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Nonlinear Dynamics of a BJT Based Colpitts Oscillator with Tunable Bias Current

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Abstract*—The effect of bias current variation in the dynamics of a conventional BJT based Colpitts Oscillator (CO) has been thoroughly examined in this paper. After formulating a suitable ac equivalent model of the CO taking care of the dc bias current, the dynamics of the system has been numerically studied. It is observed that in a CO circuit with given design parameter, a periodic oscillation starts for a critical bias current and with the variation of the bias current to a higher value chaotic oscillations are observed through a period doubling root. A prototype hardware experiment in the low RF band CO supports the observations obtained by the numerical simulations. The change in chaoticity with the variation of the operating bias current is observed by finding Maximum Lyapunov exponent (MLE) from numerically and experimentally obtained time series of the CO output data. The technique of bias current variation could be applicable in any frequency range including Microwave band, in principle and it has important application potential in chaos based communication systems for encoding information bits into chaotic signals.

Index Terms*— Bias current tuning, Chaotic Colpitts oscillator, Maximum Lyapunov exponent Nonlinear trans-conductance model of BJT, period doubling route to chaos.

I. INTRODUCTION

The use of chaotic signals in broad band secure communication systems is being explored during last few decades[1,2] and as such, the problems of generation, modulation and synchronization of chaotic oscillations in the RF and microwave frequency band have received considerable attention from the researchers in recent years[3-4]. In this respect, the design of BJT based Colpitts Oscillators (CO) as chaos generators is well documented in the literature [5-7].The research on chaotic COs is concerned with some technological aspects important from application point of view like the enhancement of the upper limit of chaotic signal frequencies, the extension of the bandwidth of chaotic signals, the simplicity and controllability of the adopted circuits etc. As a result, the range of frequency of the chaos, generated by a BJT based CO has increased from low and medium RF range (10 kHz-10 MHz) to high and ultra high frequency range (10MHz- 1000MHz) [8-9]. Moreover, some novel circuit modifications have been proposed to overcome the limitation due to the BJT transition frequencies [10-11].

Further, the role of device nonlinearity on the CO dynamics, chaotic properties of two stage CO, their synchronization behavior etc have been studied in the literature [12-13].

But, to the knowledge of the authors, the effect of variation of operating dc bias current on the dynamics of a CO has not been thoroughly investigated. It is anticipated that the bias current tuned COs have rich application potential in chaos based communication systems, where mapping of the information bits as chaotic signals is an important design requirement. For this purpose, an electrical control of some design parameters of chaos generator circuits would obviously be of importance. In the present work, the bias current tuning technique of a BJT based CO as a means of the variation of the dynamics of the CO has been thoroughly studied. The principle of operation of the technique discussed here is not limited to any frequency band and can well be applied to microwave range CO. However, experimental studies reported in the paper is at low RF band, without any loss of generality.

The paper has been organised in the following way. In section 2, developing a suitable model of the active device accounting the effect of bias current variation, system equations of the CO circuit are formulated. Section 3 describes a linear analysis of the system equations. It provides the values of the system parameters required for the transition from a stable non-oscillatory to an unstable oscillatory state. In section 4, system equations are studied through numerical simulation. It has been observed that the CO shows different complex behaviours like period doubling and chaos for certain range of values of the bias current control parameters. To verify the observed complex dynamics as chaos, chaos quantifier like Maximum Lyapunov Exponent (MLE) is evaluated from the numerically obtained results using the commercial Chaos data analyser software by J C Sprott [14]. The details of experimental studies are given in section 5. Experimental output waveforms of the CO have been captured by spectrum analyser and also by a data acquisition system (DAS) along with Lab View software. The obtained data are then analysed using [14] and the results confirm the occurrence of different chaotic states of the oscillator with the variation of bias current. Experimental observations are in good agreement with the numerically simulated results. Finally, the outcome of the study has been discussed in the concluding section 6.

II. DERIVATION OF SYSTEM EQUATIONS

Fig 1(a) shows the configuration of the BJT based current controlled CO under study. Here, a current mirror type biasing circuit of the CO is used to control the oscillator dynamics [15].

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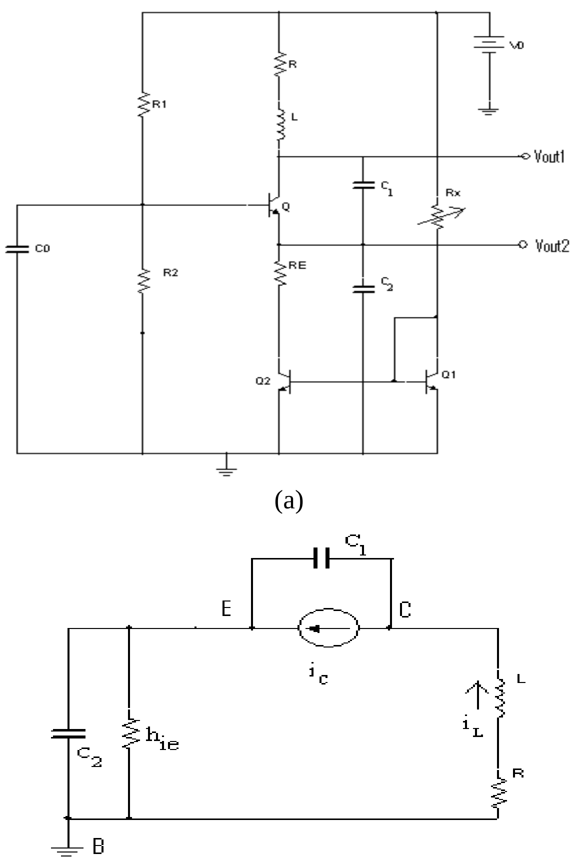
The basic oscillator circuit contains a BJT (Q), a load resistor R and a resonant circuit consisting of an inductor L and a pair of capacitors C_1 and C_2. The current mirror biasing circuit is designed using two BJTs (Q1 and Q2) and a variable resistor Rx. To analyze the system dynamics the hardware circuit is replaced by its ac equivalent model shown in Fig 1(b). It takes into account the effect of variation of bias current. A set of differential equations is formulated from this equivalent circuit for subsequent analysis.



(a)

(b)

Fig. 1: (a) Circuit diagram of the Current Controlled BJT based Colpitts Oscillator (In the Hardware experiment, values of the components taken are respectively: V0=5.2 volts, R1=R2= 1.2KΩ, R=10Ω, RE=10Ω, C0=1μF, L=0.055mH, C_1=C_2= 0.1μF, Rx= 10kΩ pot,Q,Q1and Q2 are 2N2222A NPN transistor;Vout1= V_{C1}+V_{C2} & Vout2= V_{C2}) (b) ac equivalent circuit of the BJT based Colpitts Oscillator.

A. Model of the active device Figures

In earlier works [3, 6] the active device (BJT) of the CO is replaced by a nonlinear resistor between the base and the emitter terminal and a current controlled current source between the collector and the base points. In our work, we take the familiar trans-conductance model [16] of the transistor where the collector current (i_c) is considered as a nonlinear function of the base emitter voltage (v_{be}). The parameters used to connect v_{be} with i_c are dependent on the operating bias current *(I)* of the BJT. Hence, the variation of controlling bias current could be mathematically taken into account through proper varied magnitudes of these parameters. To make the choice of parameter values for the BJT taken in the circuit realistic we measure the variation of i_c with that of v_{be} for different *I* in a 2N2222A transistor based experimental circuit using PSPICE software.

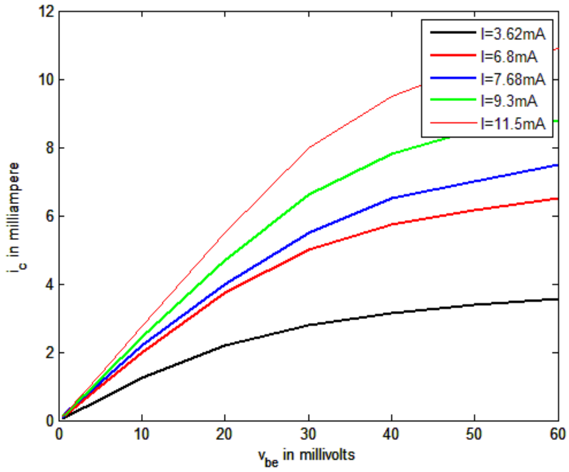


Fig 2: Variation of i_c with v_{be} of 2N2222A transistor for different dc bias current

For mathematical description of these experimentally obtained transfer characteristics, we choose i_c as power of v_{be} having linear and cubic terms with suitable weight parameters. The quadratic term is not taken to ensure the odd symmetric nature of i_c as a function of v_{be}. By proper choice of these aforesaid parameters, we write the relation of i_c as

$$i_c = ag_{m10}v_{be} - bg_{m10}v_{be}^3 \qquad (1)$$

Here, *a* and *b* are bias current dependent parameters. Intuitively magnitude of b is much less than that of *a*, since the response is linear for small values of v_{be}. g_{m10} is the trans-conductance of the BJT at the quiescent bias current (I_0). We have taken I_0 as the dc bias current required for steady sinusoidal oscillation of the CO shown in Fig1(a).The numerical values of *a*, *b* and g_{m10} for different *I* values are determined by optimal fitting of the experimental curves with the relation given in (1) after properly taken value of I_0. The set of values of *a* and *b* obtained for different bias currents are given in Table I. These values are used to compare the dynamics of the CO obtained experimentally and numerically for different bias currents. The experimental results for a particular *I* are compared with the numerical results obtained with corresponding *a* and *b*.

Table I: Variation of the parameters *a* and *b* for different dc bias current (*I*)

I_0=3.0 *mA*

I in *mA*	1.5	2.93	3.62	6.8	7.68	9.3	11.35
a	0.79	0.91	1.21	2.28	2.32	2.47	2.60
b	0.07	0.08	0.16	0.22	0.24	0.25	0.26

B. System equations

The ac equivalent circuit of the CO for a particular bias current is shown in Fig 1(b). Here, h_{ie} denotes the ac resistance between emitter and base terminal due to the device and i_c is the v_{be} dependent nonlinear current source as expressed by equation (1). The effects of junction capacitance are not explicitly considered because their magnitudes are very small and their reactances are very high at the frequency of operation of the CO.

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The dynamics of the system is described by the following set of first order nonlinear autonomous differential equations:

$$\dot{v}_{c1} = -(i_L - g_{m1}v_{c2} + g_{m3}v_{c2}^3)/C_1 \tag{2a}$$

$$\dot{v}_{c2} = -i_L/C_2 - \dot{v}_{c2}/h_{ie}C_2 \tag{2b}$$

$$\dot{i}_L = (v_{c1} + v_{c2})/L - Ri_L/L \tag{2c}$$

Here v_{C1} and v_{C2} are the voltages across C_1 and C_2 respectively and i_L is the load current. We normalize voltage variables by v_T (temperature equivalent of voltage i.e. kT/q [16]) and the current variable by I_0 (mentioned earlier) to get dimensionless state variables x, y and z. In terms of these variables the state equations can be obtained in the dimensionless form as follows:

$$\dot{x} = -g(z - ay + by^3)/Q(1-k) \tag{3a}$$

$$\dot{y} = -gz/Qk - h_r y/Qk \tag{3b}$$

$$\dot{z} = Qk(1-k)(x+y)/g - z/Q \tag{3c}$$

We have substituted

$\tau = \omega_0 t$, $\omega_0^{-1} = \sqrt{LC_1C_2/(C_1+C_2)}$, $x = v_{c1}/v_T$, $y = v_{c2}/v_T$, $z = i_L/I_0$, $h_r = L/(R(C_1+C_2)h_{ie})$, $g = LI_0/(R(C_1+C_2)v_T)$, $Q = \omega_0 L/R$, $k = C_2/(C_1+C_2)$

The parameters g , ω_0 and Q are the amplifier gain, resonant frequency and the quality factor of the resonant circuit respectively.

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III. STABILITY OF THE EQUILLIBRIUM POINTS OF THE SYSTEM WITH THE VARIATION OF BIAS CURRENT

In the analytical study of the CO dynamics, first we evaluate the equilibrium points (x *, y *, z *) in the three dimensional state space by equating the time derivatives of the state variables x , y , z to zero in (3). This gives three possible equilibrium points P1, P2 and P3 respectively where P1 is (0, 0, 0) while P2 and P3 are given by expressions written

$$(\mp\{\frac{(n/Q)(\sqrt{a/b}}{k(1-k)} + \sqrt{\frac{a+(n/m)}{b}}\}, \pm\sqrt{\frac{(a+(n/m)}{b}}, \mp\frac{n\sqrt{a/b}}{m})$$

respectively. Here, n and m are substituted for (h_r/Q) and (g/Q) respectively. Next we formulate the Jacobean matrix of the system described by (3) at respective equilibrium points and derive the eigen values of the characteristic equation. The characteristic equation is,

$$\begin{vmatrix} -\lambda & (a-3by^{*2}) & -1 \\ 0 & -\frac{n}{k}-\lambda & -\frac{m}{(1-k)} \\ k & \frac{k(1-k)}{m} & -\frac{1}{Q}-\lambda \end{vmatrix} = 0 \tag{4}$$

Here, y^* indicates the value of y at a particular equilibrium point and λ's represent the eigen values. Expanding (4) we obtain

$$\lambda^3 + p\lambda^2 + q\lambda + r = 0 \tag{5a}$$

Where,

$$p = n/k + 1/Q, q = n/Qk + 2k, r = n + mk(a - 3by^{*2})/(1-k) \tag{5b}$$

The nature of the roots of the characteristic equation 5(a) is obtained by applying the Routh-Hurwitz's criteria [17], and hence the stability of a particular equilibrium point can be predicted. The equilibrium point would be stable if the roots of 5(a) have negative real parts. According to Routh-Hertz criteria, this is possible if,

$$p > 0, q > 0, r > 0, (pq - r) > 0 \tag{6}$$

For the equilibrium points P2 and P3, although p and q are always positive but the value of r (= -2(*n* +*amk* /(*1-k*)) is always a negative quantity. So, we would not get any stable state for the system about P2 and P3. At the equilibrium point P1, values of p, q, r are,

$$p = (n/k + 1/Q), q = n/Qk + 2k, r = n + amk/(1-k) \tag{7}$$

As p , q , r are always positive then to get a stable state of the system, $(pq - r)$ should be greater than zero. Varying the magnitude of a one can change the value of $(pq - r)$ from positive to negative through zero. Thus the system would become unstable from a stable condition by the variation of a (i.e. the bias current). The critical value of a (a_c) is obtained by equating $(pq - r)$ to zero. It gives,

$$a_c = (1-k)/mk[(n/Q)^2/Q + (n/k)/Q^2 + n + (2k)/Q] \tag{8}$$

At $a = a_c$, the real parts of the pair of complex roots of (4) become zero (from negative value) leading to limit cycle of oscillation of the system. This is well known Hopf bifurcation of the nonlinear system. From (8) it is evident that, in limit cycle condition of CO, the product of the two parameters, g and a_c becomes unity as one neglects small quantities. This observation is equivalent to the observation as obtained in [6]. Fig 3 shows the nature of the variation of a_c with the Q factor of the oscillator tank circuit. However, the complete picture of the CO dynamics can be understood from

the detailed nonlinear analysis of the system equations.

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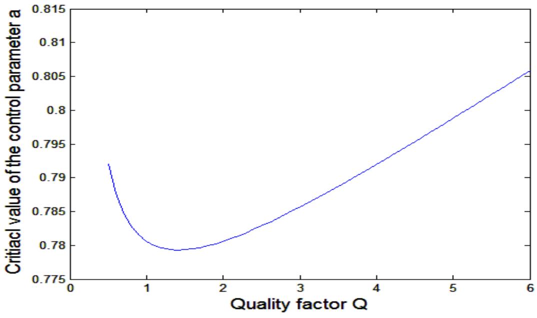
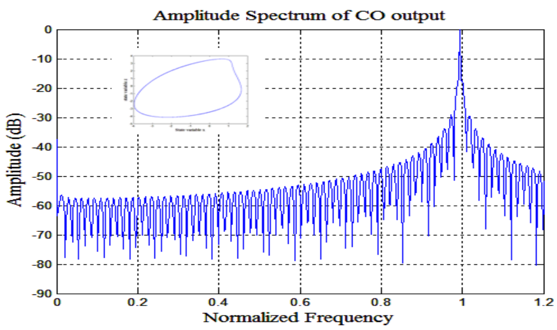


Fig 3: Variation of the critical value of the control parameter (a_c) with Q factor of the tank circuit for transition of CO dynamics from stable to oscillatory mode.

IV. NUMERICAL ANALYSIS

To understand the effect of bias current variation beyond the above mentioned critical value, one has to analyse system equations (3) without any linear approximations. However, the numerical solution of these equations for a judiciously chosen set of system parameters can throw much light into the dynamics of the system. For this purpose the set of equations (3) has been solved using 4th order Runge-Kutta algorithm in the normalized time domain. To obtain steady state values of the state variables, a good number of values close to t =0 have been discarded for rejection of initial transients. The values of the parameters k, g, Q and h_r have been chosen taking the elements of the experimental hardware circuit into consideration (described in section 5). It is observed that for a < 0.79, the state variables are fixed at (0, 0, 0), indicating a stable equilibrium state. At a =0.795 the obtained time development of the state variable z has become unstable and a limit cycle of oscillation of very small amplitude is observed. This value of *a* is nearly identical with that as predicted in (8). Fig 4(a) to Fig 4(d) depicts respectively the numerically obtained results for different bias current. They include the frequency spectrum of the state variable z and the state- space trajectories in x - z plane as shown in the inset of each figure. Each simulation experiment has been carried out taking values of the parameter a and *b* as indicated in Table 1. With the increase of the value of a, the amplitude of oscillation increases but the change in frequency is negligible. With gradual increase in the value of a, Period-1 oscillations (Fig 2(a)) are converted to multi-period oscillations through a period doubling route. This is evident from the results shown in Fig 2(b) (Period-2), Fig 2(c) (Period-4) and Fig 2(d) (chaotic, as broad band spectrum is observed) respectively.



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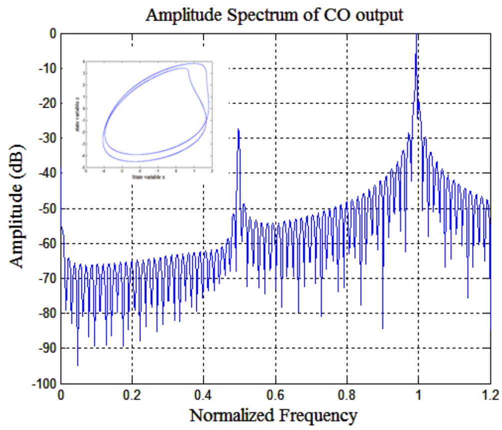

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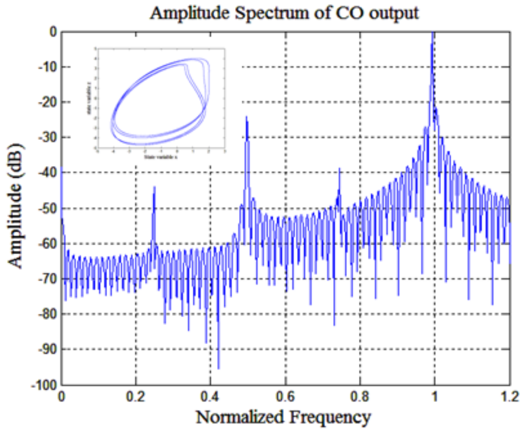

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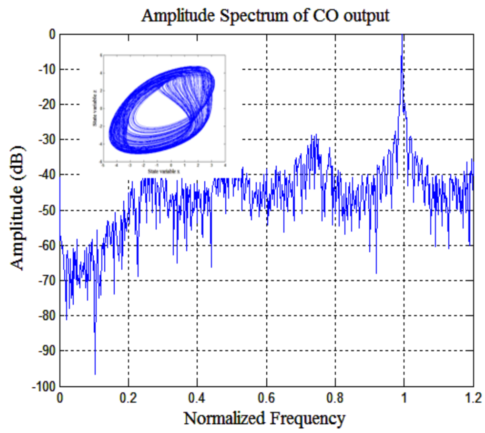

(d)

Fig 4: Numerically computed Frequency spectrum of z and State space trajectory in the x-z plane (inset) for different values of the bias current control parameter *a*

(a) *a*= 2.22, (b) *a*=2.28, (c) *a*= 2.32, (d) *a*=2.47

[g=1.32, Q=4.0, k=0.5, h_r=0.04, b=0.2]

To obtain a complete picture of the CO behavior with the change in bias current, a one dimensional bifurcation diagram of the oscillator output with a as control parameter is drawn. In the program, for solving the system equations (3), the value of a has been increased in small steps (0.001) and the steady state output of z is examined for each value of a. The local maxima of oscillating z in time domain have been obtained and plotted along y axis for corresponding a as shown in Figs 5(a) and 5(b) respectively.

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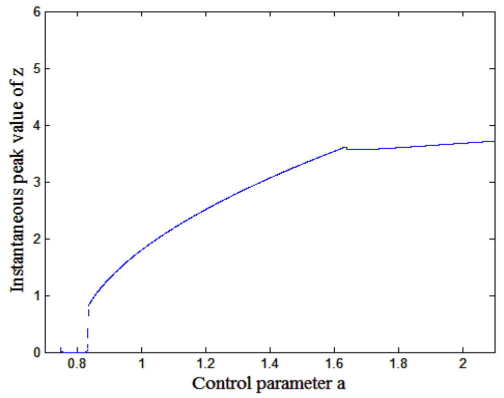
Fig 5(a) shows variation of z in the range of a from 0.7 to 2.1. From this figure, the nature of generation of oscillation from a non oscillatory condition can be observed. In Fig 5(b), CO dynamics is examined with the variation of control parameter a from 2.0 to 2.6.



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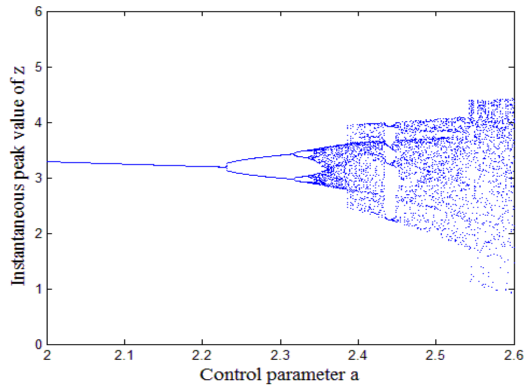

(b)

Fig 5: Bifurcation diagram of the oscillator output for the range of control parameter *a* (a) from 0.7 to 2.1, (b) from 2.0 to 2.6 (g=1.32, Q=4.0, k=0.5, h_r=0.04)

It shows the Period-1 behavior remains up to a =< 2.25, Period-2 behavior is observed for 2.26 < a < 2.31, Period-4 for 2.31 =< a < 2.35and chaotic oscillations are obtained for a >= 2.36. Table II presents the obtained results of the numerical analysis in summarized form. It indicates the range of bias current and corresponding values of the parameter *a* (as is given in Table I) for different dynamics of the CO with the variation of bias current.

Table II: Numerically obtained different ranges of the control parameter *a* and bias current *I* for different dynamics of the CO

Range of a	0.79-2.25	2.28-2.30	2.31-2.35	2.36-2.60
Range of I in *mA*	1.5- 6.7	6.8-7.67	7.68-8.9	9.0-11.35
Nature of oscillation	Period-1	Period-2	Period-4	Chaotic

Further, nature of complexity of the dynamics of the system is examined for the range of a from 2.36 to 2.6 (where the CO shows chaotic behavior) by finding the Maximum Lyapunov Exponent (MLE) using [14].The obtained results are given in the Table III below:

Table III: Numerically computed values of MLE for different values of the control parameter *a* indicating variation of chaotic state:

Control parameter a	2.40	2.45	2.50	2.55	2.60
MLE	0.045	0.050	0.070	0.108	0.112

The increase in the positive values of MLE with the increase of the control parameter a confirms that a variation of chaotic dynamics in the CO is possible by tuning the bias current.

V. EXPERIMENTAL STUDIES

The hardware experiment is performed using the circuit as shown in Fig 1(a). The basic CO circuit is based on a 2N2222A type transistor (Q) (f_T =300MHz) and is designed using passive components like an inductor (L), capacitors (C_1, C_2 and C_0), resistors R_1, R_2. The current mirror circuit is designed using a pair of identical transistors and a variable resistor R_X. By varying R_X, the bias current (I) of the CO can be varied. At first, the variation of I is calibrated with the variation of Rx. Then, varying the current I in the current mirror circuit, the dynamics of the CO is examined by noting the variation of the frequency (f) and the peak amplitude (A) of the oscillator output. For I <1.45 mA, no oscillation is observed at the CO output. As I cross this limit, building up of oscillation starts. It has been observed at I =1.49 mA, f and A of the oscillator are 97 KHz and 0.06 volts respectively. With further increase of I , both f and A of the oscillator output are increased. However, rate of increase of the frequency of oscillation is very small compared to the change in its peak amplitude. The value of I at which peak amplitude of the oscillator output remains almost steady is considered as its quiescent bias current. It has been observed at I =3.0 mA, f and A of CO are respectively 100 kHz and 1.42 $volts$. As I increases, Period-1 oscillation of the CO remains up to I=5.5 mA and when I becomes greater than 5.5 mA, Period-1 oscillation transits to Period-2 and with further increase in I , Period-4 (at I =8.0 mA), Period-8 (at I =8.7 mA) and then chaotic behavior (at I =9.0 mA) are visualised at the CO output. These observations are obtained from the time development of the oscillator output voltage (proportional to the current i_L), the state space trajectories between the voltage ($v_{C1}+v_{C2}$) and the voltage v_{C2} and the spectral characteristics of the oscillator output. Some of these observations are given in Fig 6(a) to Fig 6(d) respectively.

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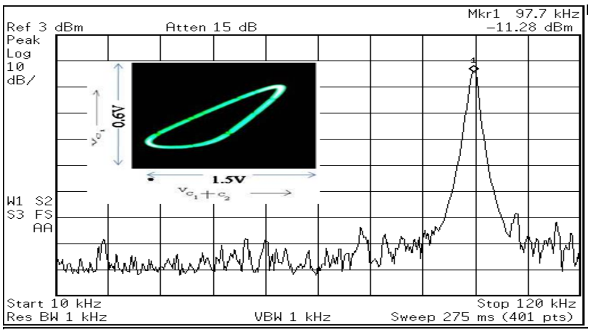

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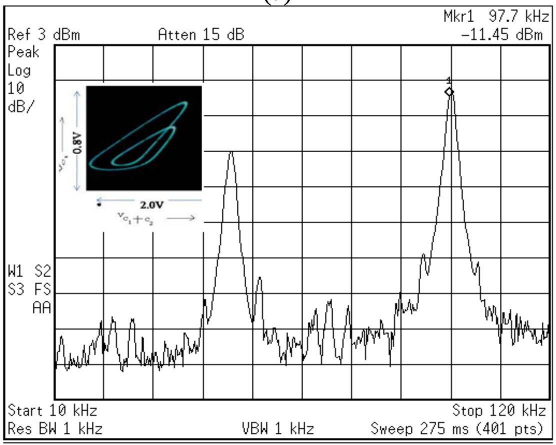

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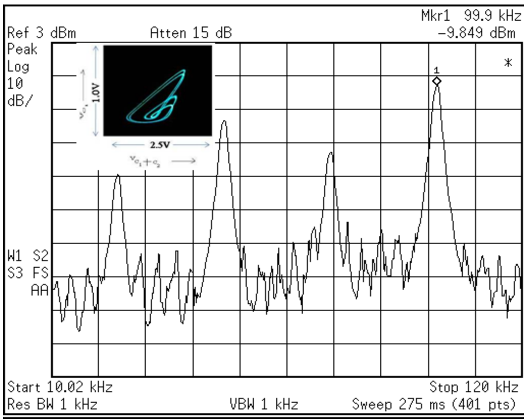

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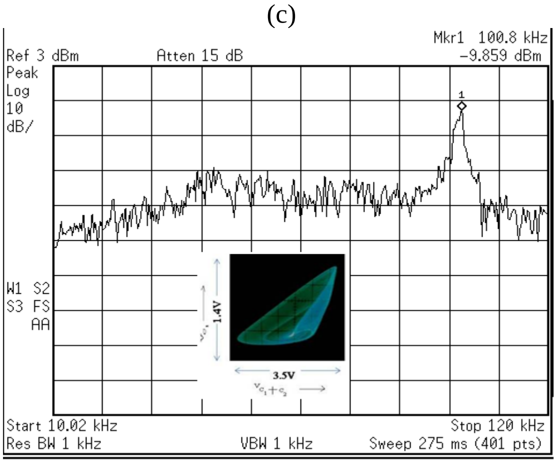

(d)

Fig 6: Experimentally obtained Frequency spectrum of $v_{(C_1+C_2)}$ and State space trajectory between $v_{(C_1+C_2)}$ and v_{c_1} (inset) for different values of bias current (a) I=5.0 mA,(b) I=6.0 mA, (c) I=8.4 mA, (d) I=11.5 mA

To characterize the chaotic behavior in the CO dynamics, we have extracted the experimental data using LAB View software and then MLE is evaluated for different bias current. Positive values of MLE as obtained from the experimental data confirms about the chaoticity in the CO dynamics. The increase in the positive value of MLE with the increase of bias current qualitatively agrees the observations as obtained from the numerical analysis.

IV. CONCLUSION

Effect of variation of bias current on the dynamics of a classical BJT based CO has been investigated. For mathematical modeling of the CO, nonlinear variation of the trans-conductance of the transistor with the variation of bias current has been considered. Linear stability analysis of the equilibrium points of the oscillator system has been done. It predicts that for a fixed set of system parameters, as the bias current control parameter crosses a critical limit, the dynamics of the CO transits from a stable non-oscillatory state to an unstable oscillatory state. Extensive numerical simulation of the system equations has been done. It reveals that the variation of bias current results into a number of complex dynamical states of the CO. One would get period doubling scenario leading to chaos in the CO dynamics as a result of the tuning of the dc bias current. A hardware experiment has also been performed in the low RF band using discrete circuit components. The nature of the CO output is examined in real time as well as in frequency domain. Experimental observations agree well with the simulation results. To confirm the chaotic behavior of the CO, the chaos quantifier, MLE is evaluated from the numerical as well as the experimentally obtained time domain CO output data. Though the experiment is performed at low RF frequency range (because of the available infrastructure), the conclusions are general and applicable to higher frequency ranges also. The variation of chaotic state with bias current has significant implications in the respect of application of chaotic COs in practical fields. In chaos based secure communications, by varying the bias current of the CO, information bits can be mapped into chaotic oscillations of different characters.

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REFERENCES

[1] M P Kennedy, R Rovatti, G Setti, *Chaotic Electronics in Telecommunications*, Taylor and Francis, 2000.

[2] L Elarson, L S Tsimring, J M Litt, *Digital Communications using Chaos and nonlinear dynamics*, Springer, 2006.

[3] T Jiang, S Qiao, Z Shi, L Peng, J Huangtu, W Z Cui, W Ma and L Ran, "Simulation and Experimental evaluation of the Radar Signal performance of chaotic signals generated from a Microwave Colpitts oscillators", Progress in Electromagnetic Research, PIER,2009, vol. 90, pp. 15-30.

[4] Sarkar, B. C., C. Koley, A. K. Guin, and S. Sarkar, "Some numerical and experimental observations on the growth of oscillations in an X-band Gunn oscillator", Progress In Electromagnetics Research B, 2012 vol. 40, pp. 325–341.

[5] M P Kennedy, "Chaos in the Colpitts oscillator", IEEE Trans on Circuits and Systems I: Fundamental Theory and Applications, vol. 41, no. 11, 1994 pp. 771-774.

[6] G. M. Maggio, O. D. Feo, M.P. Kennedy, "Nonlinear Analysis of the Colpitts Oscillator and Applications to Design", IEEE Trans on Circuits and Systems-I: Fundamental Theory and Applications,September, 1999 vol. 46,no. 9.

[7] T Jiang, S Qiao, Z G Shi, L Ran, "Ambiguity Function of Chaotic Radar with Colpitts Oscillator", PIERS Proceedings, Hangzhou, China, March 24-28, 2008.

[8] Z. G. Shi and L X Ran, "Microwave Chaotic Colpitts Oscillator: Design, implementation and Applications" , Journal of Electromagnetic Waves and Applications, vol. 20, no. 10, 2006 pp. 1335-1349.

[9] G Z Shi, S Qiao, K S Chen et al, "Ambiguity functions of direct chaotic radar employing microwave chaotic Colpitts oscillator", Progress In Electromagnetics Research, PIER vol. 77, 2007 pp. 1-14.

[10] A Tamasevicus, G Mykolaitis, S Bumeliene, A Ceenys, A N Anagnostopoulos, E Lindberg, "Two stage chaotic Colpitts oscillator", Electronics Letters,vol. 37, no. 9, 2001 pp. 549-551.

[11] A Tamasevicus, S Bumelieneand E Lindberg, "Improved chaotic Colpitts oscillator for ultra high frequencies",Electronics Letter, vol. 40, 2004 pp. 25-26,2004.

[12] S Bumeliene, A tamasevicious, G Mykolaitis, A Bazaliauskas,E lindberg, "Numerical investigation and experimental demonstration of chaos from two stage Colpitts oscillator in the ultrahigh frequency range", Nonlinear Dynamics, vol.44, 2006 pp. 167-172.

[13] J Y Effa, B Z Essimbi, J M Ngudam, "Synchronization of improved chaotic Colpitts oscillators using nonlinear feedback control", Nonlinear Dynamics, vol. 58, 2009 pp. 39-47.

[14] Sprott, J. C., Chaos Data Analyzer Package, Web address: http://sport.physics.wise.edu/cda.htm

[15] Jacob Millman, *Microelectronics: Digital and Analog Circuits and Systems*, Mc Grawhill International Student Edition, 1981.pp. 537-539

[16] A S Sedra and K C Smith, *Microelectronic Circuits*, Oxford University Press, 2004. p470

[17] M E Valkenberg, Network Analysis, 3rd edition, Prentice Hall of India, 2007.pp. 307-310.

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