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Two-stage chaotic Colpitts oscillator for the UHF range

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Introduction

Chaos in the Colpitts oscillator was first reported at the kilohertz frequencies [1]. Later the circuit was investigated in the high frequency (HF: 3 to 30 MHz) range [2,3]. Chaotic oscillations were demonstrated at the fundamental frequency f^*=23 MHz using the 2N2222A [2] also at f^*=26 MHz using the 2N3904 [3] bipolar junction transistors, both with approximately the same threshold frequency f_T of 300 MHz. By means of the PSpice simulations chaos was predicted at f^*=500 MHz using the microwave AT41486 type transistor with f_T of 3 GHz [2] and at f^*=1 GHz employing the BFG520 transistor with f_T of 9 GHz [4]. However these results were not confirmed experimentally at that time. Very recently we demonstrated chaos in a hardware prototype at f^*=450 MHz, f^*=780 MHz, and f^*=1060 MHz using the BFG520 microwave transistor [5]. Analysis shows that in classical (single-transistor) Colpitts oscillators, chaotic oscillations can be generated up to approximately $f^*\approx 0.1 f_T$, that is at $f^*\approx$900 MHz with the BFG520. Indeed, only weak chaos with 20 to 30 dB height peaks at f^* also at its sub-harmonic and higher harmonic components can be expected for f^*=1000 MHz [4]. Moreover, the PSpice simulations indicate that chaotic oscillations observed experimentally at f^*=1060 MHz in [5] are due to the parasitic elements, like wiring inductance and wiring loss resistance that can be important at the ultrahigh frequencies.

In this paper we recall to a two-stage Colpitts oscillator introduced and discussed several years ago [3,4] and promising higher fundamental frequencies, up to $f^*\approx 0.3 f_T$. We describe an example of a hardware implementation of the modified oscillator and present experimental evidence of its chaotic performance in the ultrahigh frequency (UHF: 300 to 1000 MHz) range.

Circuit

Simplified circuit diagram of the two-stage Colpitts oscillator [3,4] is sketched in Fig. 1, meanwhile its specific hardware implementation is presented in Fig. 2.

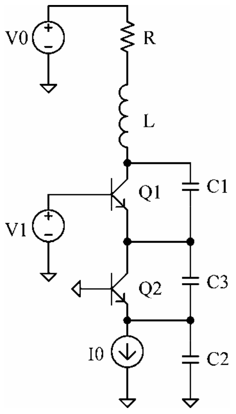

Fig. 1. Two-stage Colpitts oscillator

In comparison with the classical single-transistor Colpitts oscillator [1,2,5] the two-stage modification includes an extra transistor Q2 and an extra capacitor C3. We note that both transistors, Q1 and Q2 in respect of AC signals are in a common-base configuration.

The fundamental frequency f^* of a two-stage Colpitts oscillator can be estimated as

$$f^* = \frac{1}{2\pi}\sqrt{\frac{C_1C_2 + C_1C_3 + C_2C_3}{LC_1C_2C_3} - \frac{R^2}{L^2}}. \qquad (1)$$

The actual experimental circuit diagram is shown in Fig. 2. Meanwhile its parameters values are discussed in the next section.

The Q1-Q2-based stages compose the intrinsic two-stage Colpitts oscillator while the Q3-based one is an emitter follower inserted to buffer the influence of the measuring devices. The resonance tank combines the loss resistor R, the inductor L, and three series capacitors C1, C2, C3. The C4 is a coupling capacitor. Small auxiliary capacitors of 300 pF (not shown in the circuit diagram) are connected in parallel with the main blocking capacitors C0 to improve filtering at high frequencies. The bias emitter current I_0 can be tuned by varying the voltage source V2.

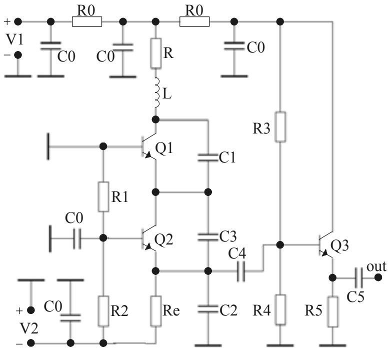

Fig. 2. Full circuit diagram of a two-stage Colpitts oscillator

Parameters

In the hardware prototypes the circuit parameters were the following: R_0=100 Ω, R_1=510 Ω, R_2=3 kΩ, R_3=5.1 kΩ, R_4=3 kΩ, R_5=200 Ω, R_e=1.5 kΩ, C_0=47 nH, C_2=10 pF, C_3=10 pF C_4=1 pF, C_5=270 pF (other parameters of the tank elements, namely R, L, and C_1 depend on the chosen fundamental frequency f^* and are given in the caption to Fig. 4). We note, that in a real circuit the total tank inductance L consists of: (1) the L_{ext} controlled by an external inductive element, (2) the parasitic inductance of the loss resistor L_{R}, and (3) the parasitic inductance L_{C0} of the filter capacitor. Thus, $L=L_{\text{ext}}+L_{\text{R}}+L_{\text{C0}}$. The two latter values are each approximately 2 nH. The microwave transistors BFG520 discussed in the Introduction were employed in the circuit. The specific values of the supply voltages V_1 and V_2 were adjusted to achieve the desired chaotic performance of the oscillator.

PSpice simulations

Simulations of the circuit in Fig. 2 were performed by means of the Electronics Workbench Professional simulator, based on the PSpice software. The Gummel-Poon model of the transistors was employed. Chaotic performance of the oscillator is observed in a sufficiently wide range of the control parameters and is illustrated in Fig. 3 with a typical phase portrait. It was simulated using the following tank and supply values: R=47 Ω, L=16 nH, C_1=2.4 pF, C_2=C_3=10 pF, V_1=10 V, V_2=24 V.

Equations and numerical integration

Dynamics of the two-stage oscillator in Fig. 1 is described by the following ordinary differential equations:

$$\begin{cases} C_1 \dfrac{dV_{C1}}{dt} = I_L - I_{EQ1}(r, V_{C2}, V_{C3}), \\ L\dfrac{dI_L}{dt} = V_0 - V_{C1} - V_{C2} - V_{C3} - RI_L, \\ C_3 \dfrac{dV_{C3}}{dt} = I_L - I_{EQ2}(r, V_{C2}). \\ C_2 \dfrac{dV_{C2}}{dt} = I_L - I_0. \end{cases} \tag{2}$$

In eqn. (2) the forward current gain of the transistors is assumed to be $\alpha = 1$, that is the base currents are neglected. The r is the differential resistance of the base-emitter junction in the forward-active mode. In this simplified mathematical model the r is considered to be a constant parameter. Meanwhile in experiments it can be slightly controlled by tuning the emitter dc bias current I_0.

By introducing the dimensionless quantities

$$x = \frac{V_{C1}}{\rho I_0},\ y = \frac{I_L}{I_0},\ z = \frac{V_{C2}}{\rho I_0},\ v = \frac{V_{C3}}{\rho I_0},\ t = \frac{t}{\tau},$$

$$a = \frac{\rho}{r},\ b = \frac{R}{\rho},\ \rho = \sqrt{\frac{L}{C_1}},\ \tau = \sqrt{LC_1},\ \varepsilon_{2,3} = \frac{C_{2,3}}{C_1},$$

and using the piece–wise linear approximations of the current-voltage characteristics of the base-emitter junctions

$$F_1(a,z,v) = \begin{cases} 1 - a(z+v), & a(z+v) < 1, \\ 0, & a(z+v) \geq 1. \end{cases} \tag{3}$$

$$F_2(a,z) = \begin{cases} 1 - az, & az < 1, \\ 0, & az \geq 1. \end{cases} \tag{4}$$

a set of equations convenient for numerical integration is obtained:

$$\begin{cases} \dot{x} = y - F_1(a,z,v), \\ \dot{y} = -x - z - v - by, \\ \varepsilon_3 \dot{v} = y - F_2(a,z), \\ \varepsilon_2 \dot{z} = y - 1. \end{cases} \tag{5}$$

The result of numerical integration of eqn. (5) with $a = 11.5$, $b = 0.6$, $\varepsilon_{2,3} = 4$ is presented in Fig. 3 (right).

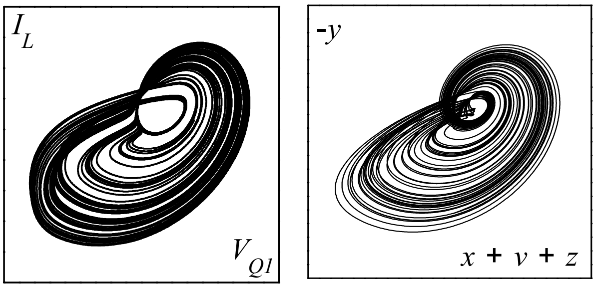

Fig. 3. Typical chaotic phase portraits, current through the inductive element ($I_L \propto y$) *vs.* collector voltage ($V_{Q1} \propto (x+v+z)$). PSpice results (left) and results from eqn. (5) (right)

Experimental results

Several power spectra were taken at different f^* with spectral resolution of 120 kHz. Two of them are presented in Fig. 4. The spectra are broadband continuous ones with rather flat rises at the fundamental frequencies f^* and around the sub-harmonics $f^*/2$ or $f^*/3$ and $2f^*/3$.

In comparison with a single-stage oscillator [5] the modified version exhibits essentially better spectral features. For example, at f^*=600 MHz the lower and the upper frequency band limits are f_1=250 MHz and f_2=700 MHz within the spectral unevenness of 10 dB, while f_1=150 MHz and f_2=1000 MHz within the unevenness of 20 dB. Thus, for the central frequency $f_c=(f_2+f_1)/2$ of about 500 MHz the relative bandwidth $\Delta = (f_2-f_1)/(f_2+f_1)$ is 0.47 and 0.74, respectively. Moreover, the power spectrum at f^*=1100 MHz covers the full UHF range (300 to 1000 MHz, f_c= 650 MHz, Δ = 0.54) with the unevenness of less than 6 dB.

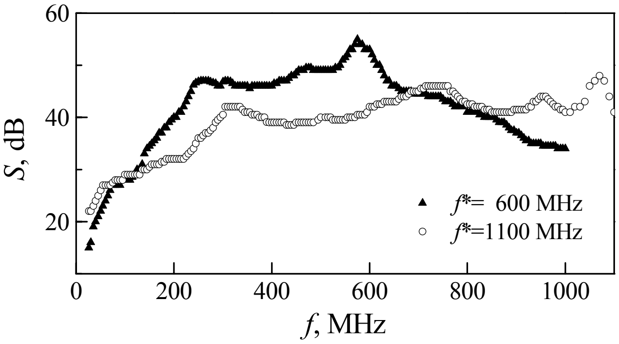

Fig. 4. Experimental power spectra from the two-stage Colpitts oscillator: R= 33 Ω, L_{ext}= 12 nH, C_1= 2 pF, V_1=10 V, V_2=25 V at f^*=600 MHz, and R= 17 Ω, L_{ext}= 4 nH, C_1= 1 pF, V_1= 6.3 V, V_2= 27 V at f^*=1100 MHz

Conclusions

A hardware prototype of the two-stage Colpitts oscillator has been designed for the UHF range and described in details. The two-stage chaotic Colpitts oscillator has better spectral characteristics than a classical single-stage oscillator.

Acknowledgments

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G. Mykolaitis, A. Tamaševičius, S. Bumelienė, A. Baziliauskas. Lindberg E. UAD ruožo dviejų pakopų chaotinis Colpittso generatorius // Elektronika ir elektrotechnika. - Kaunas: Technologija, 2004. - Nr.4(53). - P.13-15.

Aprašomas dviejų pakopų chaotinio Colpittso generatoriaus eksperimentinis variantas. Jame panaudoti BFG520 tipo mikrobanginiai tranzistoriai, kurių ribinis dažnis 9 GHz. Generatorius ištyrinėtas skaitiškai ir eksperimentiškai. Būdingi faziniai portretai ir plačiajuosčiai tolydiniai galios spektrai rodo, kad generatorius generuoja chaotinius virpesius ultraaukštųjų dažnių ruože (UAD: 300–1000 MHz). Palyginti su klasikiniu vienos pakopos Colpittso generatoriumi, dviejų pakopų generatorius pasižymi geresnėmis spektrinėmis charakteristikomis. Santykinis dažnių juostos plotis yra 0,47 arba 0,74, kai centrinis dažnis yra maždaug 500 MHz, o leistinas spektrinio tankio netolygumas – atitinkamai 10 dB arba 20 dB. Il. 4, bibl. 5 (anglų kalba; santraukos lietuvių, anglų, rusų k.).

G. Mykolaitis, A. Tamaševičius, S. Bumelienė, A. Baziliauskas. Lindberg E. Two-Stage Chaotic Colpitts Oscillator for the UHF Range // Electronics and Electrical Engineering. - Kaunas: Technologija, 2004. - No.4(53). – P.13-15.

A hardware prototype of the novel two-stage Colpitts oscillator employing the microwave BFG520 transistors with the threshold frequency of 9 GHz is described. The circuit is investigated both numerically and experimentally. Typical phase portraits and broadband continuous power spectra demonstrate chaotic performance of the oscillator in the ultrahigh frequency range (UHF: 300 to 1000 MHz). The two-stage chaotic Colpitts oscillator exhibits better spectral characteristics compared to a classical single-stage Colpitts oscillator. The relative bandwidth is 0.47 and 0.74 for the central frequency of about 500 MHz within the spectral unevenness of 10 dB and 20 dB, respectively. Ill. 4, bibl. 5 (in English; summaries in Lithuanian, English, Russian).

Г. Миколайтис, А. Тамашявичюс, С. Бумялене, А. БазиляускасА., Э. Линдберг. Двухкаскадный хаотический генератор Колпица для УВЧ диапазона // Электроника и электротехника. - Каунас: Технология, 2004. - № 4(53). – С.13-15.

Описывается экспериментальный прототип нового двухкаскадного генератора Колпица, использующий микроволновые транзисторы BFG520 с граничной частотой 9 ГГц. Генератор исследован численно и экспериментально. Характерные фазовые портреты и широкополосные непрерывные спектры демонстрируют хаотическую генерацию на ультравысоких частотах (УВЧ: от 300 до 1000 МГц). Двухкаскадный хаотический генератор Колпица обладает лучшими спектральными характеристиками по сравнению с классическим однокаскадным генератором. Относительная ширина полосы на центральной частоте около 500 МГц при неравномерности спектра 10 дБ и 20 дБ составляет соответственно 0,47 и 0,74. Ил. 4, библ. 5 (на английском языке; рефераты на литовском, английском и русском яз.).