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Experimental demonstration of 1.5 GHz chaos generation using an improved Colpitts oscillator

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Abstract Experimental study of the ultrahigh-frequency chaotic dynamics generated in an improved Colpitts oscillator is performed. Reliable and reproducible chaos can be generated at the fundamental frequency up to 1.5 GHz using the microwave BFG520 type transistors with the threshold frequency of 9 GHz. By the tuning of the supply voltages, we observe complex nonlinear dynamics like period-one oscillation, period-two oscillation, multiple-period oscillation, and chaotic oscillation. Typical time series, autocorrelation, and broadband continuous power spectrum are presented. Furthermore, compared with the corresponding classical Colpitts oscillator, the main advantage of the improved circuit is in the fact that by operating in a chaotic mode it exhibits higher fundamental frequencies and a lower peak side-lobe level.

Keywords Chaos · Colpitts oscillator · Nonlinear dynamics · Ultrahigh frequency

1 Introduction

Chaotic oscillators have attracted much attention regarding their potential application to secure and spread spectrum communications [1–4]. Broadband chaotic oscillations at high megahertz and several gigahertz frequencies are of special interest [5]. To date, the most successful schemes for generating broadband chaotic signals use optic [6, 7], electrooptic [8], and optoelectronic devices [9]. However, the use of all-electronic devices is desirable because electronic components are inexpensive, compact, and stable.

Generating broadband chaotic signals in the radio frequency range are challenging by using all-electronic components. The challenges in part come from the electronic components, such as operational amplifiers, are not readily available above a few GHz. Therefore, new techniques for chaos generation need to be explored. Some recent efforts have started to address the issue of an all-electronic generation of chaotic oscillation in technologically relevant radio frequency bands. For instance, chaos in the very-high-frequency range has been demonstrated in a time-delay system with a diode-based nonlinearity [10]. A high speed chaotic delay-system with a transistor-based nonlinearity [11] was also shown. Compared with the complex circuits above, a simple circuit based on the Colpitts oscillator is proposed [12–14]. Experiments have demonstrated that chaotic oscillations in the ultrahigh frequency ranges can be generated in the classical Colpitts oscillator and two-stage Colpitts oscillator [15, 16]. However, to the best of our knowledge, chaos generated by improved Colpitts oscillators is only proved by simulations [17–19] and have not been confirmed experimentally so far.

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In this paper, we experimentally demonstrate the chaos in the ultrahigh-frequency band generated by an improved chaotic Colpitts oscillator. We provide details about the dynamics characteristics of the improved Colpitts oscillator. In addition, we present a comparison of chaos generated by the improved Colpitts oscillator and the corresponding classical Colpitts oscillator. The experimental results demonstrate that the improved Colpitts oscillator shows some better chaotic characteristics than the corresponding classical Colpitts oscillator.

2 Circuit model

Circuit diagrams of classical and the improved chaotic Colpitts oscillators are both shown for comparison in Figs. 1a and 1b, respectively. In the circuits, the BFG520 transistors with the threshold frequency f_T of 9 GHz are used as the gain components. The resonance tank combines the loss resistor R, the inductor L, and two series capacitors C_1 and C_2. The main difference between the classical and the improved the Colpitts oscillator is that the inductor L is moved from the collector to base. Moreover, compared with the structure of the improved Colpitts circuit as shown in [17], we remove the series resistor in the base.

3 Experimental results

The hardware implementation of the improved Colpitts oscillator is shown in Fig. 2a. The corresponding prototype board is shown in Fig. 2b. Two BFG520 transistors (Q_1 and Q_2) are adopted in the circuit. Q_1 is used as the gain component while Q_2 is an emitter follower inserted to buffer the influence of the measuring devices. The supply voltages, V_1 and V_2, are adjusted to obtain chaotic performance. The chokes L_0 and the blocking capacitors C_0 are used to separate the

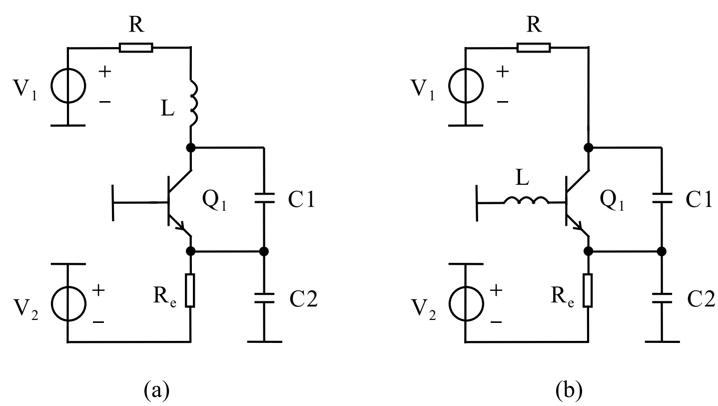

Fig. 1 Circuit diagrams of chaotic Colpitts oscillators. (**a**) Classical Colpitts oscillator, (**b**) improved Colpitts oscillator

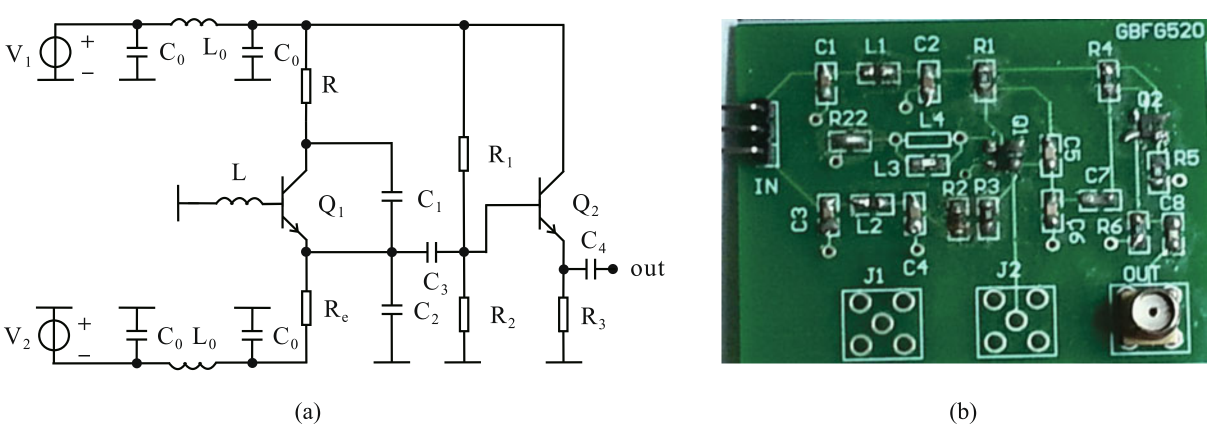

Fig. 2 (**a**) Experimental setup of the improved Colpitts oscillator. (**b**) Prototype board

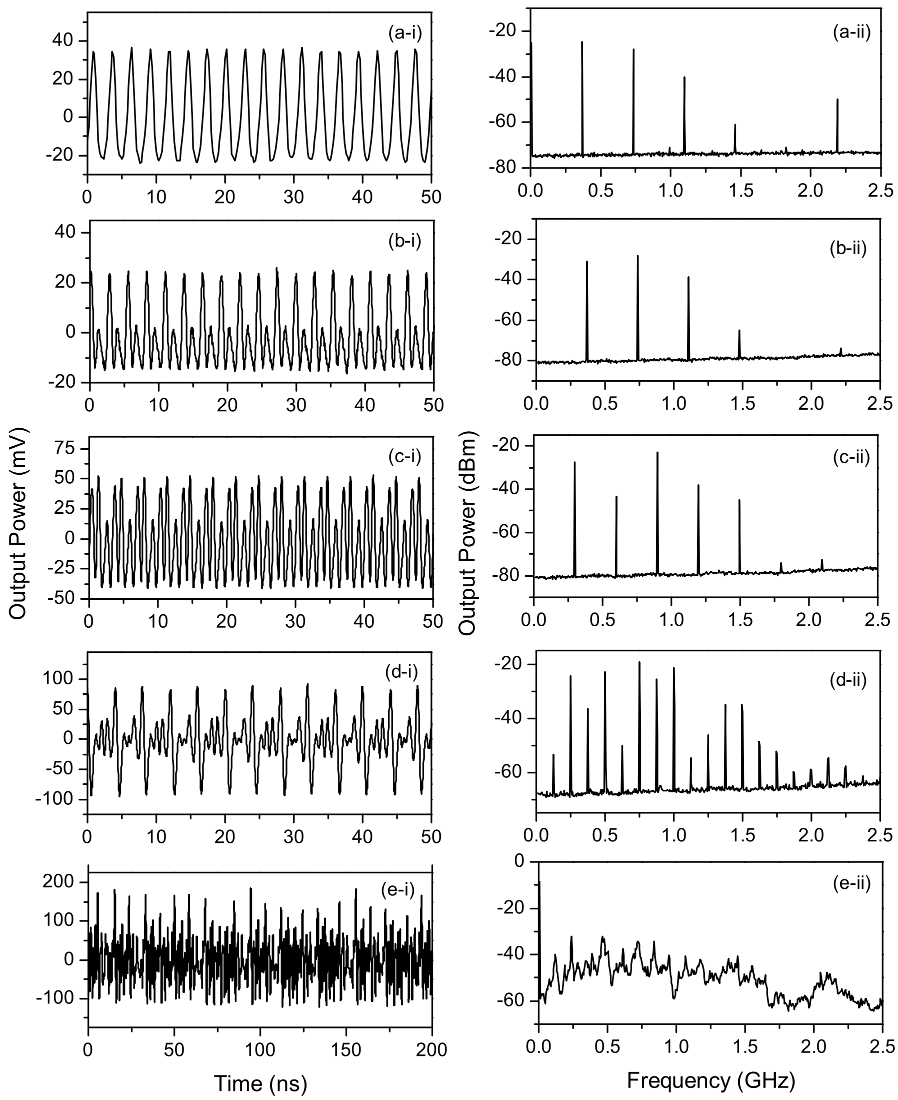

Fig. 3 Time series (*the first column*) and power spectrum (*the second column*) of different oscillation states. (**a-i**) and (**a-ii**) period-one oscillation, (**b-i**) and (**b-ii**) period-two oscillation, (**c-i**) and (**c-ii**) period-three oscillation, (**d-i**) and (**d-ii**) multiple-period oscillation, (**e-i**) and (**e-ii**) chaotic oscillation

DC supply voltages and the AC signals. C_3 is a coupling capacitor. The hardware implementation of the classical Colpitts oscillator is similar to the improved Colpitts oscillator except for the inductor L is moved from the base to the collector.

The chaotic signal output is detected by an rf spectrum analyzer (HP 8563E) and a digital oscilloscope (LeCroy SDA806Zi-A). The resolution bandwidth (RBW) and video bandwidth (VBW) of the rf spectrum analyzer are set as 1 MHz and 100 kHz, respectively. The oscilloscope works at the sampling rate of 40 GS/s.

In the circuit, $C_3 = 2$ pF, $C_4 = C_0 = 100$ nF, $R_1 = 5.1$ kΩ, $R_2 = 3$ kΩ, $R_3 = 200$ Ω, $L_0 = 10$ μH. The tank elements, i.e., L, C_1, C_2, R, and R_e, determine the fundamental frequency f^* of the chaotic oscillation in the following way:

Table 1 Typical parameter values of improved Colpitts oscillator

f^* (MHz)	L (nH)	$C_1 = C_2$ (pF)	R (Ω)	R_e (Ω)
580	15	10	12	200
710	10	10	20	510
1500	2.2	10	10	510

$$f^* = \sqrt{(C_1 + C_2)/(LC_1C_2)}/2\pi \qquad (1)$$

Through choosing different tank elements as shown in Table 1, we obtain chaos of different fundamental frequencies.

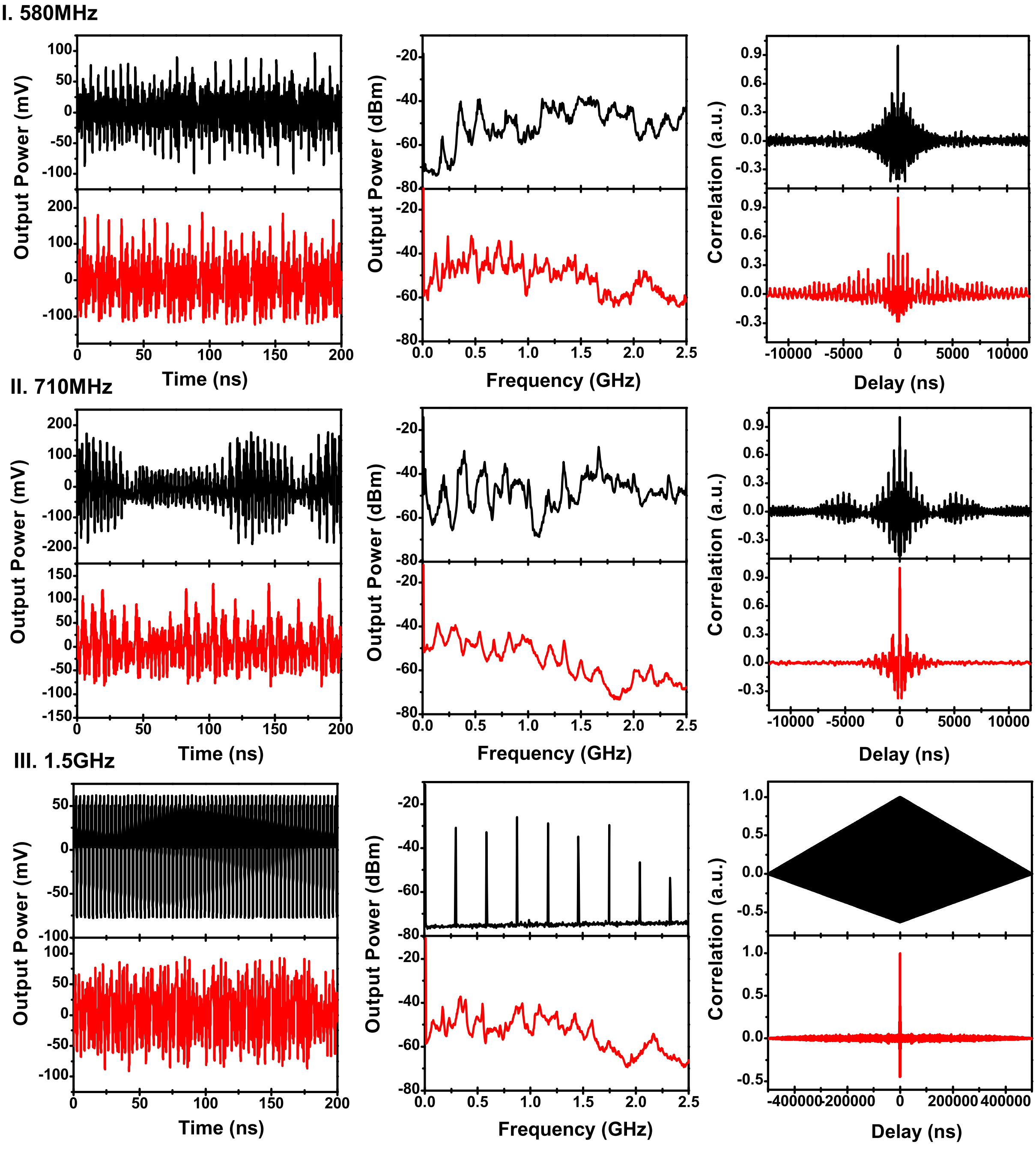

Fig. 4 Time series (*the first column*), power spectrum (*the second column*), and autocorrelation trace (*the third column*) of the classical Colpitts oscillator (*the black trace*) and the improved Colpitts oscillator (*the red trace*) at different fundamental frequencies

Figure 3 shows the effects of the supply voltages on the dynamics of the system. In the improved Colpitts oscillator, the complex dynamics develop as the supply voltage is increased. The tank elements used in the experiment are $L = 15$ nH, $C_1 = C_2 = 10$ pF, $R_e = 200\ \Omega$, and $R = 12\ \Omega$. When the value of V_1 is fixed at 1 V, we adjust the value of V_2 from 2.4 V to 14.8 V, various dynamical oscillations are observed, such as period-one oscillation, period-two oscillation, multiple-period oscillation, and chaotic oscillation. These show the sensitivity of the improved Colpitts oscillator to tiny changes in V_2. Their time series and power spectrum are shown in Fig. 3. The experimental results demonstrate chaos could arise through a series of period oscillations when using the supply voltages as the control parameter. Our experimental results have good quantitative agreement of the predicted as shown in [18]. The dynamics characteristics of the classical Colpitts oscillator are similar to the improved Colpitts oscillator. The complex dynamics are observed by tuning the values of the supply voltages.

Figure 4 shows the time series, power spectrum, and autocorrelation traces of the chaotic oscillation at the fundamental frequencies of 580 MHz, 710 MHz, and 1.5 GHz, respectively. The red traces and the black traces are the improved Colpitts oscillation and the corresponding classical Colpitts oscillation, respectively. Studies indicate that the characteristics of the improved Colpitts oscillator are superior to the corresponding classical Colpitts oscillator. From Fig. 4, we can see that there are no significant differences in time series and power spectrum between the classical Colpitts oscillator and the improved Colpitts oscillator when the fundamental frequencies are 580 MHz and 710 MHz. But the autocorrelation curve of the improved Colpitts oscillator has a lower peak sidelobe level (PSL), which is −3.78 dB and −5.30 dB at 580 MHz and 710 MHz, respectively. The PSL of the corresponding classical Colpitts oscillator is −3.01 dB and −1.88 dB, respectively. When the fundamental frequency is 1.5 GHz, the difference between the two oscillators is evident: The improved Colpitts oscillator can exhibit chaotic oscillation, while the classical Colpitts oscillator can only obtain a periodic state. This is because in the classical Colpitts oscillator, the zero-bias collector-base capacitance grounds the collector node and acts as a parasitic element destroying chaotic oscillation [17, 19]. Thus, the fundamental frequency of the chaos is limited at 10 % of the threshold frequency of the transistor.

4 Conclusions

In summary, our experimental results demonstrate the improved Colpitts oscillator can generate chaotic oscillation. By using these all-electronic devices, chaotic oscillations at GHz frequencies are generated. The rich dynamics are observed through tuning the values of the supply voltage. Furthermore, compared with the classical Colpitts oscillator, we find that the improved Colpitts oscillator can improve the randomness of the chaos. This system can be used for high-speed chaotic communications or other applications demanding broadband chaos.

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