International Journal of Computational and ExperimentalScience and Engineering
(IJCESEN)
Vol. 1-No.2 (2015)pp. 36-40
http://dergipark.ulakbim.gov.tr/ijcesen

***ISSN:*2149-9144**

ResearchArticle

Theoretical and Experimental Investigation of an L-band Chaotic Oscillator [#]

Abdelkader SENOUCİ[1]*, Achour OUSLIMANI[2], Abed-Elhak KASBARI[2], Abdelkrim BOUKABOU[3]

[1]EMP /Bordj El Bahri, Alger-Algérie
[2]ENSEA/ECS-Lab, Cergy-Pontoise, France
[3]Jijel University / Electronics Department, Jijel-Algeria

* CorrespondingAuthor : senouciaek@gmail.com

[#] Presented in "2nd International Conference on Computational and Experimental Science and Engineering (ICCESEN-2015)"

Keywords
ADS
Bifurcation
Chaotic oscillator
Microwave oscillator

Abstract: An L-band microwave buffered chaotic oscillator is designed and realized on a glass teflon hybrid technology. The buffers are optimized in order to match the microwave 50 Ω − 12 GHz oscilloscope without changing significantly the chaotic output characteristic. Dynamical behaviours of the oscillator are theoretically investigated using both numerical studies based on mathematical model and ADS software simulation. First of all, the theoretical study is based on the Matlab simulation, where transistors are modeled by simple mathematical description which is limited only for low frequencies. Nevertheless, it provides a valid approximation to broach a preliminary theoretical investigation. Here, times series, phase portraits, Lyapunov exponents and bifurcation diagrams of the chaotic system are performed. Secondly, in order to account for the increasing frequency, we use the ADS software simulation in which the transistor is described by a high frequency model. Indeed, the impact of microstrip critical lines interconnections and active probes are taken into account in ADS simulations. Spectral and time-domain measurements on the 3.6 GHz spectrum analyzer and 12 GHz oscilloscope are achieved. Experimental characterization gives a fundamental frequency of 2.14 GHz. This microwave chaotic oscillator exhibits attractive spectral characteristics. A good agreement between theoretical and experimental results is obtained.

1. Introduction

Potential applications of chaotic oscillators inspired many researchers to generate broadband chaotic signals [1, 2]. Particular interest is given to the chaotic generators operating in the field of radio frequencies [3, 4, 5]. Besides that, chaotic oscillators have been used for secure communication, data transmission and microwave radar applications [6-9].
Several works using operational amplifiers for generating broadband chaotic signals have been reported in the literature [10, 11]. However, these electronic components operate below the GHz. Moreover, simple circuits, based on the Colpitts oscillator and operable in the macrowave range have been proposed and discussed by several authors [12-17]. Several simulation studies have demonstrated the feasibility of these chaotic generators. However, few practical realizations have been achieved in the radio frequency range. In this work, we present theoretical and experimental investigations of a buffered oscillator for L-band applications.
The oscillator based on microwave transistors with threshold frequency of 9 GHz is realized on a glass teflon hybrid technology. The impact of critical microstrip lines on dynamical behaviour of the oscillator is also investigated.

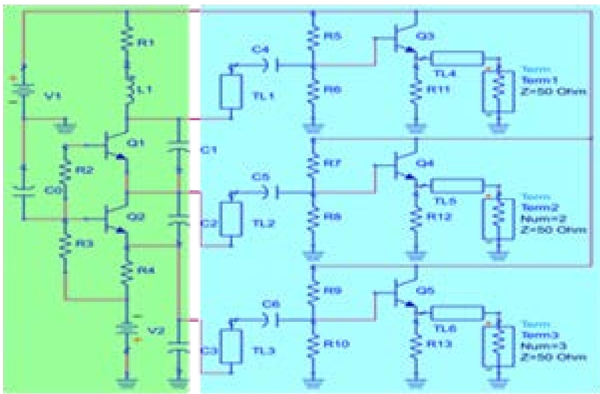


Figure1. *Circuit diagram of the microwave chaotic oscillator.*

2. Theoretical study

The theoretical study is discussed according to the following methodology. First of all, the theoretical study is based on the Matlab simulation, where transistors are modeled by simple mathematical description which is limited only for low frequencies. Nevertheless, it provides a valid approximation to broach a preliminary theoretical investigation. On the other hand, and to take into account the increasing frequency, we use the ADS software simulation in which the transistor is described by complete model taking into account high frequency effects. In this case, the model is more precise and closer to reality.

2.1. Numerical study

The schematic diagram of the chaotic generator is depicted in Fig.1. The resonant circuit consists of resistor R1, the inductor L1, and capacitors C1, C2, and C3. The fundamental frequency of the chaotic generator is given as follows:

$$f_0 = \frac{1}{2\pi\sqrt{LC_{eq}}} \qquad (1)$$

where $\mathrm{Ceq} = \mathrm{C1\,C2\,C3}/(\mathrm{C1\,C2} + \mathrm{C1\,C3} + \mathrm{C2\,C3})$.

Applying the Kirchhoff's laws to the oscillator in the schematic diagram of Fig.1, we obtain the following differential equations:

$$\begin{cases} C_1\dot{V}_{C_1} = I_L - \alpha_1 f(V_{BE_1}) \\ C_2\dot{V}_{C_2} = I_L - I_0 + (1-\alpha_1)f(V_{BE_1}) + (1-\alpha_2)f(V_{BE_2}) \\ C_3\dot{V}_{C_3} = I_L + (1-\alpha_1)f(V_{BE_1}) - \alpha_2 f(V_{BE_2}) \\ L\dot{I}_L = V_0 - V_{C_1} - V_{C_2} - V_{C_3} - RI_L \end{cases} \qquad (2)$$

where $\mathrm{V_{BE_i}}\,(\mathrm{i} = 1,2)$ are the base-emitter voltages of each transistor. These voltages may be expressed in terms of the state vector components as: $\mathrm{V_{BE_1}} = \mathrm{V1} - \mathrm{VC2} - \mathrm{VC3}$ and $\mathrm{VBE2} = -\mathrm{VC2}$.

VCi denote the voltages across capacitors Ci, $(\mathrm{i} = 1,2,3)$. f(VBE) is an exponential function expressed by: $\mathrm{I_E} = \mathrm{f(V_{BE})} = \mathrm{I_s}\left(\exp\left(\frac{\mathrm{V_{BE}}}{\mathrm{V_T}}\right) - 1\right)$.

$\mathrm{I_E}$ is the emitter current, and $\mathrm{I_s}$ is the saturation current of the B-E junction. The current source $\mathrm{I_0}$ is used to provide the bias, and $\mathrm{I_L}$ the current flowing through the inductor L. $\alpha_\mathrm{i}\,(\mathrm{i} = 1,2)$ are the common-base forward short-circuit current gains.

By neglecting the base currents and setting $x_i = (V_{C_i} - V_{C_i}^0)/V_T$, $(i = 1,2,3)$; $x_4 = \rho(I_L - I_0)/V_T$; $\rho = \sqrt{L/C_2}$; $t = \tau\sqrt{LC_2}$; $\varepsilon = R/\rho$; $\sigma_1 = C_2/C_1$; $\sigma_2 = C_2/C_3$; $\gamma = \rho I_0/V_T$. The dimensionless state-space representation of (2) becomes:

$$\begin{cases} \dot{x}_1 = \sigma_1(x_4 - \gamma\phi(x_2 + x_3)) \\ \dot{x}_2 = x_4 \\ \dot{x}_3 = \sigma_2(x_4 - \gamma\phi(x_2)) \\ \dot{x}_4 = -x_1 - x_2 - x_3 - \varepsilon x_4 \end{cases} \qquad (3)$$

where

$\dot{x}_1 = dx_i/d_\tau$ and $\phi(y) = \exp(-y) - 1$.

$V_T \approx 26\,mV$ at room temperature. $(V_{C_1}^0, V_{C_2}^0, V_{C_3}^0, I_L^0)$ is the equilibrium point obtained by setting the right-hand side of (2) to zero.

In order to define routes to chaos in the microwave chaotic system under study, equations (3) are solved numerically using the standard fourth-order Runge-Kutta algorithm. Two elements can be used to identify the type of transition leading to chaos. The first indicator is the Lyapunov exponent and the second one is the bifurcation diagram.

1) *Lyapunov Exponents*: We take the initial values of the chaotic system (3) as $(x1, x2, x3, x4) = (0.5, 0.5, 1, 1)$ and the parameter values as $\sigma1 = 4.55$, $\sigma2 = 1$, $\gamma = 5.95$, $\varepsilon = 1.21$. Then the Lyapunov exponents of the chaotic system (3) are numerically obtained as $\lambda1 = 0.46$; $\lambda2 = 0$; $\lambda3 = -0.56$; $\lambda4 = -0.69$. Fig.2 depicts the dynamics of the Lyapunov exponents of the chaotic system (3).
2) *Bifurcation analysis*: Each tiny change of any control parameter of the microwave oscillator deserves to be carefully investigated. Our emphasis is on the effect of γ, which have a strong relation with the biasing current I_0. Therefore, to study the sensitivity of the microwave chaotic system, the chosen control parameter was varied in the interval $0.00 < \gamma < 2.00$. Fig.3 illustrates a simulated bifurcation diagram proving the dependence of the dynamical behaviour of the chaotic oscillator on the control parameter. From Fig. 3, we can observe different behaviours of microwave chaotic oscillator including a one-period solution and orbits of increasing period.

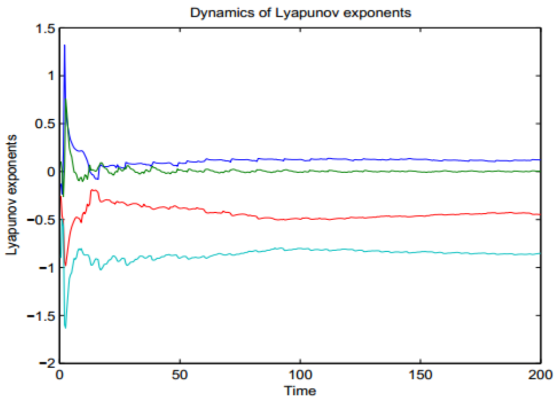


Figure2. *Dynamics of Lyapunov exponents.*

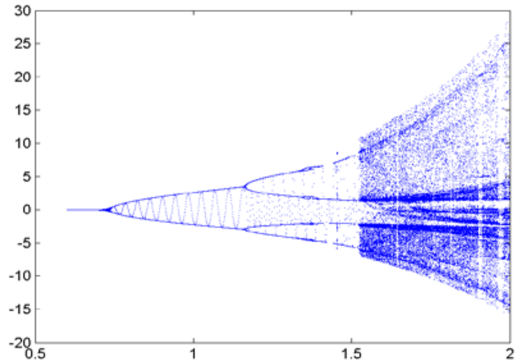


Figure3. *Bifurcation diagram.*

2.1. ADS software simulation

In order to account for the increasing frequency, we use the ADS software simulation in which the transistor is described by a high frequency model. Also, the impact of microstrip critical lines interconnections and active probes are taken into account in ADS simulations. The time series and phase portraits from the ADS simulation are shown in Fig. 6.

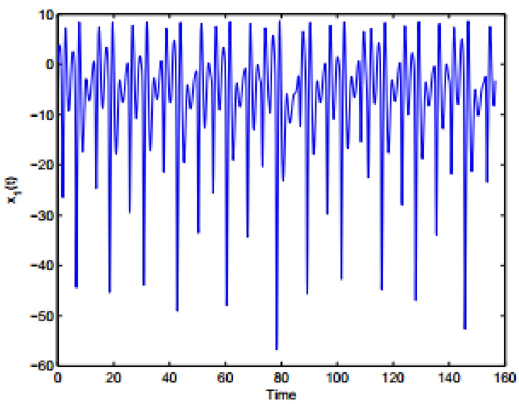
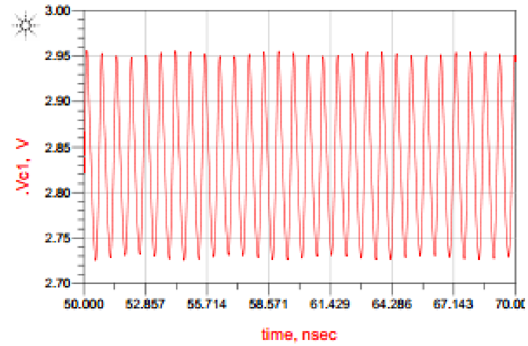
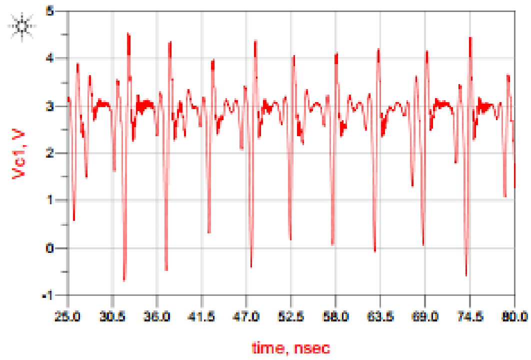


Figure4. *Time evolution of state variables.*



(a)



(b)

Figure6. *Time evolution of state variables.*

Fig. 5 illustrates the effect of the biasing current I_0 (i.e., control parameter γ) on the dynamics of the circuit oscillator. The variation of I_0 is performed by slowly adjusting the voltage V2. When monitoring the biasing current, we can observe that the electronic circuit presents various types of bifurcation. As depicted in Fig. 5, increasing I_0 results to periodic and chaotic regimes. This is clearly shown by time evolution of the dynamical system under investigation.

3. Experimental validation

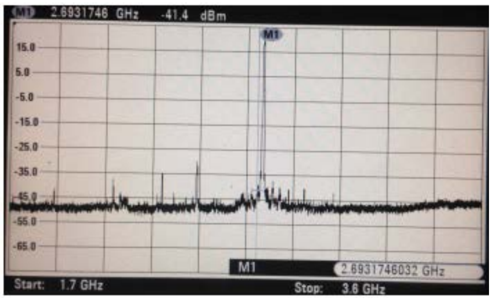
Our aim in this part is to verify the theoretical results obtained previously, by carrying out an experimental study. Experimental measurements have been achieved by using a 12 Ghz – 40 GSa/s oscilloscope Agilent DSO 81204B and a 3.6 GHz spectrum analyzer. Therefore, a buffer is used in order to match oscillator outputs with the measuring devices without altering behaviours of the microwave oscillator. Spectral and time-domain measurements on the 3.6 GHz spectrum analyzer and 12 GHz oscilloscope are achieved. Experimental characterization gives a fundamental frequency of 2.14 GHz. This microwave chaotic oscillator exhibits attractive spectral characteristics.

3.1. Design of the experimental circuit

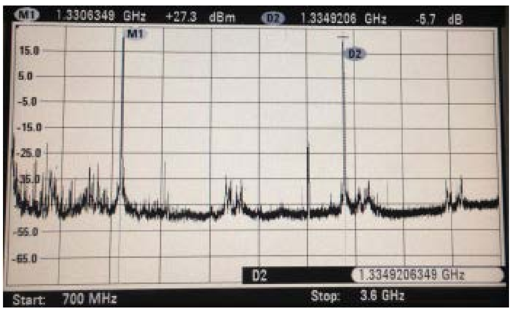
In this section, we expose a hardware implementation of the system (3). Fig.1 illustrates the electronic circuit that has been designed to realize the system (3). The chaotic microwave oscillator was built using the surface-mount devices and BFG520 bipolar junction transistors. Fig.8 shows the real physical prototype designed and implemented on a bread board.

3.2. Experimental results

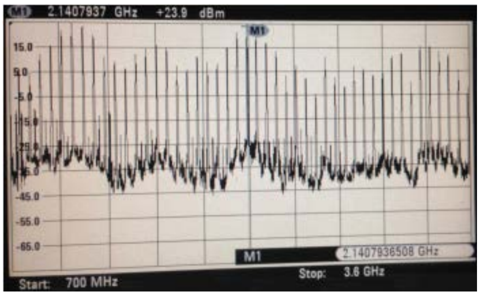
By choosing appropriate values for inductance, resistors, capacitors and voltages: L1 = 15nH, R1 = 47Ω, R2 = 22KΩ, R3 = 33KΩ, R4 = 680Ω, R5 = 33KΩ, R6 = 68KΩ, R7 = 33KΩ, R8 = 68KΩ, R9 = 33KΩ, R10 = 68KΩ, R11= 270Ω, R12 = 270Ω, R13 = 270Ω, C0 = 47nF, C1= 2.2pF, C2 = 10pF, C3 = 10pF, C4 = 1nF, C5 = 1nF, C6 = 1nF,V1 = 4V, and by tiny changing the voltage V2 in (0V...10V) range, we realized an experimental electronic circuit for the system (3).
Spectral and time-domain measurements on the 3.6 GHz spectrum analyzer and 12 GHz oscilloscope are achieved. Experimental characterization gives a fundamental frequency of 2.14 GHz. This microwave chaotic oscillator exhibits attractive spectral characteristics. In Fig. 6 are depicted spectral characteristics of one-period, two-period and chaotic signals, respectively. In Fig. 7, we present the time evolution of the microwave outputs. As in ADS simulation, this figure evinces the effect of the biasing current I_0 (i.e., control parameter γ) on the dynamics of the circuit oscillator. By comparing experimental results of Fig.7 and those obtained numerically from Figs. 4, and 5, it can be concluded that a good qualitative agreement between the numerical simulations and the experimental realizations is obtained.



(a) spectrum of the 1-period output

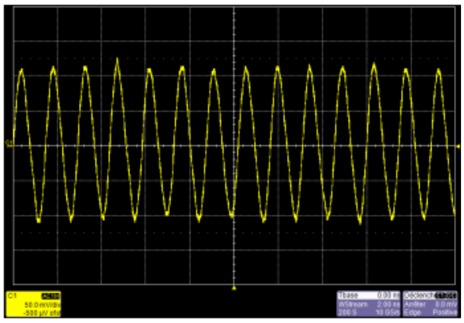


(b) spectrum of the 2-period output

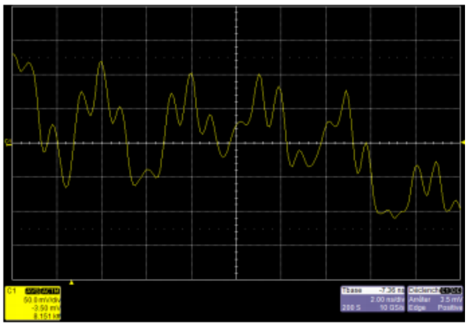


(c) spectrum of the chaotic output

***Figure6**. Spectrum of the microwave oscillator outputs.*



(a) Time evolution of the periodic output



(b) Time evolution of the chaotic output

***Figure7**. Time evolution of the microwave oscillator outputs.*

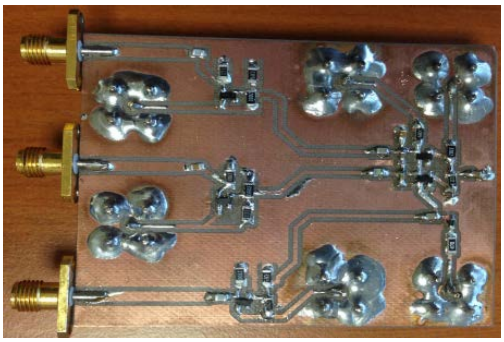


***Figure8**. Electronic circuit of the microwave chaotic oscillator.*

4. Conclusion

In summary, we have investigated the bifurcation structures of a microwave chaotic oscillator. The interest devoted to this type of oscillator is mainly due to its multiple potential applications in engineering and in communications. This

microwave chaotic oscillator exhibits attractive spectral characteristics. The electronic structure of the oscillator was first presented and the modeling process was performed to derive a mathematical model describing the behaviour of the oscillator.
The ADS simulations performed with 9 GHz threshold frequency transistors demonstrate that the highest fundamental frequency is 2.14GHz for the proposed microwave chaotic oscillator.
To highlight the effects of bias on the dynamics of the system, I_0 was chosen as the main control parameter. The analysis revealed the extreme sensitivity of the dynamical behaviour of the oscillator to tiny changes in I_0. A real physical prototype was designed and implemented on a bread board.
For designing and realizing this microwave chaotic oscillator, we have considered, during simulations, the increasing frequency, the impact of microstrip critical lines interconnections and active probes.

Acknowledgement

The authors would like to thank the related editors and anonymous reviewers for their useful comments, which have improved this paper.

References

[1] J-G. Wu, L-J. Zhao, Z-M. Wu, D. Lu, X. Tang, Z-Q. Zhong, and G-Q. Xia, Direct generation of broadband chaos by a monolithic integrated semiconductor laser chip, Opt. Express. 21 (2013) 23358-23364
[2] J. Cao, S. Zhou, D. Inman, and Y. Chen, Chaos in the fractionally damped broadband piezoelectric energy generator Nonlinear Dynamics, Springer Netherlands. 80 (2015) 1705-1719
[3] S-M. Han, O. Popov, A. S. Dmitriev, Flexible Chaotic UWB Communication System With Adjustable Channel Bandwidth in CMOS Technology, IEEE Transactions on Microwave Theory and Techniques. 56-10 (2008)2229 - 2236
[4] F. Caudron, A. Ouslimani, R. Vezinet, and A-E. Kasbari, Chaotic behaviour in receiver front-end limiters, Progress In Electromagnetics Research Letters. 23 (2011) 19-28
[5] S. Grishin, E. Zar'kova, and Y.Sharaevskii, Generation of chaotic microwave pulses in broadband self-oscillating ring system with ferro-magnetic film under the action of external pulse-modulated microwave signal Technical, Physics Letters, SP MAIK Nauka/Interperiodica. 37 (2011) 237-240
[6] Z. Shi, S. Qiao, K. Chen, W. Cui, W. Ma, T. Jiang, and L. Ran, Ambiguity functions of direct chaotic radar employing microwave chaotic colpitts oscillator, Progress In Electromagnetics Research. 77 (2007)1–14
[7] A. Senouci, A. Boukabou, K. Busawon, A. Bouridane, and A. Ouslimani, Robust Chaotic Communication Based on Indirect Coupling Synchronization, CSSP. 34 (2015) 393-418.
[8] M. L'Hernault, J.-P. Barbot, and A. Ouslimani, Feasibility of Analog Realization of a Sliding-Mode Observer: Application to Data Transmission, IEEE Transactions on Circuits and Systems I. 55 (2008) 614-624
[9] T. Jiang, S. Qiao, Z. Shi, L. Peng, J. Huangfu, W. Cui, W. Ma, and L. Ran, Simulation and experimental evaluation of the radar signal performance of chaotic signals generated from a microwave colpitts oscillator, Progress In Electromagnetics Research. 90 (2009)15–30
[10] A. S. Elwakil, M. P. Kennedy, Inductorless hyperchaos generator, Microelectronics Journal. 30 (1999)739–743
[11] F. R. Tahir, S. Jafari, V-T. Pham, C. Volos, and X. Wang, A Novel No-Equilibrium Chaotic System with Multiwing Butterfly Attractors, International Journal of Bifurcation and Chaos. 25-4 (2015)
[12] M. P. Kennedy, Chaos in Colpitts oscillator, IEEE Trans. Circuits Syst. I. 41 (1994)771–774
[13] S. Bumeliene, A. Tamasevicius, G. Mykolaitis, A. Baziliauskas, and E. Lindberg, Numerical investigation and experimental demonstration of chaos from two-stage Colpitts oscillator in the ultrahigh frequency range, Nonlinear Dyn. 44 (2006)167–172
[14] J. X. Li, Y. C. Wang, and F. M. Chang, Experimental demonstration of 1.5 GHz chaos generation using an improved Colpitts oscillator, Nonlinear Dynamics. (2013)
[15] J. Kengne, J. C. Chedjou, G. Kenne, and K. Kyamakya, Dynamical properties and chaos synchronization of improved Colpitts oscillators, Commun Nonlinear Sci. Numer. Simul. 17 (2012)2914–23
[16] A. Buscarnio, L. Fortuna, M. Frasca, and G. Sciuto, Coupled inductor based Colpitts oscillator, Int J Bifurcation Chaos. 21 (2011)569–74
[17] G. M. Maggio, O. D. Feo, and M.P. Kennedy, Nonlinear analysis of the Colpitts oscillator and applications to design, IEEE Trans Circuits Syst – I. 46 (1999) 1118–29.