UWB Microwave Chaotic Oscillator: from Distributed Structure to CMOS IC Realization

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***Abstract*—Development of the effective sources of ultrawideband signals is stimulated by much interest to ultrawideband communication technologies. Chaotic oscillators can play the role of such sources. In the report structure of the microwave ring oscillator capable to generate ultrawideband microwave chaotic signal with uniform power spectral density, is proposed. Its evolution from distributed elements implementation to CMOS IC realization is demonstrated in simulation and experimentally. Dynamics of the basic oscillation modes are investigated, the fact of the chaotic generation is shown. It is demonstrated that such oscillators can be used in different wireless communication applications as a compact device for UWB microwave chaotic signal generation with uniform power spectral density in frequency bandwidth up to 5 GHz and integrated output power reaches about 20 dBm.**

***Index Terms*—UWB, communications technologies, chaotic oscillator, CMOS IC.**

I. Introduction

Application of ultrawideband (UWB) signals is actively investigated in communications. In particular, UWB signals are adopted in wireless personal area networks (WPANs) that are developed within the limits of IEEE 802.15.4a standard. One of the signal types that are recommended for use in UWB WPANs as an information carrier is chaotic signals.

Chaotic oscillations have certain advantages which make them attractive to use in UWB applications. Among these are: ultrawide bandwidth (naturally spread spectrum), large variety of chaotic modes in oscillators and possibility of their control, relative simplicity of oscillators, self-synchronization, stability to fading in multipath environment, etc.

A promising approach to UWB communications is the so called direct chaotic communication (DCC) scheme. The basic idea of DCC is that generation of chaotic carrier, its modulation and demodulation by information signal are performed in microwave band [1 - 3].

Effective sources of UWB chaotic signals are necessary for implementation of such systems. These sources must have a simple structure, form a chaotic signal in a necessary frequency band and provide uniformity of power spectral density. The main requirements to the sources are: low weight and size, reliability, low power consumption, etc.

In this report, structure of the ring UWB microwave oscillators based on three active elements and capable to generate ultrawideband microwave chaotic signal with uniform power spectral density, is proposed. Its evolution from distributed elements implementation to CMOS IC realization is demonstrated in simulation and experimentally. Dynamics of the basic oscillation modes are investigated, the fact of the chaotic generation is shown. It is shown that such oscillators can be used in different wireless communication applications as a compact device for UWB microwave chaotic signal generation with uniform power spectral density in frequency bandwidth up to 5 GHz and integrated output power reaches about 20 dBm.

II. General chaotic oscillators structure

In the given section the general structure of the offered oscillators is described.

Block scheme of the proposed ultrawideband microwave chaotic oscillator is presented in Fig. 1.

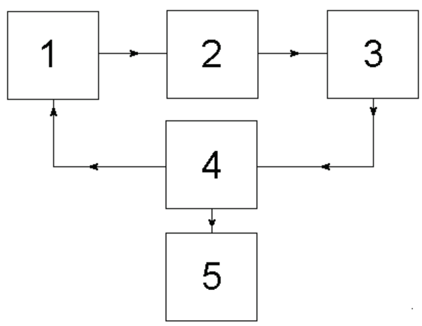

Fig.1. General block scheme of the proposed ultrawideband microwave chaotic oscillator.

The oscillator contains three active elements (1-3) which are represented by microwave amplifiers. All these active elements are connected in series beginning from the first, and

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the output of amplifier 3 is connected to the input of frequency-selective circuit 4 (FSC), which also play a role of the coupler. This FSC gets amplified and limited signal away to load 5 and feeds the remaining part of the signal to the input of the amplifier 1. Thus, active elements 1–3 and FSC 4 make a closed loop.

In the given work three modifications of the oscillators with such block scheme are shown and evolution from one to another is demonstrated.

A. Oscillator with distributed structure

The first modification is the oscillator with distributed structure [4].

To improve characteristics of the generated signal (such as output power or frequency bandwidth), the first, second and third frequency-selective structures, in practical represented by distributed microstrip lines, 6, 7 and 8 are inserted between active elements 1 and 2, 2 and 3, 3 and FSC 4, respectively in the oscillator. FSC in this case also replaced by microstrip coupler (Fig. 2a). In practice, such distributed circuits can be inserted selectively, e.g., only between chips 1, 2 and 2, 3, or only one frequency-selective circuit in either position.

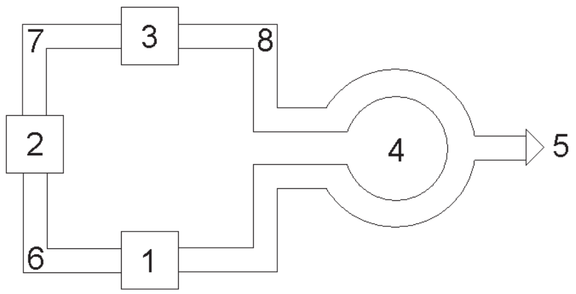

Fig. 2a. Block scheme of microstrip version of UWB microwave chaotic oscillator with distributed topology.

One of the experimental topology of the chaotic oscillators with distributed elements and its typical experimental power spectral density are demonstrated on the Fig 2b and 2c correspondingly.

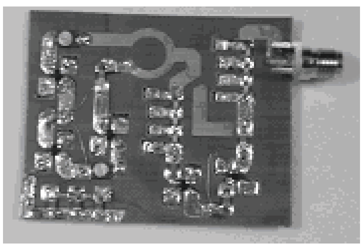

Fig. 2b. Experimental testbed of the microstrip version of UWB microwave chaotic oscillator with distributed topology.

In such oscillator it is possible to receive chaotic oscillations with uniform power spectral density in the bandwidth up to 5 GHz and output power up to 20 mW.

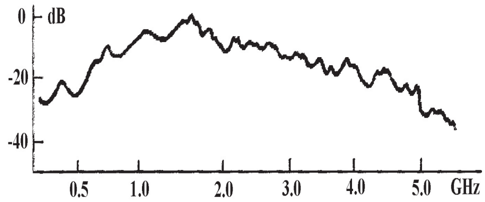

Fig. 2c. Typical chaotic oscillations power spectral density for oscillator with distributed topology (experiment).

B. Oscillator based on the lumped elements

Advantages of the oscillator with distributed structure are very wide bandwidth of generated oscillations and the high output power. Disadvantages are big size (30 mm*50 mm) and use of the distributed elements.

If it is possible to use narrow bandwidth (up to 3 GHz) and lower output power (up to 5 mW) such type oscillators can be realized exclusively on the lumped elements (without a any micristrip lines) [5].

In this case all distributed elements 6-8 (Fig.2a) are eliminated and microstrip FSC 4 replaced by the lumped FSC based on the two 3-rd order U-shaped high or low pass filters (PF) are made on lumped L and C elements and are connected as shown in Fig.3a.

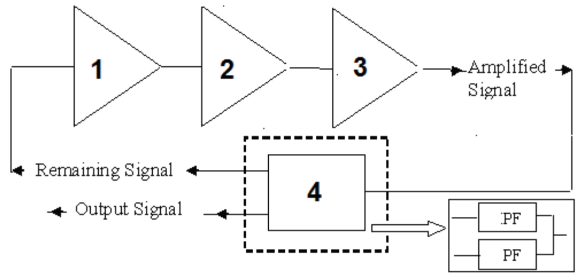

Fig. 3a. Block scheme of the UWB microwave chaotic oscillator with lumped FSC (PF –low or high pass filter).

Advantages of this type oscillator are wide bandwidth of generated oscillations, small size (10mm*15mm) and use of the lumped elements.

One of the experimental topology of the chaotic oscillators with lumped elements and its typical experimental power spectral density for high frequency FSC are demonstrated on the Fig 3b and 3c correspondingly.

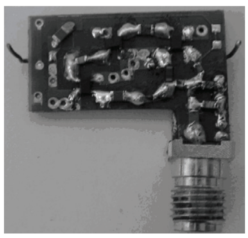

Fig. 3b. Experimental testbed of the UWB microwave chaotic oscillator with lumped elements.

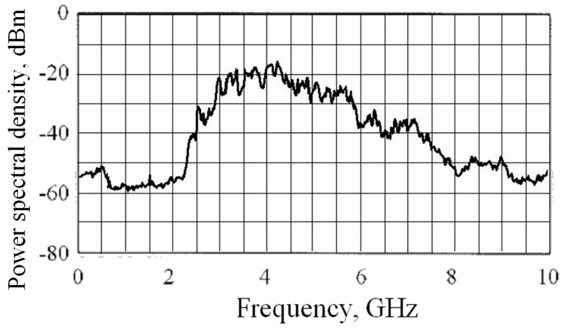

Fig. 3c. Typical chaotic oscillations power spectral density for oscillator with lumped elements (experiment).

Also transition to device on lumped elements is necessary in view of such system implementation as monolithic integrated circuit (IC) on the CMOS technology.

C. *CMOS chaotic oscillator*

If it is possible to use bandwidth up to 2 GHz and lower output power up to 1 mW ring oscillators can be implemented as IC on CMOS technologies since 180 nm [6].

The block-scheme of the chaotic oscillator on CMOS structure (Fig. 4a) in this case consist of three identical two-cascade amplifiers (1-3) and frequency selective circuit (FSC), closed in a feedback ring.

The first cascade of the each amplifier is an inverter (common-source circuit) with negative feedback. The second cascade is a buffer (common-drain circuit). The first cascade amplifies input signal. The second has gain of an order of unit, smaller level of saturation in comparison with the first cascade and behave as a limiter. FSC (5) consisting of high or low frequencies one RC and two LC sections, together with amplifiers frequency characteristic limits a power spectrum of oscillations to a demanded frequencies range.

Output signal is taken from the chaotic oscillations generation loop through the buffer amplifier 4 (Point B).

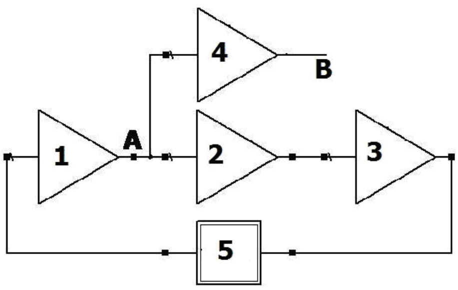

Fig. 4a. Block scheme of CMOS oscillator. 1, 2, 3 – amplifiers; 4 – output buffer amplifier; 5 – frequency selective circuit; A –point of signal taken from a feedback ring; B – out.

One of the experimental topology of the chaotic oscillator implemented as IC on the CMOS technology 180 nm (topology size about 1mm*1 mm) and its typical power spectral density for high frequency FSC for modeling and experiment are demonstrated on the Fig 4b, 4c and 4d correspondingly.

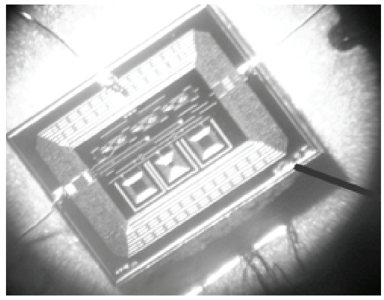

Fig. 4b. Experimental chaotic oscillator implementation as IC on the CMOS technology 180 nm.

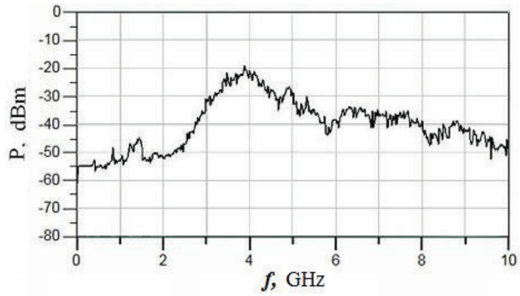

Fig. 4c. Typical chaotic oscillations power spectral density for 180nm CMOS oscillator with high frequencies FSC sections (modeling).

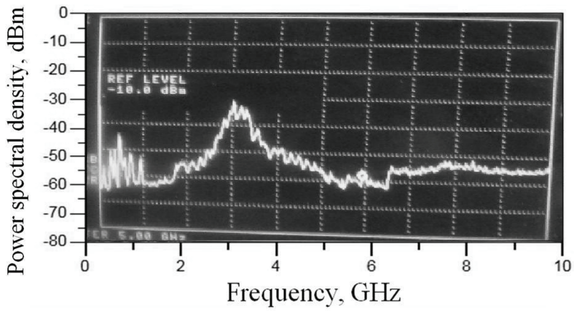

Fig. 4d. Typical chaotic oscillations power spectral density for 180nm CMOS oscillator with high frequencies FSC sections (experiment).

III. SIMULATION

Let's consider on example of CMOS oscillator, why in such systems it is possible to generated UWB microwave chaotic oscillations.

For simulation of the CMOS oscillator, its model based on active and passive elements of the 180 nm CMOS technology process was designed according to block-scheme represented on the Fig. 4a. Modelling was made in engineering package Advanced Design System (ADS). As an observable variable signal voltage *U(t)* on the system out (point B on the Fig. 4a) was used.

An analysis of spectral characteristics of the model has shown that for the chosen values of system parameters at different supply voltage various oscillation modes, including chaotic, are observed. Single-frequency mode of oscillations is observed at a frequency close to 4 GHz when system amplifiers supply voltage is U_a = 1.2 V. The supply voltage increase up to U_a = 1.27 V leads to excitation of oscillations on the second frequency about 1 GHz. Then amplitudes of the double-frequency oscillation subharmonics become more intensive and, at last, oscillations become chaotic at U_a = 1.7 V (Fig. 4c).

Evolution of oscillations is summarised on the single-parameter bifurcation diagram of oscillations modes (Fig. 5). Along axis *U* maximums of signal *U(t)* are placed on given diagram at the adiabatic slow change of parameter U_a.

As follows from the diagram analysis, single-mode oscillations are excited at first time, when supply voltage is sufficiently small. Then supply voltage increase leads to excitation of double-frequency oscillations mode and invariant torus is formed in oscillations phase space. The further voltage increase leads to structural reorganization of the resonances on the torus which finally comes to its subsequent destruction and transition to chaos. Such structural reorganization of the resonances is reflected in an increase of the number of oscillations spectral components.

Thus, chaotic oscillations are excited on the basis of double-frequency oscillations mode destruction. The described process illustrates a general principle of chaotic oscillations generation in proposed self-oscillatory system. Frequency range and bandwidth of the generated oscillations utterly corresponds to those of amplifiers used and the cutoff frequency of the FSC.

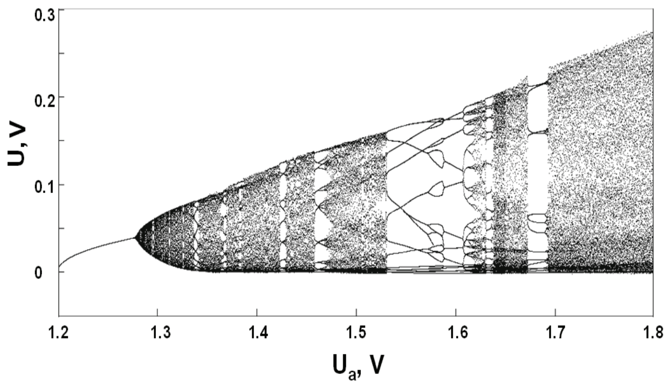

Fig.5. Single-parameter bifurcation diagram of oscillations modes. *Ua* – supply voltage, *U* – oscillations amplitude.

Possibility of double-frequency oscillations mode in the system is explained by the following circumstance. As follows from the phase-frequency response, represented on the Fig 6, in the range from 0 to 10 GHz two frequencies have phase incursion $2\pi n$, where n is an integer. According to Nyquist-Mihaylov criterion, self-sustaining oscillations can excite on each of these frequencies in case the amplitude balance is fulfilled (feedback loop gain is above unit).

Analysis of the amplitude-frequency response shows that at supply voltage 1.2 V the feedback loop gain becomes more than unity at a frequency close to 4 GHz. So, at this frequency a first self-sustaining oscillation mode appears. Then, at supply voltage 1.27 V, the feedback loop gain becomes more than unity at both frequencies: close to 4 GHz and 1 GHz. So, self-sustaining oscillations are possible on these two frequencies.

For the distributed oscillator and oscillator based on the lumped elements this scenario of chaotic oscillations development is also valid. But for their phase-frequency response in the range from 0 to 10 GHz more then two frequencies have phase incursion $2\pi n$.

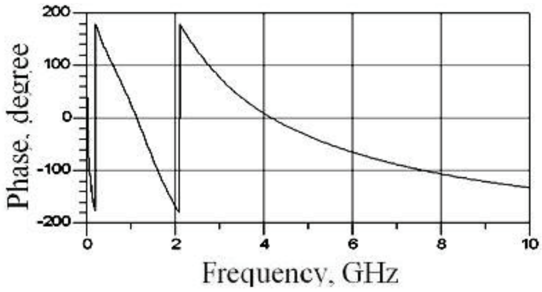

Fig.6. Phase frequency response of the oscillator feedback loop

IV. Conclusion

In the report structure of the microwave chaotic ring oscillator capable to generate ultrawideband microwave chaotic signal with uniform power spectral density, is proposed. Its evolution from distributed elements implementation to CMOS IC realization is demonstrated. Dynamics of the basic oscillation modes are investigated.

Chaotic oscillations in such oscillator type are really excited on the basis of double-frequency oscillations mode destruction mechanism.

Proposed ring microwave chaotic oscillators can be used in different wireless communication applications as a compact device for UWB microwave chaotic signal generation.

Chaotic oscillations of the proposed oscillators have uniform power spectral density in frequency bandwidth up to 6 GHz and integrated output power reaches about 20 dBm.

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