Design of a Microwave Chaotic Oscillator using Symmetric Active Load

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Abstract: - In this paper, a microwave chaotic oscillator with symmetric active load is presented. Compared to the classical Differential bipolar Chaotic Colpitts Oscillator (DCCO) produces anti-phase dual output carriers with intense chaotic behaviour, better linearity and very good encryption capabilities. Advanced Design System (ADS) 2008 Update 1 simulations performed up to 30 GHz, which demonstrate the effectiveness of DCCO with symmetric active load.

Key-Words: Microwave*,* Chaos, Differential Chaotic Colpitts Oscillator, Active Load, AC Load, Current Source.

1 Introduction

Chaos in the Colpitts oscillator, first reported in [1], has recently attracted a lot of interest due to its applications in encryption and modulation methods applied to communication systems for high security systems such as military. In this paper we propose a microwave version of the chaotic Colpitts oscillator with active load, by using BJTs type of pnp and npn. The proposed circuit adds functionality to the classical balanced Colpitts oscillator in the sense that it produces anti-phase signals with larger fluctuations of output signal, showing bigger chaotic performance. There are many topologies of high frequency chaotic oscillators that have been developed in the past. One of them includes the single-transistor microwave chaotic oscillator which produces band-limited power spectrum [6]. Moreover, a two-stage chaotic Colpitts oscillator, which was presented some years ago, enables the fundamental frequency of chaotic oscillations to be increased by a factor of three and can give i.e. chaotic fundamental frequencies of 3 GHz. In addition to that, chaotic behaviour has been reported in Colpitts Oscillators at VHF and UHF frequency bands. This has been confirmed experimentally [7].

A previous topology of balanced chaotic Colpitts oscillator using passive R load has been proposed [5]. In comparison to that topology, the novel one proposed at this paper, gives much higher fundamental frequency of chaotic oscillations. Moreover, several proposed chaos-based modulation schemes, including Differential Chaos Shift Keying [2], [3] and Differential Noise Shift Keying [4], require the generation of a chaotic waveform at a high frequency and its inverted signal.

Traditionally, balanced signals are obtained by the use of passive or active baluns, with the latter being often more complex and sensitive to the operating condition. Balanced oscillators providing anti-phase outputs can eliminate the need of baluns. Based on this topology, the microwave symmetric oscillator of this paper with active load at the collector of the main BJT differential pair, gives capability for anti-phase outputs with intense chaotic behaviour, instead of using resistor R as in the case of [5].

The outline of this paper is as follows: Section 2 describes the circuit design whereas simulation results are presented in Section 3. Finally, Section 4 gives a conclusion with useful remarks from the paper.

2 Circuit Design

The proposed Microwave Chaotic Oscillator with symmetric Active Load is shown in figure 1. As it is known, a differential output can be produced by coupling two identical Colpitts oscillators and sharing their emitter to ground capacitors. Since the center node, where both capacitors are connected together, is a differential virtual ground, the original operation of the oscillators remains unchanged when the two sides oscillate 180^0 out of phase. The differential operation will be guaranteed if the center node is left floating and not grounded.

Noting that the current through the main transistors, Q1 and Q2, in each of the one transistor Colpitts oscillators flows for less than the half of the oscillation period, is possible and favorable to replace the emitter-to-ground dc current sources by one dc current source and a timed switch which alternates the current between the two sides of the oscillator as it has been proposed in [5]. The threshold frequency of this time switched pair is very crucial because it does change the frequency of operation of the chaotic oscillator. If we use timed switch transistors with higher ft then the chaotic behaviour increases and the possibility for higher fundamental frequency of oscillations can be achieved with correct use of feedback loop components such as capacitors and inductors.

In figure 1, at the collectors of the differential pair, 2 BJTs (Type PNP 2N2904 of National Semiconductors) are used as active loads giving an AC load which has a high value while the DC voltage drop is small. This do not happen when we use a large passive load as i.e. a large resistor. Such large AC load impedance is desirable in order to increase the AC gain in the circuit in contrast to the linear resistors that are used at the classical Differential Chaotic Colpitts Oscillator of [5].
In other words, the active load increases the AC gain of amplifying transistor pair and changes the oscillator dynamics giving intense chaotic signal output. The collector of the differential pair of the oscillator is biased at a high DC voltage value, allowing a high voltage swing at the output. This voltage swing increases also the output compression point of the oscillator and thus the linearity of the system.

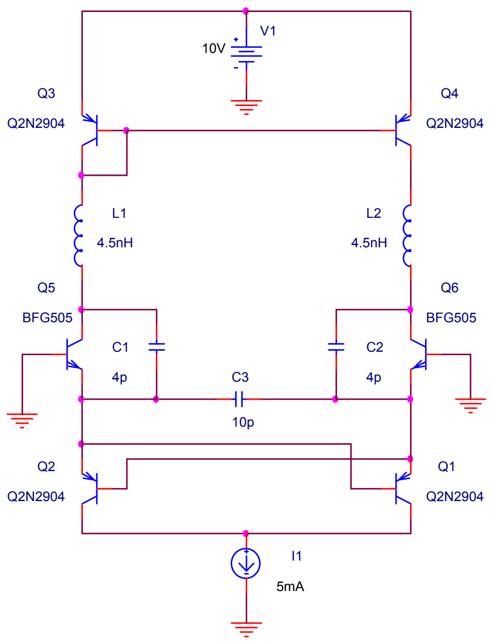

Fig. 1. Circuit Layout of the Differential Chaotic Colpitts Oscillator with Active Load.

The main transistors that produce the chaotic carriers are the Q5 and Q6 (Type NPN BFG425W of Philips). The current of Q5 and Q6 are controlled by a pair of Q3 and Q4 (Type PNP 2N2904). Moreover, the negative resistance of this tail cross-coupled pair provides a very effective means to enhance the signal loop gain, improving the start-up condition. The use of one current source facilitates the circuit implementation and provides the same current flow to the output transistors, thus enhancing the quality of the output signals. The main characteristics of the transistors that are being used in the circuit are shown in Table 1.

Type of BJT	BFG425W NPN	2N2904 PNP
Ft	25 GHz	200 MHz
Capacitance (CB)	300 fF	8 pF
Capacitance(EB)	575 fF	30 pF
Bf	145	90.73
Vce(max)	4.5 Volt	40 Volt
Ic(max)	30 mA	600 mA

Table 1. Electrical Characteristics of the two transistors that are being used [9], [10].

The fundamental frequency of the proposed Chaotic Balanced Colpitts Oscillator with Active Load can be calculated as:

$$f = \frac{1}{2\pi\sqrt{L_1 \frac{C_3 2C_1}{C_3 + 2C_1}}} = 1.125GHz \quad (1)$$

3 Simulated Results

In order to assess the behaviour of the chaotic oscillator we used the Advanced Design System (ADS) 2008 Update 1 of Agilent, which is based on a p-spice engine. Fig. 2 depicts the anti-phase outputs of the simulated Microwave Chaotic Oscillator with symmetric Active Load circuit. As it is obvious, the outputs from the collectors of Q5 and Q6 are 180^0 out of phase.

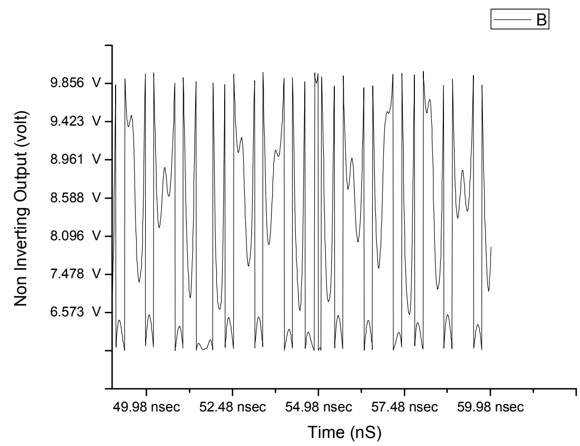

Fig. 2. (a) Time domain signal of the non inverting output

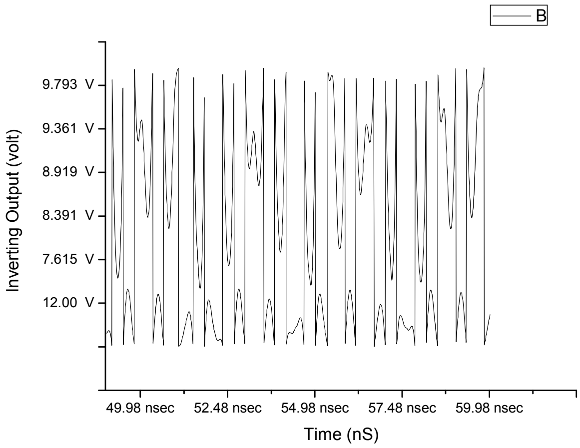

Fig. 2. (b) Time domain signal of the inverting output

In fig. 3 we plot the current signals that pass through the inductors L1 and L2: I_Probe1.i & I_Probe2.i and exist at the collectors of the main differential pair. It is obvious the 180 degree out of phase for the two cases of current graphs.

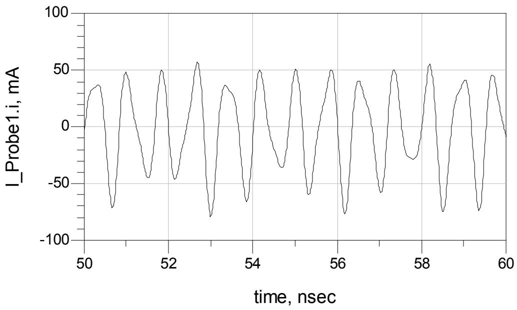

Fig. 3(a) Current versus time for the non-inverting output

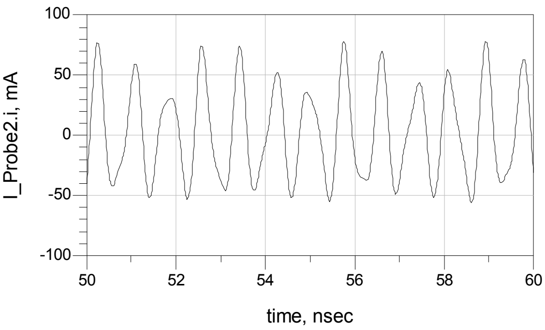

Fig. 3(b) Current versus time for the inverting output

In fig. 4 the voltage signals versus time at the collectors of the current mirror are shown.

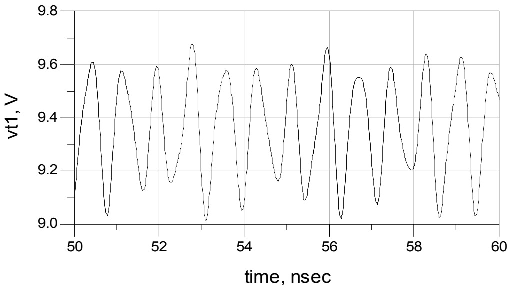

Fig. 4(a) Voltage versus time at the current mirror collector for the non-inverting part of circuit.

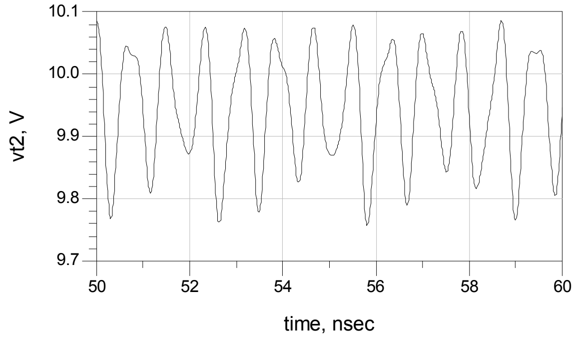

Fig. 4(b) Voltage versus time at the current mirror collector for the inverting part of circuit.

In fig. 5 we plot the output power spectrum for one output signal –the Non inverting output, and we can see the fundamental frequency of operation at 1.1 GHz which is close to the expected value from the equation (1). We can also see higher frequency harmonics up to 30 GHz giving intense chaotic behaviour.

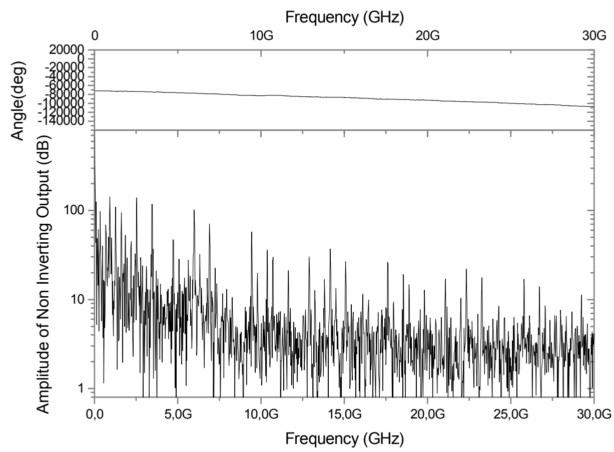

Fig. 5. Output spectrum of the non inverting output of microwave chaotic oscillator with symmetric active load.

In fig. 6 we plot the phase portrait of Vc-Ve for each BJT transistor of the differential pair (Voltage Collector versus the Voltage of Emmiter) both for the Inverting and the Non Inverting output. As can be concluded, the chaotic nature of signal is obvious, with big variations of amplitude of the output signal:
(a) From 6.5 Volts up to 12 Volts for the Non Inverting output
(b) From 7 Volts up to 13 Volts for the Inverting output

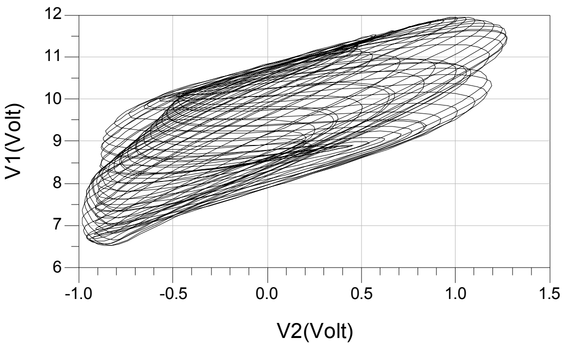

Fig. 6. (a) Phase portrait of the collector voltage versus the emitter of the Non Inverting output.

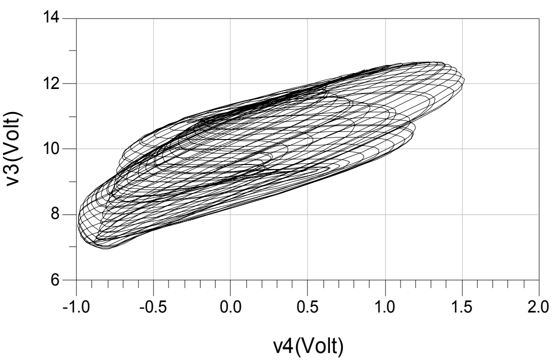

Fig. 6. (b) Phase portrait of the collector voltage versus the emitter of the Inverting output.

4 Conclusion

A Microwave Chaotic Oscillator with symmetric active load has been proposed and is capable of producing anti-phase signals. The presented circuit design has numerous advantages such as the intense chaotic behaviour of the output signal because of the use of Active Loads instead of passive resistances and the improvement of the linearity and compression at the output of the oscillator in comparison to [5]. These factors can give more capabilities for secure and encrypted communication systems such as the military systems.

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References:

1 Kennedy M. P.: "*Chaos in the Colpitts oscillator*", IEEE Trans. Circuits and Systems, vol. 41, pp. 771–774, Nov. 1994

2 Kolumban G.,.Kennedy M. P and Chua L. O.: "*The Role of Synchronization in Digital Communications Using Chaos—Part II: Chaotic Modulation and Chaotic Synchronization*", IEEE Trans. Circuits and Systems, vol. 45, pp. 1129–1140, Nov. 1998.

3. Galias Z and. Maggio G. M.: "*Quadrature Chaos-Shift Keying: Theory and Performance Analysis*", IEEE Trans. Circuits and Systems, vol. 48, pp. 1510–1519, Dec. 2001

4. Shimming T and. Hasler M.: "*Optimal Detection of Differential Chaos Shift Keying*", IEEE Trans. Circuits and Systems, vol. 47, pp. 1712–1719, Dec. 2000

5. O. Tsakiridis, E. Zervas, M. Koutsioumpos and J. Stonham.: "*Design of a Chaotic Balanced Colpitts Oscillator*", WSEAS Trans. on Circuits and Systems, vol. 3, pp. 839-841, June 2004.

6. A. I. Panas, B. Ye. Kyarginsky, and N. A. Maximov, "Single-transistor microwave chaotic oscillator", *Proc.NOLTA-2000*, Dresden, Germany, vol. 2, pp. 445-448, September 17-21, 2000

7.Tamaševičius, A., Mykolaitis, G., Bumelienė, S., Baziliauskas, A, Krivickas, R., and Lindberg, E., 'VHF and UHF chaotic Colpitts oscillators', in *Proceedings of the 12th International Workshop on Nonlinear Dynamics of Electronics Systems*, Évora, Portugal, May 9–13, 2004, pp. 328–331.

8. O. Tsakiridis, V. Stefanidis, E. Zervas and J. Stonham: "Single-Ended Chaotic Colpitts Oscillator with Active Load", *The 11th Experimental Chaos and Complexity Conference,* Lille, France, June 1-4 2010 (accepted).

9. Datasheet of PNP 2N2904 of National Semiconductors (http://www.national.com/analog)

10. Datasheet of Type NPN BFG425W Wideband transistor of Philips Semiconductors (www.nxp.com).