrip BPF.

In general, circuit parameters can be different. System equations for both versions 1 and 2 were described and investigated in [6–9]. So, here we give simulation results for version 2, demonstrating basic modes of the oscillator (Fig.3)

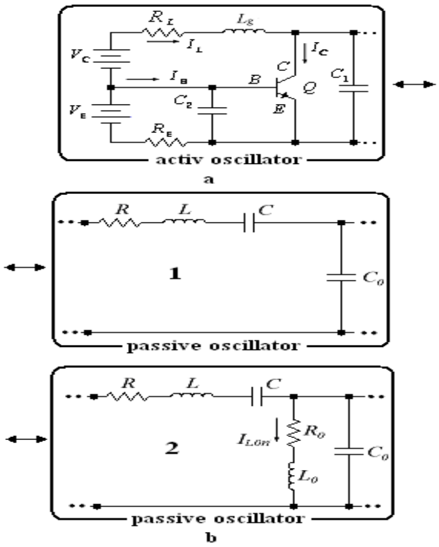
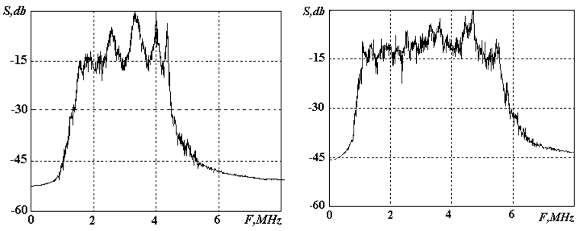


Fig. 2. (a) Three-point oscillator (active oscillator), (b) a typical units of different BPF (versions 1 and 2) (passive oscillator).

Frequency range of the power spectrum (Fig. 3) is defined by the amplitude-frequency response of the total BPF it and can be changed by means of varying the BPF response. Thus, changing the resonant circuit response and also C_1, C_2 values it is possible to form chaotic signals with desired spectral band in preassigned frequency range.



a b

Fig. 3. (a) power spectrum of chaotic oscillations at the oscillator output for ($L = 5\mu H, C = 1nF, L_0 = 2.5\mu H, C_0 = 2nF$); (b) power spectrum for $(L = L_0 = 5\mu H,\ C = C_0 = 1nF)$.

Developing this approach, we consider chaotic oscillator design of second level (Fig. 1) using oscillator model with nonlinear resonant circuit as the passive oscillator [5]. In this case, the resonant circuit contains a varactor diode instead of capacitor. The design assumes the presence of coupling between the two first-level oscillators, each being, in turn, a system of coupled active and passive oscillators (Fig. 4).

System dynamics can be described by the following equations:

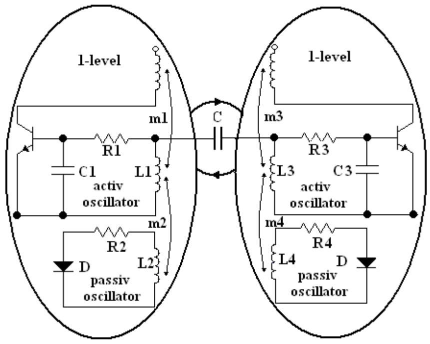


Fig. 4. Second level oscillator formed from two (1,2) first-level chaotic oscillators coupled with capacitor C.

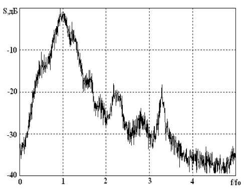
$$\ddot{x}_1 + (\delta_1 - f(x_1))\dot{x}_1 + x_1 = k_1\ddot{x}_2 + \alpha_1\ddot{x}_3$$
$$\ddot{x}_2 + \delta_2\dot{x}_2 + \omega_1^2\varphi(x_2) = k_2\ddot{x}_1$$
$$\ddot{x}_3 + (\delta_3 - f(x_3))\dot{x}_3 + x_3 = k_3\ddot{x}_4 + \alpha_2\ddot{x}_1$$
$$\ddot{x}_4 + \delta_4\dot{x}_4 + \omega_2^2\varphi(x_4) = k_4\ddot{x}_3$$

where $\delta_1 = R_1\sqrt{C_1/L_1}$, $\delta_2 = R_2\sqrt{C_{od}/L_2}$, $\delta_3 = R_3\sqrt{C_3/L_3}$, $\delta_4 = R_4\sqrt{C_{od}/L_4}$ are damping factors for resonant circuits of the oscillators 1 and 2, respectively; $k_i = m_i/L_i$, $i = 1\ldots4$ are coupling strengths between the resonant circuits in each of the oscillators; $\alpha_1 = C/(C + C_1)$, $\alpha_2 = C/(C + C_3)$ are couplings between the oscillators, where C is the coupling capacitor; $x_i = q_i/q_0$, $i = 1\ldots4$ is dimensionless variable of charge; $f(x) = b/(1 + x^2)$ is time derivative of the current at the output of oscillator amplifier element (current $J_k = J_0 arctg(q/q_0)$); $\varphi(x) = 1 - \exp(-x) -$ is approximation of dimensionless voltage at the varactor diode capacitor; $\omega -$ is the ratio of the fundamental frequency of the nonlinear resonant circuit to frequency of the linear resonant circuit in each of the oscillators.

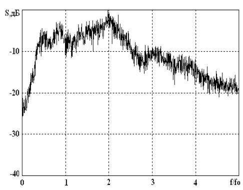
Methods of digital investigation of the equations in this paper was as follows: at first, it was assumed that there was no coupling between oscillators. We found parameter domain where autonomous oscillators demonstrate chaotic behavior. Next, this parameter domain was considered in detail. Analyzing bifurcation diagrams, spectral characteristics, Lyapunov exponents and waveforms, we chose parameters corresponding to the most developed chaotic oscillations. Then we fixed these characteristics and considered the system of coupled oscillators as a function of coupling factor (Fig. 5). In this case we assumed that partial frequencies of the oscillating systems are close.

Simulation showed that the selected parameter provides stable chaotic oscillations in the system. In addition, changing coupling value changes the bandwidth of chaotic oscillations. Increasing coupling from 0 to 0.75 results in extension of the generating bandwidth by more than a factor of three (Fig. 5).

Change of the bandwidth of coupled oscillators is close to changing amplitude-frequency response of individual coupled resonant circuits depending on the coupling factor. Note that above results were obtained when the mutual action of the oscillators was the same. If this balance is broken then the total bandwidth is decreased whereas the spectral characteristic nonuniformity is increased the more the less the symmetry of the mutual action of oscillating systems.



a



b

Fig. 5. Spectral characteristics of the second-level oscillator signal as a function of coupling value ($\alpha_1 = \alpha_2 = \alpha$) between the first-level oscillators.($a - \alpha = 0; b - \alpha = 0.75.$)

Simulation allows us to conclude that when the above conditions are satisfied, one can obtain stable generation of chaotic oscillations with controllable bandwidth.

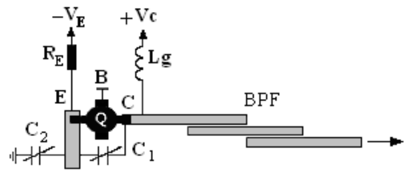
IV. Experiments

Let us illustrate effectiveness of the proposed approach on example of a microwave chaos generator. The generator topology is given in Fig. 6. It is made on a material of 1 mm thickness and dielectric constant $\varepsilon = 10$. Note that the generator with the similar topology was first considered in [10, 11] where the transition to chaos was based on period-adding bifurcations.

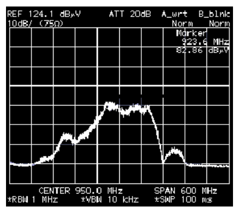
Transistor 2T938A-2, [7], is used in the three-point generator as the active element, so the lumped elements C_1, C_2, R_E, L play the same role as the elements in Fig. 2. Resonator based on coupled microstrip lines (RE) realizes the function of the resonant circuit (passive oscillator). The generator modes are tuned with variable capacitors C_1, C_2 (4/30 pF) and by varying voltages V_E, V_C .

Experiments with the generator showed that the bandwidth and nonuniformity of chaotic signal power spectrum at the generator output are defined by the bandpass and nonuniformity of the resonator amplitude-frequency characteristic just as in the case of simulation.

However, since the transistor impedance influences the resonator frequency response, additional correction of the spectrum with variable capacitors is necessary. As illustration, Fig. 6b demonstrates signal spectrum at the generator output. Basic figures of the generated chaotic signal are: bandwidth at 10 dB level is 150 MHz, central frequency ~ 950 MHz, spectrum ruggedness less than 5 dB, output signal power 2 mW



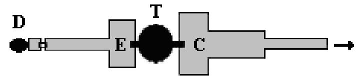
a



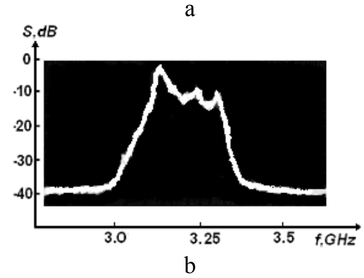
b

Fig. 6. Topology of generator (a) and its power spectrum (b) in frequency range 880–1030 MHz.

Let us consider another example of microwave chaotic generator, whose low frequency model with varactor diode was studied above (Fig. 7).



a



b

Fig. 7. Topology (a) and power spectrum (b) of microwave chaotic generator corresponding to the proposed approach.

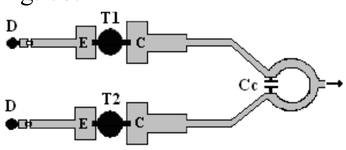
The generator is of microstrip technology. It contains one bipolar transistor KT982 (Russia). Foiled dielectrics with different dielectric constants ($\varepsilon = 2.7,...10$) were used as substrate material. Output (collector) topology is two-stage transformer matching output transistor impedance and the external 50 Ω load in the operation frequency band. The transformer may be considered as an analog of the linear resonant circuit in the above-described generator model. Microstrip resonator in the emitter circuit, matches the varactor diode impedance with the input transistor impedance. On the other hand, electrical length of the resonator ($L = \lambda/4$) defines the central frequency of the generator signal. This part of the generator may be considered as the nonlinear resonant circuit of the above model. The feedback between the linear and nonlinear circuits is realized by means of internal capacitors of the microwave transistor. Note that the use of varactor diode as nonlinear element (nonlinear capacitor) with no energy expenses on its controlling allows us to increase generator efficiency up to 25–30 % in chaotic mode.

The spectrum of chaotic signals at the generator output is given in Fig. 7b. Here, the central frequency is 3.2 GHz whereas the bandwidth at 10-dB level is ~200 MHz.

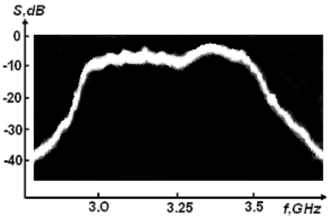
Let us continue design the generator structure according to the block diagram. Now, let us take chaotic oscillators of the first level (see Fig. 1b) as interacting oscillating systems.

Here the following variants are possible: 1 – resonators of both oscillators have the same characteristics or equivalent topology (in microstrip implementation), then the band extension of generated oscillations takes place due to an increase of coupling between the oscillators; 2 – oscillators have similar topologies scaled for adjacent frequency ranges; 3 – simultaneous use of two above variants. We shall call such an oscillating system the second-level chaotic oscillator.

The spectrum of chaotic oscillations (frequency range 3000–3500 MHz at –10 dB level) of exactly this generator (variant 1), i.e., the generator based on two mutually coupled oscillators with identical topologies is given in Fig. 8b.



a



b

Fig. 8. Experiments (a) broadband generator topology composed of identical coupled first-level oscillators; (b) power spectrum of the second-level generator in frequency range 3000–3500 MHz.

The oscillators were coupled by means of an unbalanced power adder and the coupling can be adjusted with capacitor C_c (Fig. 8a). As follows from comparison of this case and the single generator (Fig. 7), the spectrum bandwidth is increased approximately two times while the smoothness is decreased. The system efficiency is also decreased to ~ 15 %.

Following this principle of generator design, it is possible to implement wideband and ultrawideband chaotic generators using the first level oscillator as the basic structure element. In this case, topology dimensions should be scaled to necessary frequency band.

V. Conclusion

An approach to chaotic oscillator design with prescribed and controlled bandwidth in different frequency ranges was verified by means of simulation and experiments.

Microwave ultrawideband generator, designed using this approach, represents a fractal structure consisting of topologically similar interacting chaotic oscillators connected as a whole in required frequency range.

This paper is supported in part by the Russian Foundation for Basic Investigations (Project 03-02-16747).

References

[1] A. Dmitriev. “Storing and retrieving information in one-dimensional dynamical systems”, Radiotekhnika i elektronika, v. 36, No. 1, pp. 101-108, 1991 (in Russian).
[2] M. Hasler “Advances in communications using chaos”, Zarubeznaya radioelektronika. Uspekhi sovremennoi radioelektroniki, No. 11, pp. 33-43, 1998 (in Russian).
[3] A. Dmitriev, B. Kyarginsky, N. Maksimov, A. Panas, S. Starkov “Perspectives of designing RF and microwave direct chaotic communications”, Radiotekhnika, No. 3, pp. 9-20, 2000 (in Russian).
[4] K. Lukin, “Noise radar technology for short-range applications”, Pros. Of Inter. Conf. On Radar Systems, RADAR-1999, May 17-21, 1999, Brest, France.
[5] N. Maksimov, V. Kislov “Chaotic and regular dynamic of self-oscillating systems with p-n transition”, Radiotekhnika i elektronika”, No.12, pp. 1487-1492, 1997 (in Russian).
[6] N. Maksimov., A. Panas “ RF single-transistor band-pass chaotic oscillator”, Zarubeznaya radioelektronika. Uspekhi sovremennoi radioelektroniki, No. 11, pp. 61-69, 2000 (in Russian).
[7] A. Panas., B. Kyarginsky, N. Maksimov. “Single-transistor microwave chaotic oscillator”, Proc. of NOLTA'2000, Dresden, Germany, pp. 445- 448, 2000.
[8] N. Maksimov, A. Panas and S. Starkov “Chaotic oscillators design with preassigned spectral characteristics”, Proc. of ECCTD’01, Espoo, Finland,

Vol. III, pp. 429-432, 2001.
[9] A. Dmitriev, E.Efremova, N. Maksimov "Controling spectrum envelope in single-transistor chaotic oscillator", Radiotekhnika i elektronika, (to be published, in Russian)
[10] N. Maksimov, V. Kislov, "About one regularity of the transition from deterministic to chaotic dynamic in self-oscillating system", Pis'ma v ZTF, Vol. 9, No.16, pp. 979-982,1983.