Nonlinear time series analysis of an externally triggered double transistor chaotic circuit

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Abstract

In this paper the results of a nonlinear analysis of the output signal form an externally triggered double transistor chaotic circuit, in order to reveal the presence of chaos, are presented. Nonlinear time series modeling techniques are applied to analyze the circuit's output voltage oscillations. The method proposed by Grasberger and Procaccia is performed. The circuit is consisted of an AC-voltage source, a linear resistor R, a linear inductor L and two bipolar junction transistors. Multisim is used to simulate the circuit and shows the presence of chaos. This software is selected, since it provides an interface as close as to the real implementation environment. The phase space is reconstructed using the delay embedding theorem suggested by Takens. The first minimum of the average mutual information from the collected data shows the time delay. Using MATLAB code this parameter is estimated and found equal to 5. This analysis gives useful information in order to fully characterize the circuit operation. The chaotic signal processes, exhibits several innate characteristics beneficial to communications systems. The presence of chaos in electronic devices could be used as an encryption method.

***Keywords*:** Chaos in electronic devices, Time Series Analysis, Chaotic attractors, nonlinear circuits.

1. INTRODUCTION

The research field of chaotic dynamic is directed towards applications in electronics. There is a growing interest for chaotic signal generation sources. In regards to this, various circuits have been proposed in literature. Many of these chaotic circuits are based on the operation of a single bipolar junction transistor (BJT) (M.P. Hanias & Tombras, 2009). Each of these circuits has been considered as an externally driven and controlled chaotic signal generator using, firstly, an ordinary DC power supply, and, then, an AC power supply.

In this paper, we describe a double BJT chaotic circuit which is externally driven by a signal generator.

2. CIRCUIT DESCRIPTION

The complete circuit layout is shown in figure 1. The circuit it is consisted of two BJT transistors, a BC107BP (npn type) and a BC177AP (pnp type), in a common emitter configuration. Each transistor is connected with a collector resistor $R_1= R_3=30\Omega$ and a common emitter degeneration resistor $R_2=3.0k\Omega$. The circuit is driven by a sinusoidal external voltage source connected at the base of the transistor with amplitude V_0 as applied through an inductor L=55μH directly to the transistor base and is powered supplied by a DC voltage V_{cc}=12 volts connected through the R_1, R_3 and a V_{ee}=-12 volts connected through the R_2.

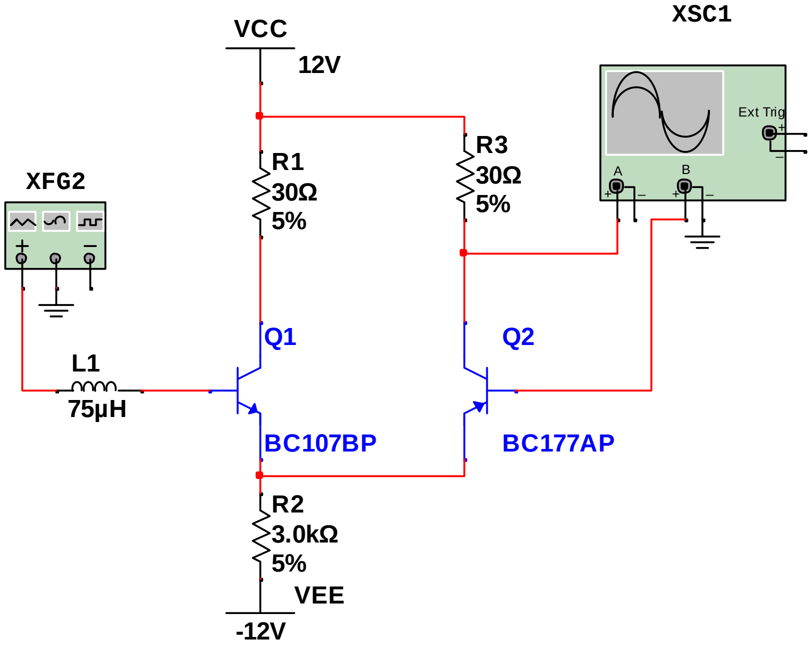

Figure 1 Schematic of the considered RLT circuit

We simulate the circuit of fig 1 in Mulstisim, which is widely accepted for circuit simulation [(Li, Chu, Zhang, & Chang, 2009)]. Another factor for preferring the software mentioned above is the fact that his interface is close to real implementation of an electronic circuit. After the simulation the time series recorded by the oscilloscope it is shown in figure 2.

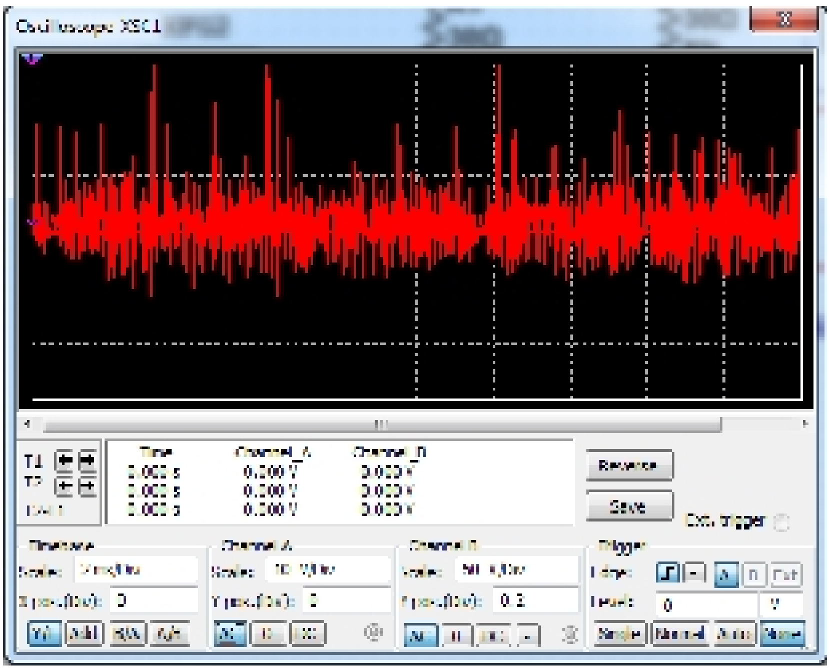

Figure 2 The result of simulation, it is presented the chaotic signal $V=V_b(t)$ for the RLT circuit of Fig.1

Clearly, voltage $V_C(t)$ depends on the collector current $i_C(t)$ which is an important circuit parameter, since it will become chaotic when or if the circuit exhibits chaotic operation. These data are saved to an external file and imported to MATLAB. A specific MATLAB source code has been developed for this task, also TISEAN package is used. (Hegger, Kantz, & Schreiber, 1998)

3. ANALYSIS

We apply the analysis method proposed by Grassberger and Procaccia (Grassberger & Procaccia, 1983) this method has been successfully applied in similar cases (M P Hanias, Giannis, & Tombras, 2010).In addition, Takens theory is applied (Takens, 2003) for reconstruction of the original phase space.

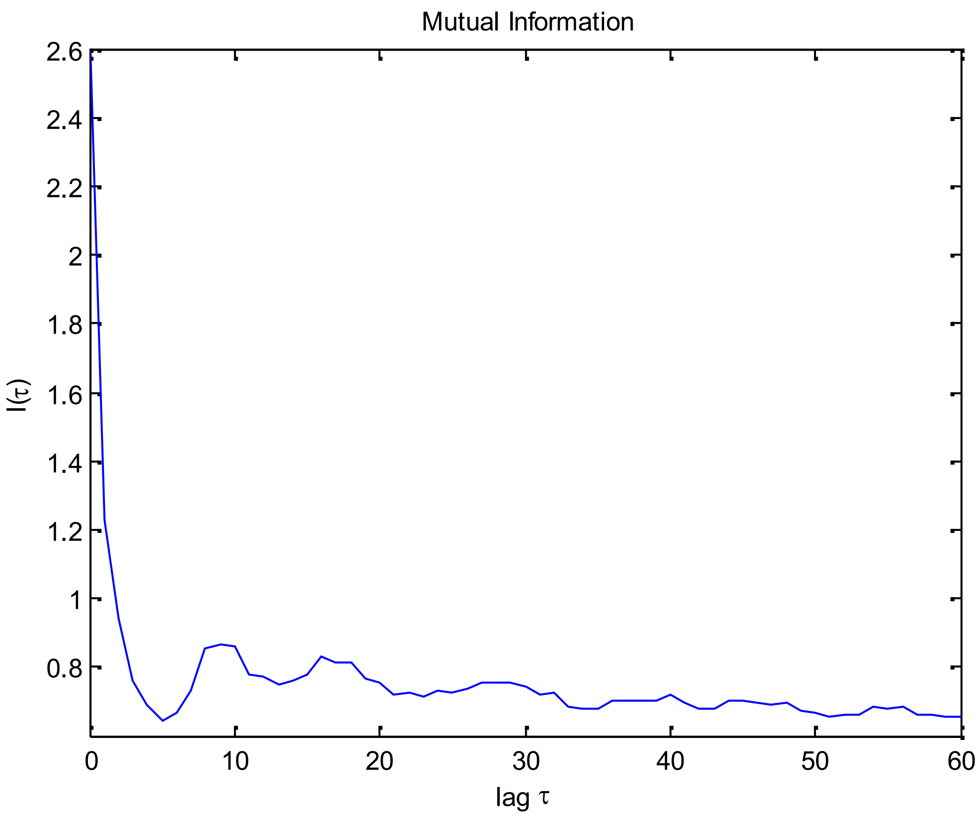

Figure 3 Average mutual information I(τ) vs. time delay τ.

For a scalar time series as it is in our case the recorded voltage time series across the base of the transistor, $V_b(t)=V_t$ where $t=1,2,3,..N$, the phase space can be reconstructed using the method of delays, (Bai, Lonngren, & Sprott, 2002). The basic idea of that method is that the evolution of any single variable of a system is determined by the other variables that it interacts with. Information about the relevant variables is thus implicitly contained in the history of any single variable. Based on this, an ‘‘equivalent” phase space can be reconstructed by assigning an element of the time series V_t and its successive delays as coordinates of a new vector time series

$$\vec{X}_l = \{V(t_i), V(t_i + ^2), V(t_i + 2^2), ..., V[t_i + (m-1)^2]\} \quad (1)$$

Where τ is referred to as the delay time and for a digitized time series is a multiple of the sampling interval used, while m is termed as the embedding dimension. The time delay τ is determined by the first minimum of the mutual information function $I(\tau)$.

Then the correlation integral is calculated for the simulated signal $V_b(t) = V_t$ when $r \to 0$ and $N \to \infty$, as is described in (Takens, 2003)

$$C(r) = \frac{1}{N_{pairs}} \sum_{\substack{l=1 \\ j=l+W}}^{N} H(r - \|\overrightarrow{X_l} - \overrightarrow{X_j}\|) \tag{2}$$

Where N is the number of the corresponding time series points, W is the Theiler window H is the Heaviside function (Kantz & Schreiber, 2004), and

$$N_{pairs} = \frac{2}{(N - m + 1)(N - m + W + 1)} \tag{3}$$

Here, the number of experimental points is $N=64144$. In equation (2) the summation counts the number of pairs $\left(\overrightarrow{X_l}, \overrightarrow{X_j}\right)$, for which the distance, the Euclidean norm, $\|\overrightarrow{X_l} - \overrightarrow{X_j}\|$ is less than r in a m Euclidean space.

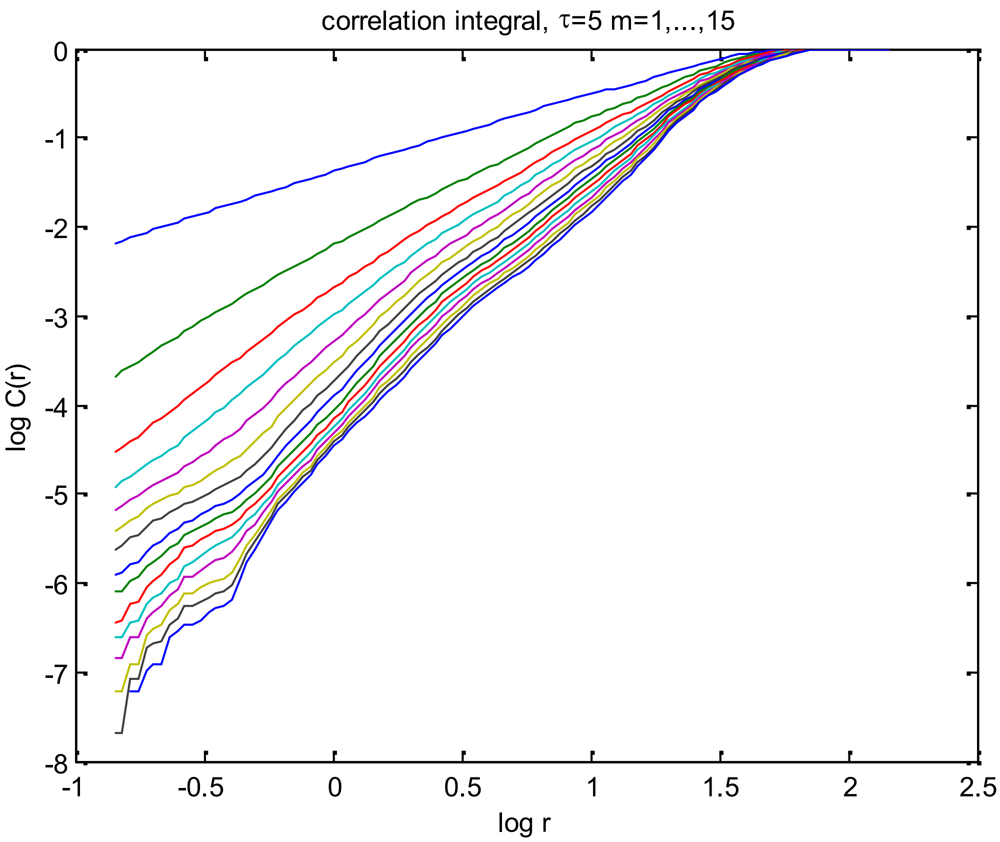

Figure 4 Relation between logC(r) and log r for different embedding dimensions m.

4. RESULTS

As shown in Figure 3, in our case the mutual information function. *I(Td)* exhibits a local minimum at $\tau = 5$ time steps and, thus, we shall consider $\tau = 5$ as the optimum delay time. As it is defined in Eq. (2), the correlation integral *C(r)* is the limit of correlation sum and is numerically calculated as a function of *r* for embedding dimensions $m = 1,2,....,15$.

In Figure 4 it is presented the relation between the logarithms of correlation integral *C(r)* and *r* for different values of embedding dimension m. The slopes of the lower linear parts of these log-log curves, shown in Figure 5, provide all necessary information for characterizing the attractor. The average slope of these curves tend to converge to the noninteger value of 2.56.

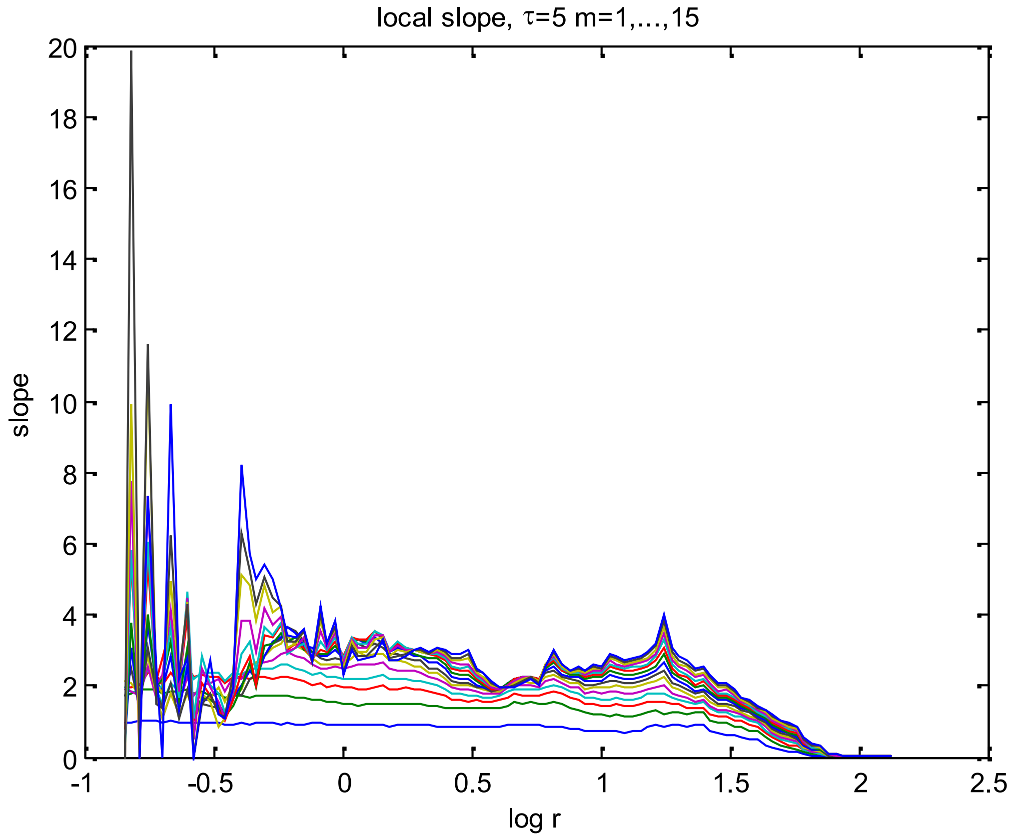

Figure 5 The corresponding slopes and scaling region of Figure 4

5. CONCLUSION

The use of a simple double transistor RTL circuit operating nonlinear region affects the chaotic state across the collector's resistor. We have verified and analyzed the experimentally obtained output voltage time series using the techniques based on phase space reconstruction.

The strange attractor that governs the phenomenon is a Lorenz type attractor who is stretching and folding in a three-dimension phase space.

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