SIMULATION AND EXPERIMENTAL STUDY OF CHAOS GENERATION IN MICROWAVE BAND USING COLPITTS CIRCUIT

Shi Zhiguo  Ran Lixin  Chen Kangsheng

(Department of Information and Electronic Engineering, Zhejiang University, Hangzhou 310027, China)

Abstract  Chaotic Colpitts circuits with fundamental frequency \( f' \) beyond 1GHz are studied by both circuit simulation and experiment using Philips’ broadband transistor with threshold frequency of 25GHz. For the basic configuration of Colpitts circuit with \( f' \) of about 1.6GHz, broadband continuous power spectra could be obtained from both circuit simulations and experiments. The harmonics of the observed signal from Agilent PSA/ESA spectrum analyzer are as noticeable as far as 12GHz. A modified Colpitts circuit structure employing the parasitic inductance of BJT (Bipolar Junction Transistor) is also proposed and investigated. By circuit simulation, chaotic attractor and broadband continuous power spectra could be obtained from the modified Colpitts circuit with \( f' \) of about 3.5GHz. Because the parasitic effects of the prototype board, the experiment result of the modified Colpitts circuit does not agree well with the simulation result. The gap between the simulation and experimental result could be bridged by replacing the lumped circuit elements with distributed ones.

Key words  Chaos; Colpitts circuit; Microwave

I. Introduction

Being one of the most important discoveries in the last several decades, deterministic chaos has been attracting a lot of interests in many disciplines. In circuit area, various chaotic circuits as well as related theories have been deeply studied. As we all know, no bandwidth limitations for the existence of high frequency chaotic oscillation are implied. This promotes the study for pursuing chaotic circuit working in higher and higher frequency band.

Lots of researchers have made great contributions to the design of chaotic Colpitts circuit with broadband characteristic since the chaotic oscillation was reported at relatively low fundamental frequency \( f' \) of 100kHz for the first time. In 1995 chaotic oscillation was reported experimentally in the high frequency range at \( f' = 25MHz \) using a general purpose 2N2222A type BJT with the threshold frequency \( f_T \) of 300MHz. In 2001 chaotic was predicted by pSpice simulation in the Colpitts oscillator at \( f' = 950MHz \) employing Philips’ broadband type BJT BFG520 with \( f_T = 9GHz \). In the latest report in year 2004, Mykolaitis et al. verified the simulation results in Ref.[3], where the highest fundamental frequency is about 1GHz. More recently, we have proposed a methodology guide for the design of chaotic Colpitts oscillator with prescribed frequency distribution. In this paper we will investigate two chaotic Colpitts circuits using Philips wideband BJT BFG425W with \( f_T = 25GHz \) by both circuit simulation and experiment. The first one is the original Colpitts circuit with \( f' \) equals to about 1.6GHz. The second one is a modified Colpitts circuit with \( f' \) of about 3.5GHz.

II. Basic Configuration of Colpitts Circuit

The basic configuration of Colpitts oscillator shown in Fig.1(a) contains a BJT as the gain element and a resonant network consisting of an inductor and a pair of capacitors. The BJT \( Q_1 \) in Fig.1(a) is modeled with a voltage-controlled nonlinear resistor \( R_E \) and a linear current-controlled current source in most references. The \( I_{CE} \) characteristic of \( R_E \) is modeled with an exponential function, namely

\[
I_E = f(V_{BE}) = I_s \exp \left( \frac{V_{BE}}{V_{T}} - 1 \right)
\]

where \( I_s \) is the inverse saturation current, \( V_{BE} \) is the base-emitter voltage of BJT \( Q_1 \), and \( V_T \approx 26mV \) at room temperature.

The state equations for the Colpitts circuit in Fig.1(a) are

\[
\begin{align*}
C_1 \frac{dV_{C_1}}{dt} &= -f(-V_{C_1}) + I_L \\
C_2 \frac{dV_{C_2}}{dt} &= I_L - \frac{V_{C_2} - V_C}{R_E} \\
L \frac{dI_L}{dt} &= -V_{C_2} - V_C - I_L R + V_t
\end{align*}
\]

where \( I_L \) denotes the current through the inductor \( L \). More detailed information of the nonlinear model and the dynamic behavior analysis of Colpitts circuits can be found in Ref.[6].
III. Colpitts Circuit with $f^*$ of about 1.6 GHz

When the oscillation frequency of chaotic Colpitts oscillator is very high, the threshold frequency of the BJT used will be very high, and the parasitic effects of the BJT will be comparable with the lumped elements in Fig.1(a). Under such circumstance, the BJT model as expressed in Eq.(1) is rather coarse to accurately simulate the behavior of a real BJT. Thus, in our simulation, the BJT $Q_1$ in Fig.1(a) is represented as the combination of some lump elements and a pSpice BJT model, as shown in Fig.1(b). The three inductors and three capacitances in Fig.1(b) are connecting inductances and packaging capacitances. The parameters of circuit elements and the pSpice model of the BJT in Fig.1(b) could be obtained from the manufactory. In Fig.1(b) the parameters listed is for the BJT BFG425W, and can be found in Ref.[7].

In circuit simulation procedure, the fundamental frequency $f^*$ was selected to be about 1.6GHz. Though the BJT model is no longer expressed as the simple exponential function in Eq.(1) as in Refs.[5,6], the methodology proposed in Ref.[5] is still a good guide for the major circuit parameters selection. Applying the parameters selection method, the circuit parameters for $f^* = 1.6$GHz are as follows: $V_+ = 10$V, $V_- = 27$Ω, $L_3 = 3.9$nH, $C_1 = C_2 = 3$pF, $R_3 = 400$Ω. Circuit simulations were conducted using ADS (Advanced Design System[8]), which is a professional radio frequency and microwave simulator. The simulation results were shown in Fig.2. The continuous spectra indicate that chaotic oscillation has been established in the circuits. The attractor obtained from the $V_{c_2} \sim V_{c_1}$ plane in Fig.2(a) has a typical shape of basic chaotic Colpitts circuits.

The experimental circuit diagram was almost the same as in Ref.[4]. The main circuit parameters were just as the listed values in the simulation procedure. The positive and negative voltage sources were used to tune the circuit to obtain desired chaotic oscillations. The prototype board was shown in Fig.3. All the circuit components are in SMD (Surface Mount Device) package.

In experiment, when $V_+ = 9.8$V and $V_- = 1.8$V, a broad continuous power spectrum can be obtained using Agilent PSA/ESA spectrum analyzer E4407B. The result is shown in Fig.4. Continuous power spectrum indicates that chaotic oscillation has been established in the experimental circuit. Compared with the experiment result in a recent reported work[4], this signal bandwidth is much wider. This is because the fundamental frequency of chaotic oscillation in Ref.[4] has almost reached the upper limit value that was determined by the threshold frequency of the BJT[9]. Here the BJT has a much higher threshold frequency than that in Ref.[9], so the upper limit of chaotic oscillation could be much higher.