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Modified Ultra-Wideband Microwave Chaotic Colpitts Oscillator with a Simplified Structure: Implementation, Experiments

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Abstract: ***Modified Colpitts oscillator with SiGe bipolar transistor as an active element was introduced, implemented and experimentally studied. It enables generation of ultra-wideband chaotic oscillations in the microwave range. Compared to its classical analogue, the oscillator has an extremely simple structure comprising only one single external reactive element (an inductor). The transistor p-n junction capacitance performs the function of oscillator external capacitors. Stable generation of chaotic oscillations in the range of 1 to 8.5 GHz (at 10 dB level) with highest ever efficiency values (7%) for a given class of oscillators has been obtained.***

Keywords: ***Chaotic Colpitts oscillator, ultra wideband chaotic oscillations, microwave band, power spectra, power efficiency, implementation, bipolar SiGe transistor***

I. INTRODUCTION

Almost fifty years have passed since the phenomenon of dynamic chaos was discovered. And while scientists and experts in different areas of research have been studying fundamentals of this amazing phenomenon, simultaneously another research of possible chaos application has been carried out. Data transmission systems using chaotic signals turned out to be one of the promising applications. At the beginning of 90-s numerous approaches of how to develop such systems were introduced and some of them were successfully tested out and approved [1-3]. The key elements of the mentioned systems were chaotic signals oscillators. At this stage, operation in the needed frequency range was the main requirement for chaotic signals oscillators. Microwave range turned out to be the most popular for the use of chaos in communication systems. A number of prospective chaos oscillator structures operating in this frequency range have been introduced in the recent years. Some of them are used in test models of chaotic signal communication systems [4-6]. A new interest in chaotic oscillators emerged with the beginning of ultra-wideband signals use in communication equipment. The fact that by their nature the chaotic oscillations are wideband and ultra-wideband signals, makes chaos oscillators highly advantageous for new generation communication systems and, primarily,

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For their wireless analogues [7-10]. This fact was registered in new IEEE standards, (802.15.4a, 802.15.6) thus heightening the interest to chaos oscillators even more. According to the specified standards, chaotic signals oscillators are suggested to be used as sources of ultra-wideband signals for wireless communications systems, in the frequency range of 3.1 – 10.6 GHz. As we are referring to the specific application of chaotic signals oscillators, assuming their mass production in the future, new requirements to chaotic signals oscillators have been moved to the forefront, in addition to their operating frequency range, generation band and emitting power level requirements. These requirements are related to certain consumer properties of oscillators, such as energy efficiency, reliability of operation in case external conditions are changed, compact overall dimensions, small weight of the device, low-voltage power supply voltages, design, main properties recurrence in all the samples, structure simplicity. The last of the listed properties is one of the main ones as in practice it defines all the other properties.

The purpose of this work is the development of the chaotic signals oscillator with the simplest structure and which will allow to receive ultra-wideband signals in the above specified frequency range.

II. MICROWAVE COLPITTS OSCILLATOR

Colpitts oscillator, whose structure is shown in Fig.1, is of special interest among currently known chaos oscillators [11-13]. This is due to the fact that it has simple structure and can produce wideband and ultra-wideband oscillations in different frequency ranges, including very important from practical point of view microwave band [14-19]. If needed, Colpitts oscillator can change characteristics of output chaotic signals (frequency band and range of a generated signal, power spectrum flatness, etc) [14-15]. The fact that only one active component (a transistor) is used and a number of components (the oscillator is made of) is minimal, makes it advantageous compared to its analogues due to its higher energy efficiency.

From the point of possible practical application of Colpitts oscillator, it is very important to choose the active element. During simulation and oscillator chaotic dynamics study, as a rule, silicon bipolar transistors were used as active elements.

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This choice is conditioned, primarily, by p-n junctions nonlinearity of these transistors which is of key importance for chaotization of oscillations. However, due to physical limitations the frequency range of silicon bipolar microwave transistor cannot exceed the gigahertz scale. That is why it is problematic to obtain ultra-wideband chaotic signals, and leads to a spectral shift of the maximum output power density toward the lower generated frequencies. In this regard, it is relevant to create chaos oscillators with a SiGe transistor used as an active element. The main advantage of these transistors over the silicon analogues is significantly higher maximum oscillation frequency reaching up to 200 GHz while maintaining the nonlinear properties of p-n junctions. In this paper we present the results of an experimental study of the Colpitts oscillator and its modified version based on the BFP 620F bipolar SiGe transistor with a cutoff frequency of 65 GHz. For the generator to operate in the microwave band it is also required to choose the right values not only for the transistor itself but also for its components as well. An example of the oscillator circuit is shown in Fig.1 As it has been shown in [15], the structure of an oscillator of this type can be considered as an RLC low pass filter, activated by a bipolar transistor. In this case, the output signal power distribution over the frequency range as well as the upper spectral limit of the oscillations occurring in such a system are determined by amplitude frequency characteristics of this filter. Values of circuit elements were chosen in such a way that frequency response peak of the above mentioned filter was close to f = 4 GHz frequency, and its effective width (band pass) corresponded to the frequency band of 3-4 GHz, thus, creating more preferable conditions for oscillations in this range. It should be noted that despite super-high operating frequencies of the oscillator, it still represents self-oscillating system with 1.5 levels of freedom, and its dynamics is described by the system of three differential equations of the first order. The non-linear analysis of such a system, along with the analysis of its chaotic oscillations characteristics, is described in detail in [12]. For the experimental study, the prototype model of the oscillator was designed; its topological layout sketch is illustrated in Fig.2. FR-4 material was used as a material for a substrate, and the elements of the generator were standard chip elements with rated values specified in Fig.1. The oscillator was powered by two power supply sources. Study of oscillator modes showed that multifrequency oscillations occur rather easily in the system at low collector-base voltages (Uc ~ 0-2 V) and relatively high emitter-base voltages (Ue ~ 6 V). At the same time, chaotic oscillations are possible, but they are unstable and exist in narrow regions of the voltage variation on transistor junctions. Output signal power spectrum (point C in Fig.1) of one of these modes is shown in Fig.3a. In this case, the spectrum has a wide frequency band, but is nonhomogeneous. Other oscillator modes were observed at much higher voltage Uc ~ 12 V and relatively low voltages Ue ~ 0.75-1.5 V. In this case, the chaos in the system took place almost immediately as soon as the emitter- transistor base junction was opened and remained when voltage was changed across junction in the indicated range. An example of spectral characteristic for the indicated mode type is shown in Fig.3b. Note that in the latter case, the width of the chaotic signal power spectrum reaches 5 GHz at the level of 15 dB. Lets now estimate power efficiency of the oscillator for the considered types of chaotic modes. For a typical mode of the first case (Fig.3a), the output signal power of a transistor collector circuit was up to 1 mW. Power supply consumption, under these conditions, was Uc = 1 V, Ic = 14.2 mA and Ue = 6 V, Ie = 14.8 mA. Thus, oscillator efficiency was within 1%. In the second mode of the oscillator operation (Fig.3b), the output power of the chaotic signal with a matched load increased up to 4.5 mW that corresponded to oscillator efficiency of ~ 2% (Uc = 12 V, Ic = 18.2 mA, Ue = 1.5 V, Ie = 18.9 mA).

III. MODIFIED COLPITTS OSCILLATOR

The peculiarity of the considered microwave range is that inductors and capacitors used in the oscillator circuit have the values of nH and pF scale. In other words, they are starting to be comparable with p-n junction capacitance and parasitic inductance of the transistor used in the oscillator. The influence of inter-electrode capacitances may lead to the fact that the oscillations in the circuit will occur even without C1 and C2 capacitors (Fig.1). In this case, feedback required for generation of oscillations may be achieved by means of transistor p-n junction internal capacitance. Thus, capacitance of the collector-emitter junction of BFP 620F silicon-germanium transistor used in our work is about ~ 0.2 pF. Accordingly, capacitances of the other junctions (collector – base and emitter – base) have a value of 0.12 pF and 0.45 pF. The oscillator structure is further simplified if the two external capacitors will be removed. In this case only one external reactive component remains in the oscillator circuit (inductance L), which together with the transistor p-n junction capacitance forms required oscillator frequency- selective circuit (Fig.4).

When supply voltages were changed in the oscillator test model (Fig.4b) built on the FR-4 substrate with external chip–elements, different oscillation modes were observed. A typical pattern of oscillations generation is shown in Fig.5. In this case, the Ue voltage was fixed at 0.75 V, and Uc voltage performed function of the control parameter, which varied in the range of 0 - 12 V. When Uc was increased up to 9 V, oscillations in the system were observed at ~ 5.6 GHz. Further increase of the voltage led to the subharmonic oscillations of a doubled period, and when the Uc values reached 11-12 V, stable chaotic oscillations were generated.

With L = 1 nH, chaotic oscillations were observed in the frequency band of 0.5-8 GHz (at flatness level of 10 dB). Signal power, in this case, was 2,5 mW with power supply consumption Uc = 11.5 V, Ic = 2.9 mA, Ue = 0.75 V, Ie = 3 mA that corresponds to the oscillator efficiency ~ 7%.

IV. CONCLUSIONS

Ultra-wideband microwave chaotic oscillator, based on a classic three-point circuit (Colpitts oscillator) and silicon-germanium bipolar transistor as an active element, was studied and implemented in this work.

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Experimentally, it was demonstrated that oscillator was capable to produce chaotic signals with a bandwidth of 5 GHz and oscillations central frequency of 4 GHz and 1-2% efficiency.

Analysis of the obtained results led to the conclusion that for considered frequency range it is possible to simplify Colpitts oscillator circuit (which is simple enough as it is). A modified Colpitts oscillator that contained only one external reactive element (an inductor), while the function of the external capacitors is implemented by p-n junction capacitance of BFP 620F SiGe transistor, was suggested and demonstrated.

For the first time, chaotic oscillations were experimentally obtained in the wider frequency band in comparison to the classical scheme (7.5 GHz) and higher efficiency ~ 7%. Efficiency values, registered in this work, are by far the best for class of microwave ultra-wideband oscillators of chaotic signals today.

The results of this work can be applied and be very promising in designing ultra-wideband microwave chaotic oscillators in chip–performance (built on chips) based on SiGe technology with a minimal number of used elements.

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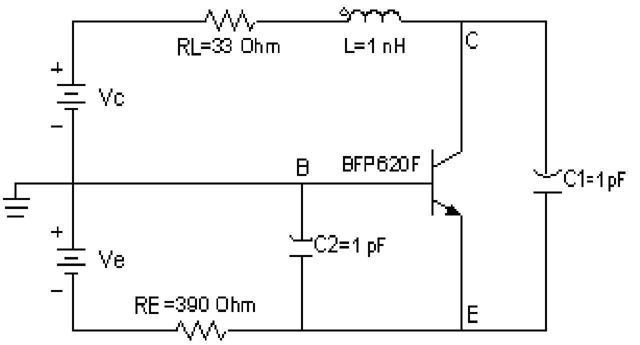


Fig.1 Colpitts oscillator with BFP 620F SiGe bipolar transistor

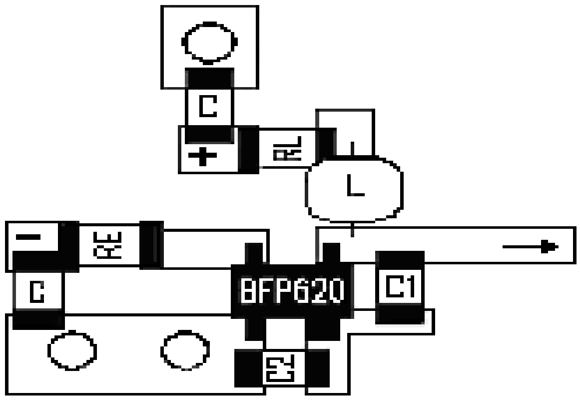
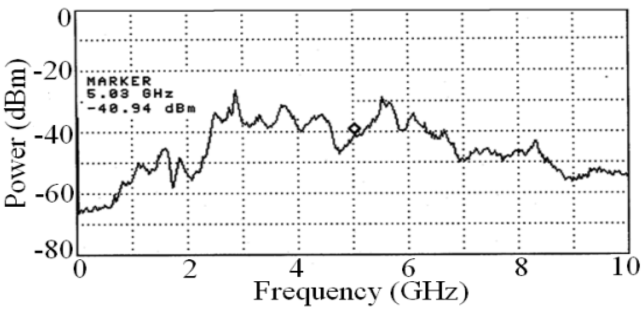


Fig.2 Oscillator test model topology. Values of circuit elements correspond to Fig.1



(A)

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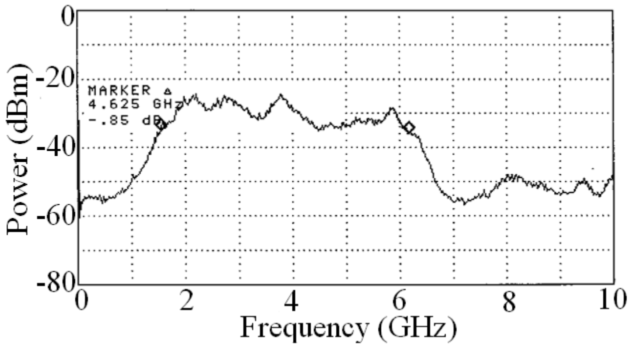
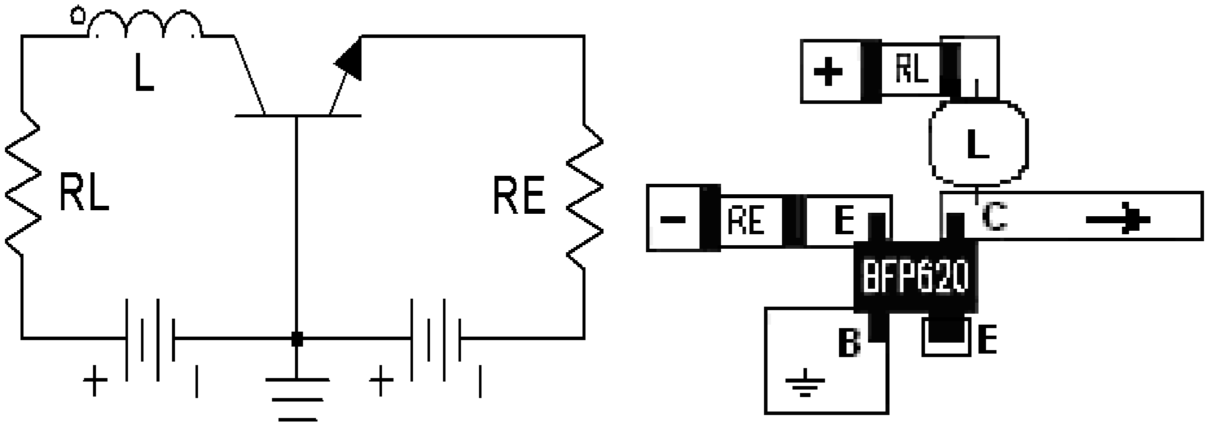


(B)

Fig.3 Power spectrum of chaotic oscillations in point C (Fig.1); a - Uc = 1 V, Ue = 6 V; b - Uc = 12 V, Ue = 1.5 V



(A) **(B)**

Fig.4 Microwave chaotic Colpitts oscillator with a simplified structure; a - oscillator circuit, b - test model topology (RL = 33 Ohm, RE = 390 Ohm, L = 1 nH)

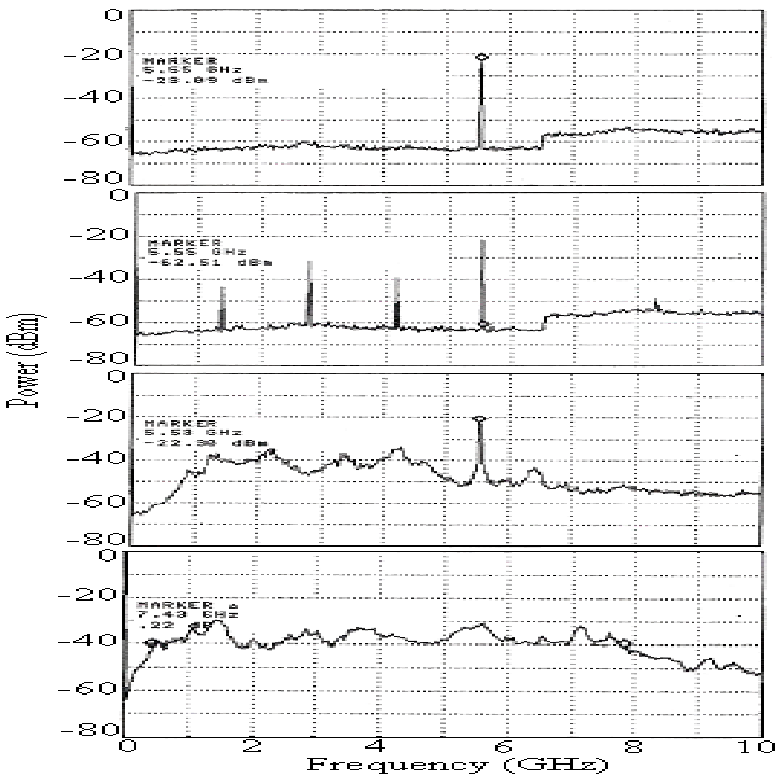


Fig.5 Output signal power spectra of a modified Colpitts oscillator with a simplified structure at a fixed Ue = 0.75 V and various (rising) Uc.

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