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A LOW-VOLTAGE COUPLED RELAXATION GENERATOR WITH CHAOTIC BEHAVIOR: SIMULATION, MEASUREMENT AND IDENTIFICATION

Abstract. *This paper in devoted to the problem of chaotic generators design, measurement and identification. A new low-voltage generator without inductive elements, based in the set of coupled relaxation generators is proposed. Generator properties are investigated both by direct measurement and numerical simulation. Identification criterion is proposed and explored. The multi-agent identification system, based on the proposed criterion is tested on data, acquired from real generator.*

Keywords: *chaotic system identification, relaxation generators, multi-agent identification methods, simulation, measurement.*

Introduction

Chaotic dynamics investigation is a valuable part of the modern non-linear systems theory enrichment. As a result, a formidable number of the chaotic generators, and corresponding mathematical models is created and researched. Some of them, as a Lorenz system [1], have a strong physical background, and a mathematical equations system was created to describe behavior of the fluid dynamic particular task. The mathematical model of the Colpitts generator [2], similarly, was created to provide description of the existent and widely used electronic schematic. Some other generators, like Chua system [3], was created in the "opposite direction": electronic schematic was created after the equations system. Nevertheless, all such systems received essential scientific interest and provides us a significant amount of the knowledge about complex dynamic systems properties.

Currently, development and research of the some new generators still actual, especially, if the new generator have a real-world prototype, and discovers a new point of view to the properties of well-known technical objects. Otherwise, creation of the simulation by the means of the schematic with operation amplifiers seems somewhat artificial.

Among the new generators, and, consequently, its mathematical models development and investigation is a valuable task itself, there is a more challenging task. Chaotic systems identification requires a special criteria and methods. So, chaotic generator development must be accompanied by the corresponding identification system synthesis.

Task definition

So, the current task assumed to consist of the following steps.

1. Create a generator, potentially with chaotic dynamics, preferably by the means of the widely-used solutions in the electronics area. Moreover, it will be better to use low-voltage and low-power approaches, to allow direct connection with the modern measurement equipment, which in turn, often uses a low-voltage micro-controller core. For example, a Colpitts oscillator, with a relatively high working and output voltages, requires a special schematic to limit ranges, and potentially may lead to unwanted disturbances during measurement. Other desirable feature is a low frequency working range with small-sized components – to minimize distortions due to limited measure channel frequency band. The next coveting feature – avoidance of the elements, which do not allow precise measurement, like inductor coils.

2. Investigate created generator, to ensure complex and/or chaotic behavior. Attractors and a frequency response plots must be represented. Collected data must be in form, which allow us to conduct comparison of the numerical simulation.

3. Create mathematical model, conduct simulations and compare with data, received on the previous stage.

4. Develop a identification system, suitable for created generator, and explore its working capacity and properties.

Chaotic generator development and measurements

More then one century of the electronic development history give us a large number of the oscillating schematic solutions. Some of them can generate nearly harmonic signal, some – provide different kinds of complex output. It's known, that essential nonlinear properties can lead to chaotic dynamics. Consequently, first of all, oscillators with essential non-linear dynamics must be considered. One of the simplest example of the such generators is the relaxation one. Some approach to chaotic signal generation was considered before [4], but direct realization of the considered method has some drawbacks. First of all, the specific main relaxation element was not described, and realization with the gas-discharge or something similar elements leads to essential problems with development and measurement. On the other hand, in the paper [5] a low-voltage chaotic oscillator was proposed. As a drawback, to provide a required degree of freedom, a inductor was used, which both limits us in the element measurement precision, and force us to measure relatively high-frequency signals.

In this paper, a combine approach is proposed. From the low-voltage chaotic oscillator the main relaxation element, based on two BJT transistors is used. From the paper [4], a set of the relaxation generators, coupled by common limited power source is borrowed. The electronic schematic of the proposed generator is show on the fig. 1.

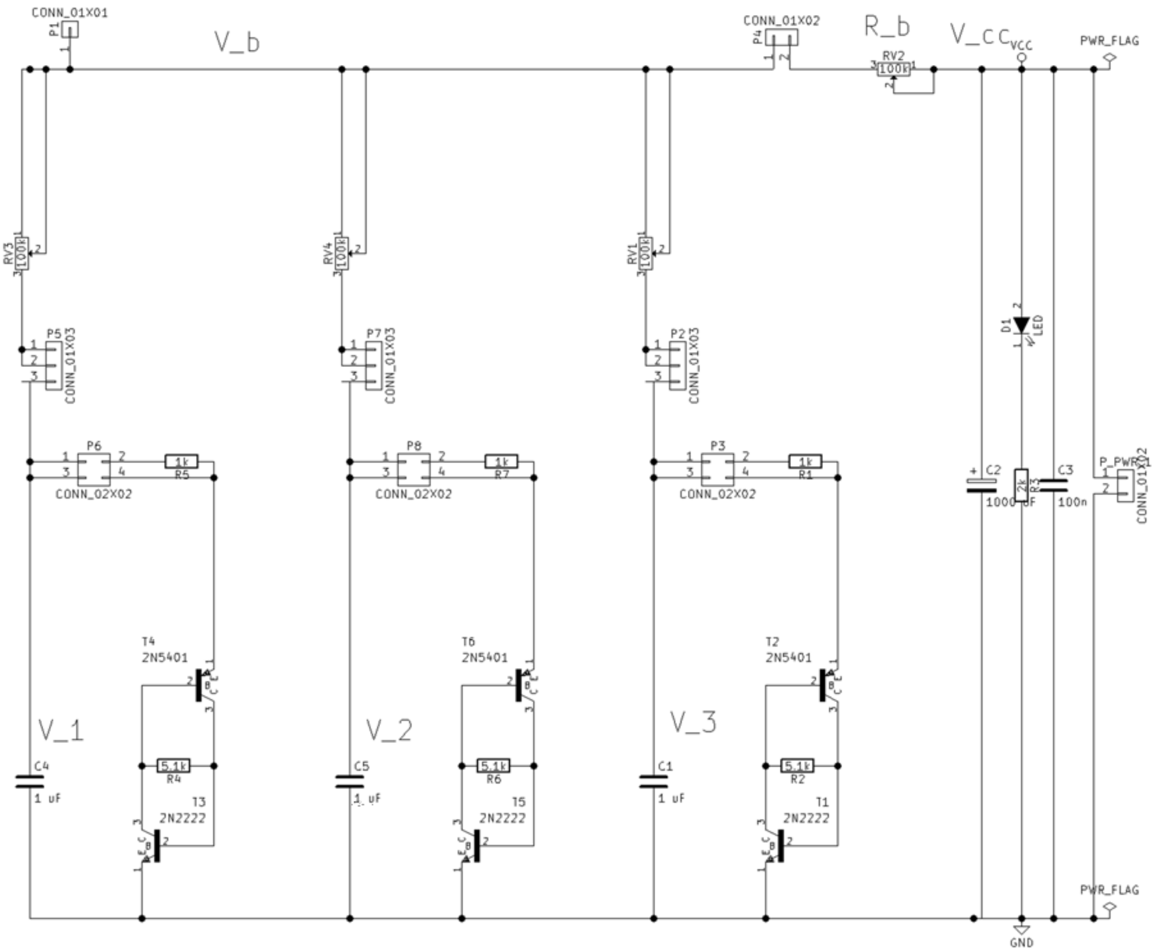

Fig. 1 – Proposed schematic of the 3 coupled relaxation generators

This scheme has a number of advantages. The relaxation core elements, formed by pair of complimentary BJT, have a low trigger voltage, approximately 0.97 V. As a result, the schematic can operate with low supply voltage, and a approximately 3 V supply from the MC schematic will be enough, and any of the output signals may be connected to internal ADC without additional elements. The power consumption is small, the main part consumes less than 1 mW.

Moreover, this scheme has a real world prototype, when a set of the pulse power supplies feed by a single limited power source.

The pure frequency of the each generator itself is defined by the capacity of the C_1, C_4, C_5 and resistance of the R_{v1}, R_{v3}, R_{v4}. No inductive elements are used. Coupling on the power source is realized by the R_b resistance. This parameter defines the interaction between the oscillators, and consequently, forms the main goal for the parametric identification. The P_4 connector has two distinct purposes: current management and run-time R_b adjustment to check identification system dynamic capabilities. The P_2, P_5, P_7 connectors allow us to switch off given oscillator for the testing purpose, and to connect measurement device. The P_3, P_6, P_8 connectors among with the R_1, R_5, R_7 resistors gives us possibility to slow down discharge process, that, on the one hand, lowers nonlinearity, and, on the other hand, simplifies simulation.

The measurement equipment was represented by the development boards with micro-controllers: STM32F429 and STM43F746. Both boards was equipped with 8MB SDRAM, to hold enough amount of acquired data from four ADC channels, and SDHC card via SDIO interface to store data. Command control was realized via UART interface and USB-UART converter board. Calibration was done with high-precision reference voltage source, among with quartz stabilized pulse generator.

As mentioned before, four measurement channels were used: the values of V_b, V_1, V_2, V_3 was acquired. Preliminary investigations shows, that with gives schematic element values the sampling rate of 10^5 samples per second is more than enough. But this, more than sufficient sampling rate corresponds to required time step for numerical simulation. Excess amount of data is quite manageable.

A large series of simulations with different values of R_b was held. The results are quite unusual for systems with can demonstrate chaotic dynamics. When the value of R_b is relatively low, the oscillators is mostly independent, the V_b spectrum consist of limited number of sharp peaks, but the attractor forms a filled cube (fig. 2).

On the contrary, when oscillators are tightly coupled (large R_b value) the attractor is not so filled, but the spectrum is contiguous (fig. 3).

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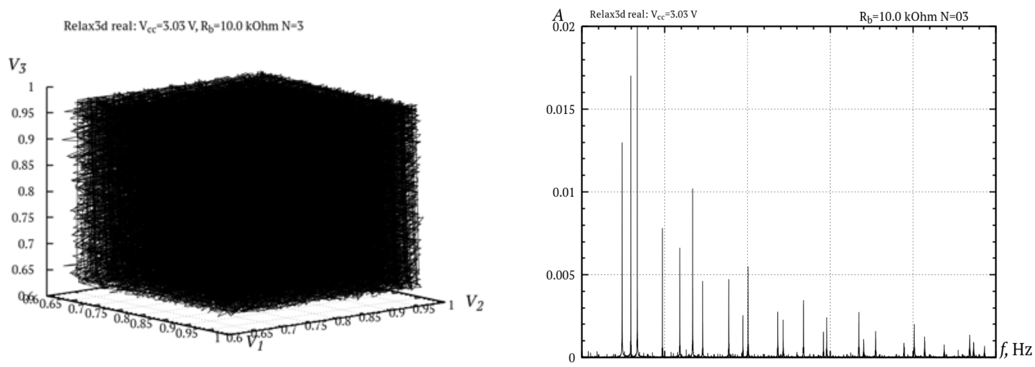

Fig. 2 – Attractor and spectrum for R_b = 10 kOhm

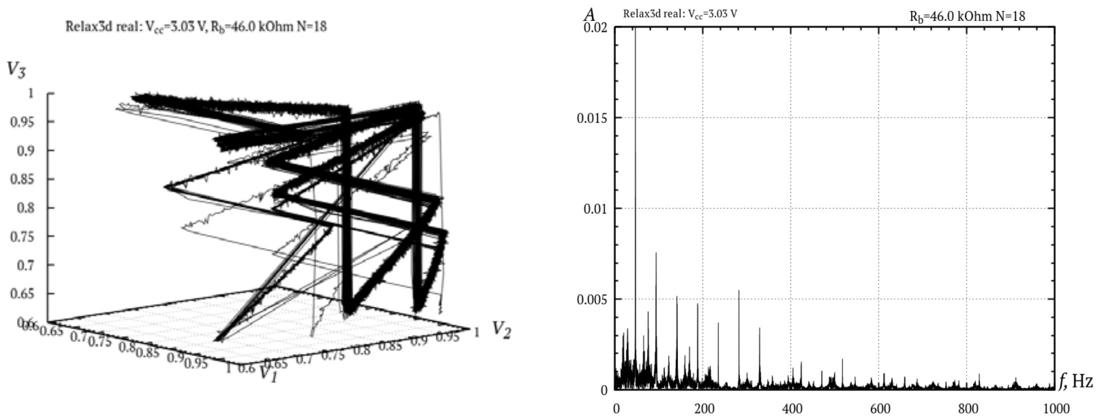

Fig. 3 – Attractor and spectrum for R_b = 46 kOhm

The bifurcation point in this case is occurs, when at least two oscillators nearly simultaneously comes to discharge condition. First discharge slows down the second, and thus, the small difference in the initial condition leads to significant changes in the phase trajectories.

Simulation

The mathematical model for the proposed generator consist from some simple parts, but requires, that state of the each oscillator will be given by the algorithm:

$$\begin{cases} V_b = V_{cc} - R_b\left(I_1 + I_2 + I_3\right) \\ C_1\dot{V}_1 = \dfrac{V_b - V_1}{R_{v1}} - \dfrac{V_1}{R_1}\mathrm{On}_1() - \dfrac{V_1}{R_1 + R_{1,\mathrm{leak}}} \\ C_2\dot{V}_2 = \dfrac{V_b - V_2}{R_{v2}} - \dfrac{V_2}{R_2}\mathrm{On}_2() - \dfrac{V_2}{R_2 + R_{2,\mathrm{leak}}} \\ C_3\dot{V}_3 = \dfrac{V_b - V_3}{R_{v3}} - \dfrac{V_3}{R_3}\mathrm{On}_3() - \dfrac{V_3}{R_3 + R_{3,\mathrm{leak}}} \end{cases}, \qquad \mathbf{(1)}$$

where R_b – resistance in the supply line, R_{vi} – resistances in charge branches, R_i – resistances in discharge branches, $R_{i,\text{leak}}$ – leak resistances, I_i – charge currents.

The simulation process was held by the developed "qontrol" simulation program. Among the simulation itself, a measurement data, acquired on the previous stage, is read and compared with model.

As expected, it is impossible to achieve object and model trajectories conforming for chaotic and similar systems. But the general attractor views, among with spectrum is similar. The simulation results under the conditions, corresponding to fig. 2 and fig. 3 is show on the fig. 4 and fig. 5.

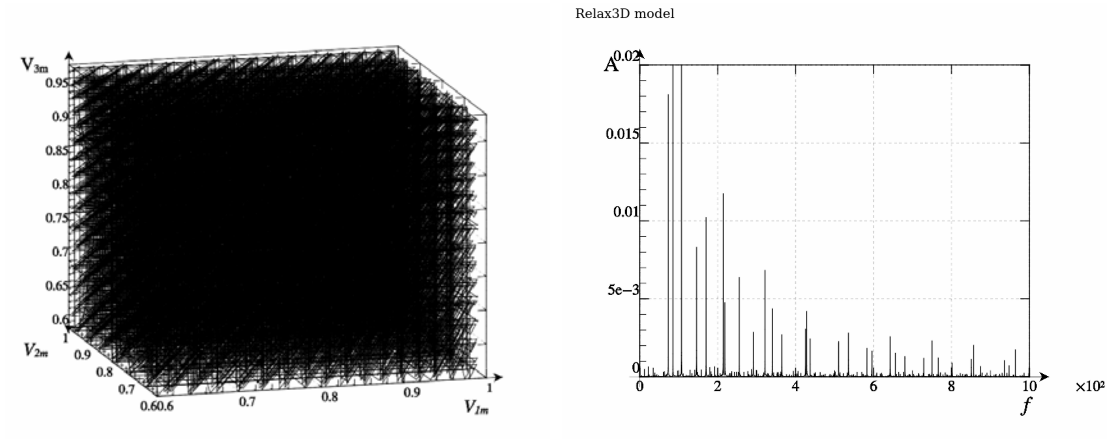

Fig. 4 – Simulation attractor and spectrum for R_b = 10 kOhm

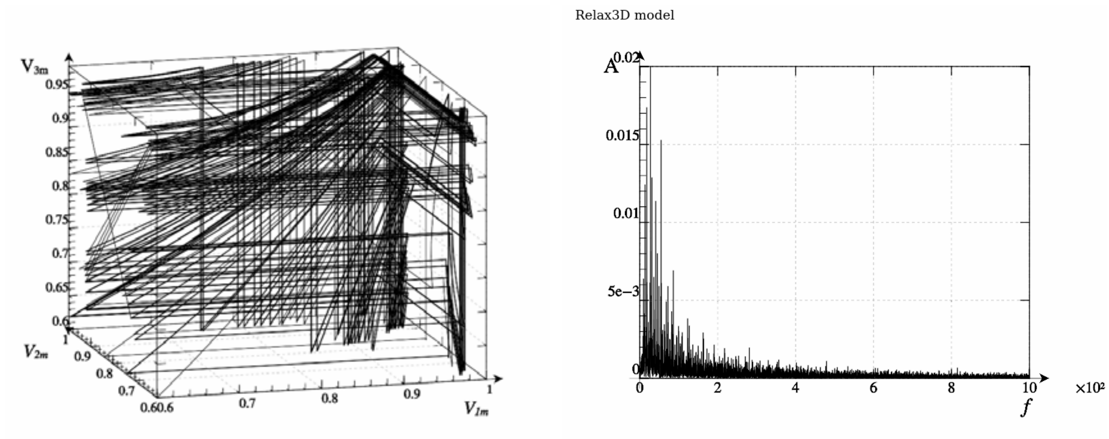

Fig. 5 – Simulation attractor and spectrum for R_b = 46 kOhm

So, the simulation results confirm real experiment results, that proposed system can demonstrate both complex-periodic and chaotic behavior. To say more about adequacy, the identification criterion must be investigated.

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Identification

The identification problem solution for such systems consists of two general steps: criterion synthesis and searching method selection.

As a first attempt, we examine energy-alike based approach. It this particular schematic, the voltage values (potentials) is more essential, then energy in the capacitance. So, the first criterion candidates was estimated:

$$q_{sv} = \overline{V_1 + V_2 + V_3}\,, \tag{2}$$

$$q_{vb} = \overline{V_b}\,, \tag{3}$$

$$q_{hv} = \frac{1}{\overline{\overline{V_b}}}\,. \tag{4}$$

The criterion (2) applicable in all range, but have relatively small changes on it. On the other hand, the (3) and (4) expressions have better slope in the beginning of the plot, but became nearly useless in the right part, where chaotic behavior is observed. To combine better parts, the next criterion was proposed:

$$q_{rv} = \frac{\overline{V_1 + V_2 + V_3}}{\overline{V_b}}\ , \tag{5}$$

This criterion seems to be the best among considered (fig. 6), and will be used in the identification system.

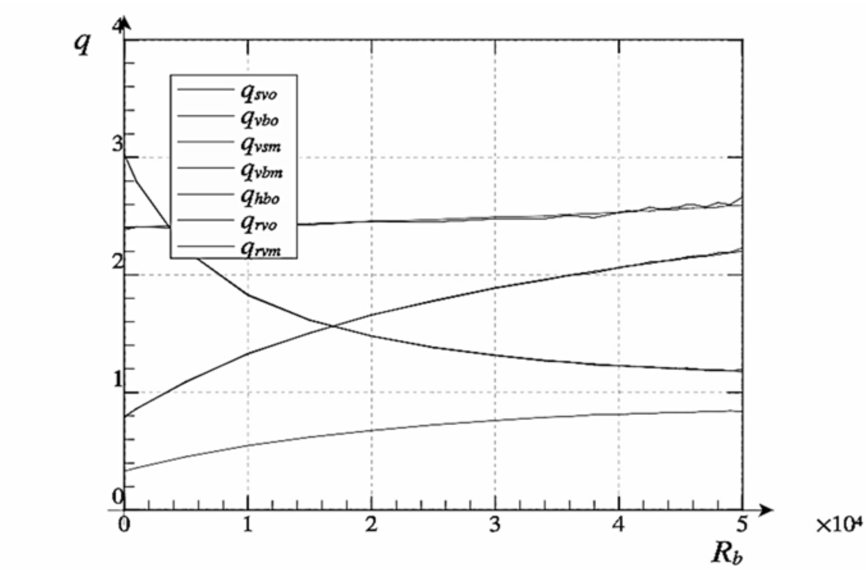

Fig. 6 – Criteria under estimation, indexes 'o' means object, 'm' – model

As fig. 6 shows, there is no essential difference between criteria values for object and model. From this fact we can derive two conclusions. The model and object under consideration is adequate in the term of all provided criteria. And as a result, identification system must demonstrate similar results both for real object and model.

As a identification system itself a proven multi-agent searching approach is used [6]. The value of R_b was adjusted by the additional resistor R_{ba}, driven by a logic-level low-R_{ds} MOSFET, controlled by a separate output channel from MC. The typical result is shown in the fig. 7.

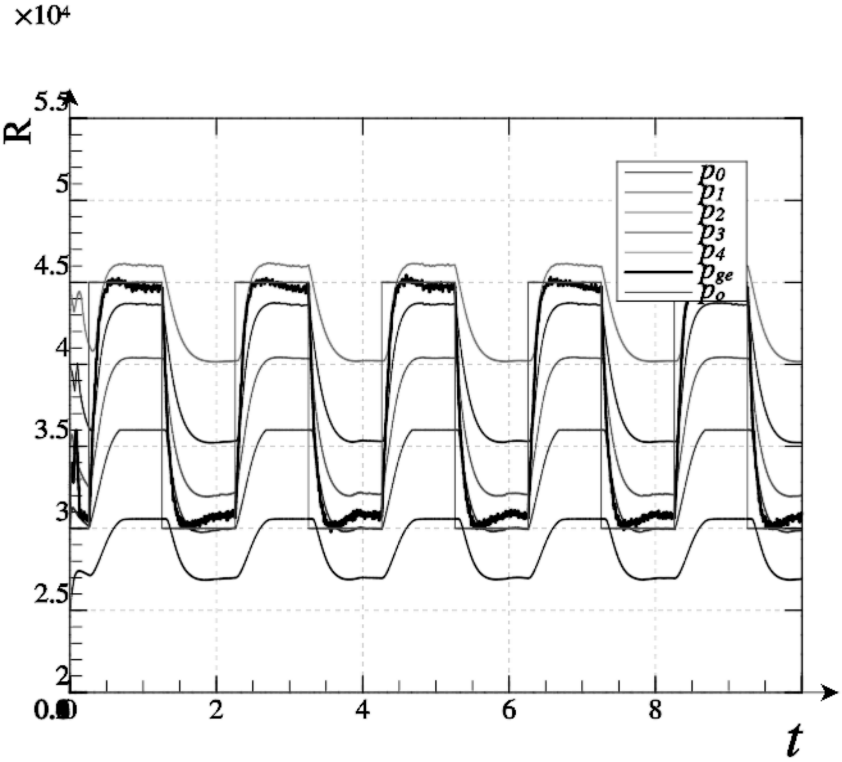

Fig. 7 – Identification process for the parameter R_b

This plot demonstrates, that identification system, based on criterion (5) and multi-agent searching approach proved good results. Identification process is stable, and searching time is suitable for given task.

Conclusions

The results of the schematic measurements, simulation and identification process allows us to make certain conclusions:

1. Proposed generator demonstrates both complex-periodic and chaotic dynamics, depending on the R_b value. The power consumption is negligible, and low output signal voltage allow direct connection to MC-based measurement equipment, that simplifies research.

2. Model (1) under numerical simulation show adequate results.

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3. Identification system, based on q_{rv} criterion and multi-agent searching method provides good results.

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