CHAOTIC PHASE SHIFT KEYING SIGNAL GENERATION

A. J. Tomashevsky, M. V. Kapranov
fks@srv-vmss.mpei.ac.ru

Moscow Power Engineering Institute (Technical University)
Dept. of Generation of Oscillations and Signals

***Abstract* – New chaotic generator scheme in the class of phase control system is offered in given work. It generates radio signals with the chaotic phase shift keying, that presents itself, practically, the signal with chaotically distributed in time moments of phase shift onto certain value. Dynamical properties of such generator, as well as spectral characteristics of chaotic oscillations generated by it is investigated.**

***Index Terms* – Oscillations, chaos, phase shift keying.**

1. INTRODUCTION

By now, dynamical chaos (DCh) is an intensive developing direction of scientific researches in the field of theory of nonlinear oscillations - Refs.1,2. Chaotic behavior was discovered in number of mathematical problems, in mechanics, thermal physics, aero- and hydrodynamics and in many other natural phenomena and systems. However, the most attractive application of chaotic oscillations is their use as new tool for secure communication - Refs.3,4.

One of the important requirements, presented to modern communication networks, is the security of transmitted information for the unauthorized access. New and highly attractive way to provide for additional confidentiality in telecommunications, aside from traditionally used, is the use of chaotic signals from nonlinear dynamical systems. Information sent with the help of modulation of noisy-like chaotic oscillation can't be demodulated by standard methods of signal processing and at absence of a priori knowledge's about the underlying dynamical system - Ref.5.

Important element in such systems is a generator of chaotic oscillations. Thereby, the development of new electronic devices generating chaotic oscillations with required and operated parameters is the highly actual problem.

Chua's circuit was the first electronic model that was specially developed for chaotic oscillation generation - Ref.6. In literature, a lot of other types of DCh generators were described, among which phase-locked loop (PLL) systems - Ref.7 take important part, because of the chaos in their is observed in non-power parameter – phase of a voltage control oscillator (VCO). There are many other systems with phase control besides PLL, such as amplifier phase control (APC) systems - Ref.8, that are used for decreasing of phase lag in amplifier tracts, injection locked oscillators (ILO) with phase-locked loop - Refs.9,10, frequency-locked loop (FLL) and so on. There are many publications about the chaotic phenomena in PLL but not so many papers in literature where chaotic dynamics of APC, ILO with PLL or FLL is investigated and reported. But systems of this class offer a number of advantages, in contrast with other generators, amongst which the possibility of direct chaotic oscillation generation with the spectrum, that is situated near the radio-frequency carrier, appears to be the most important.

By reason of high noise-immunity, phase shift keying (PSK) signals have got the broad spreading in radio communication systems. In a lot of modern protocols of cellular and trunked radio networks (for instance, GSM, APCO 25, TETRA and others) differential phase shift keying p/4-QDPSK is used, but M-code PSK signals – in CDMA type standards. So way, the investigation of signal generation principles, combining of all above-mentioned features, they are: security for non-authorized access, stability with respect to noise as well as standardization from the viewpoint of carrier generation (comparable with the modern communication protocols) and non-standard modulation and encryption types (chaotic); becomes as highly perspective problem.

New chaotic generator scheme in the class of phase control system is offered in given work. It generates radio signals with the chaotic phase shift keying (ChPSK), that presents itself, practically, the signal with chaotically distributed in time moments of phase shift onto certain value. Dynamical properties of such generator, as well as spectral characteristics of chaotic oscillations generated by it is investigated.

We present our material as follows: we consider the schematic of ChPSK generator, build the mathematical model and then we show the results of simulations with this model. We investigate the possibility of chaotic oscillation generation by means ChPSK generator. As an optional variant of chaotic generator of such type with specific features we investigate the ChPSK generator with the additional phase control loop so it's obtained the combination of ChPSK generator and APC system that has been researching by our early - Refs.11,12 as a chaotic generator. We demonstrate examples of waveforms and spectrums for regular and chaotic modes of all above-mentioned generator modifications.

2. ChPSK GENERATOR

A. SCHEMATICS

The schematic of proposal ChPSK generator is shown in Fig. 1. This consists of a radio-frequency amplifier (RFA) tract of the differential bipolar transistor cascade (VT1 and VT2) with the oscillatory LC-circuit. Base circuits are equipped with the phase converters that shift the phase of a signal in the value of $\pm\psi$ respectably (Fig. 1). The signals at input and at the output with complex amplitudes $U_1(t)e^{j\varphi_1(t)}$ and $U_2(t)e^{j\varphi_2(t)}$ are applied at inputs of phase discriminator (PD). The schematic of simplest PD is shown in Fig. 2.

There can be non-zero frequency detuning ξ_c (a disturbing factor in our model) between the oscillatory system frequency of RFA ω_0 and the frequency ω_s of the input signal. The error signals $e_{1,2}$ from PD apply at the bases of transistors and by means of voltage shifting regulate the sum phase at the output. For desired system dynamic properties feedback loops are equipped by the filters (F1 and F2) with operational transmission factors $W_{1,2}(p)$. In this case the control voltages are $g_{1,2} = W_{1,2}(p)e_{1,2}$.

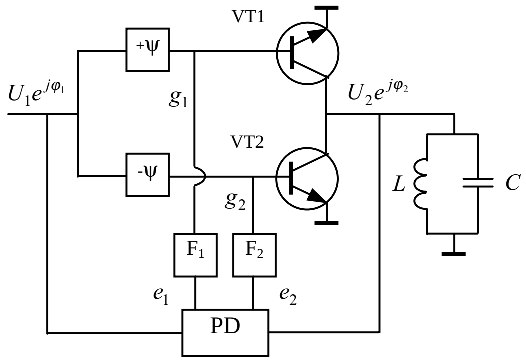

Fig. 1. Schematic of ChPSK generator.

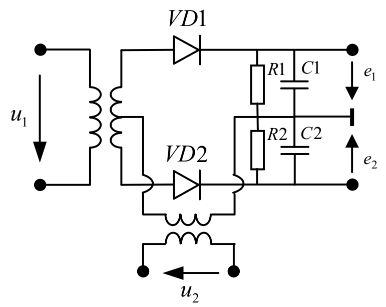

Fig. 2. Schematic of diode phase discriminator.

B. MATHEMATICAL MODEL

Let the signal voltage at the system input is

$$u_1(t) = U_1(t)\cos[\omega_s t + \varphi_1(t)] = \mathrm{Re}[U_1(t)e^{j\omega_s t}e^{j\varphi_1(t)}], \quad (1)$$

and at the output is

$$u_2(t) = U_2(t)\cos[\omega_s t + \varphi_2(t)] = \mathrm{Re}[U_2(t)e^{j\omega_s t}e^{j\varphi_2(t)}]. \quad (2)$$

Complex amplitudes $U_1(t)e^{j\varphi_1(t)}$ and $U_2(t)e^{j\varphi_2(t)}$ (refer to Fig. 1) can be connected via the operational transmission factor of RFA - Ref.10

$$U_2 e^{j\varphi_2} = K(p,\xi_c)U_1 e^{j\varphi_1}, \quad (3)$$

where $p \equiv d/dt$ – differential operator, $\xi_c = (\omega_s - \omega_0)/\omega_0\delta$ – frequency detuning of oscillatory circuit, δ – dissipation factor. The input voltage in this case consists of two parts

$$U_1 e^{j\varphi_1} = U_{11}e^{j\varphi_{11}} + U_{12}e^{j\varphi_{12}} = U_1^0 e^{j\varphi_1}\left[f(g_1)e^{+j\psi} + f(g_2)e^{-j\psi}\right] \quad (4)$$

where $f(g_{1,2})$ – normalized transit characteristic of transistors, that are supposed to be equaled for both transistors (VT1 and VT2):

$$f(g_{1,2}) = e^{Sg_{1,2}} \quad (5)$$

where S – the tangent of characteristics.

The approximated transmission factor of our RFA - Ref.8 is

$$K(p,\xi_c) = \frac{K_r}{T_c p + 1 + j\xi_c}, \quad (6)$$

where K_r – gain factor at the resonance, T_c – tank time constant.

Let the amplitude and the phase of input signal are constant: $U_1(t) = U_1^0$, $\varphi_1(t) = \varphi_1^0$. Then, with provision for (3), (4) and (6) we obtain symbolic differential equation (DE) for RFA in the form of

$$(T_c p + 1 + j\xi_c)Ae^{j\varphi} = f(g_1)e^{+j\psi} + f(g_2)e^{-j\psi}, \quad (7)$$

where $\varphi = \varphi_2 - \varphi_1^0$ – phase difference of signals at the output and at the input, $A = U_2/(K_r U_1^0)$ – normalized amplitude of output signal. The DE for control voltages are

$$g_{1,2} = W_{1,2}(p)e_{1,2} = EW_{1,2}(p)F_{1,2}(\varphi, A), \quad (8)$$

where $F_{1,2}(\varphi, A)$ – normalized characteristics of PD, according to each output, E – maximum voltage at output of PD.

Equations (7) and (8) are just the general mathematical model in the symbolic form of the ChPSK generator we investigate.

C. SIMULATION RESULTS

Choose a simple differentiating RC-circuit for both filters with transmission factor

$$W_{1,2}(p) = \frac{T_{1,2}p}{T_{1,2}p + 1}, \quad (9)$$

where $T_{1,2}$ – filter time constant; approximate the PD characteristics as

$$F_{1,2}(\varphi, A) = \pm A\sin\varphi. \quad (10)$$

In this case we obtain the nonlinear 4-order DE system for the model of ChPSK generator and chaotic oscillation can appear in such circuit. There are results of computer simulations of our model follow below.

These are the waveforms of the phase at the output of ChPSK scheme in the Fig. 3. It shows oscillation in the circuit when one parameter (the constant phase shift ψ) is varied and all other parameters are fixed.

As it can be seen, the phase shift keying in value of ψ appears in this circuit and the moments of keying can be chaotically distributed in time (Fig. 3, c).

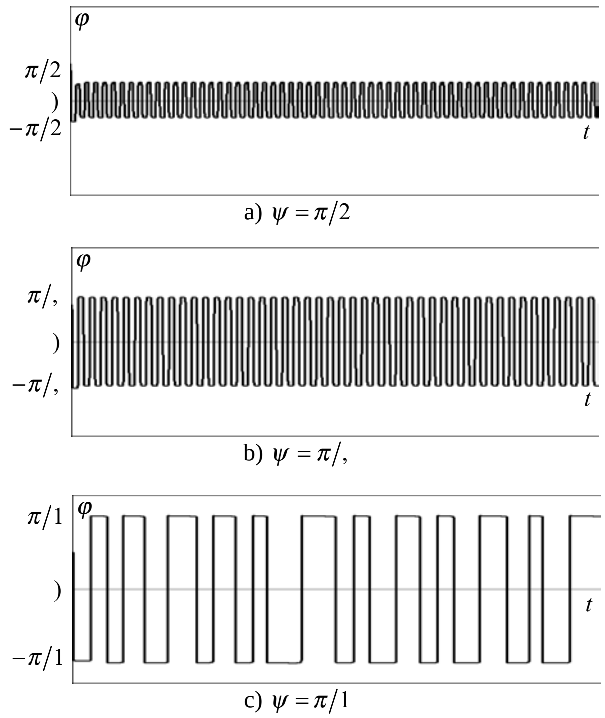

Fig. 3. Waveforms of the phase of the output signal of ChPSK generator; $\xi_c =)\,])\,)\,(\,,\ \tau_{(R} = T_{(R} / T_c =)\,](\,.$

There is a waveform of normalized radio frequency signal at the output of the ChPSK in Fig. 4,a and the spectrum of this signal in Fig. 4,b.

$$\overline{u}_1 cte = Acte os.0\omega_s t + \varphi_1 cte[\qquad (11)$$

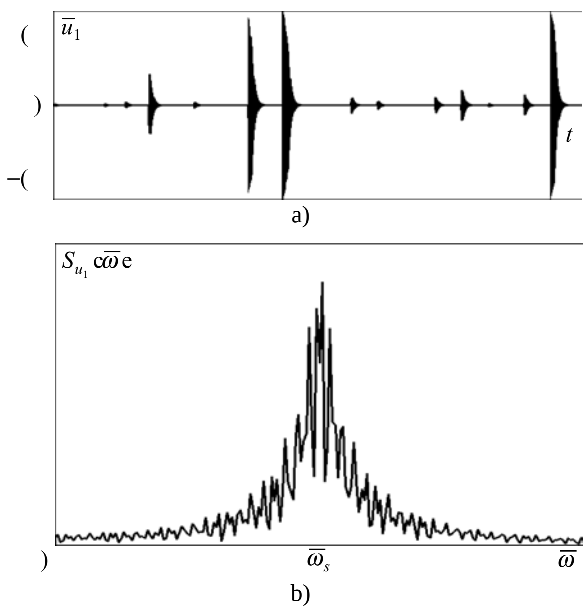

Fig. 4. Waveform and spectrum of the radio frequency signal at the output from ChPSK generator; $\xi_c =)\,])\,)\,(\,,\ \tau_{(R} =)\,](\,;\ \overline{\omega}_s = \omega_s T_c = 1)\,.$

3. ChPSK GENERATOR WITH PHASE CONTROL

A. BLOCK DIAGRAM

Originally, amplifier phase control (APC) systems were designed for stabilization of undesirable phase lag in RFA tracts, working under influence of some disturbing factors. - Ref.8. One of the variants of block diagram of simplest APC is shown in Fig. 5.

This include a radio-frequency amplifier tract with feedback loop. The phase discriminator (PD) measures the phase difference between a phase $\varphi_($ of the input signal and a phase φ_1 of the output one. This difference appears because of non-zero frequency detuning ξ_c The error signal e from PD applies at frequency controller (FC) that contributes the reactive conductivity into the oscillatory circuit of RFA, which results in additional compensation detuning. For desired system dynamic properties the feedback loop is equipped by the loop filter (LF) with operational transmission factor $W cpe$. There is a phase shifter (PS) in the system for performing the condition of zero error signal from PD when $\varphi_($ equals to φ_1 .

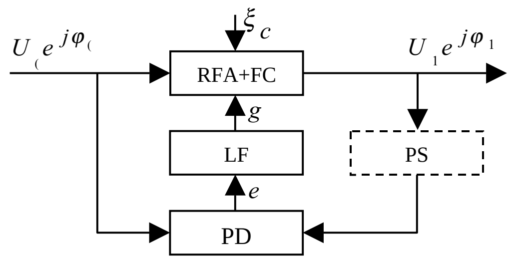

Fig. 5. Block diagram of APC system.

B. SIMULATION RESULTS

We consider below in short the possibility to generate the ChPSK signal with the help of ChPSK generator in Fig. 1 with additional APC circuit as shown in Fig 5. Fig. 6 demonstrates the specific chaotic oscillation that conclude in the output phase of such system (Ω – maximum corrective detuning).

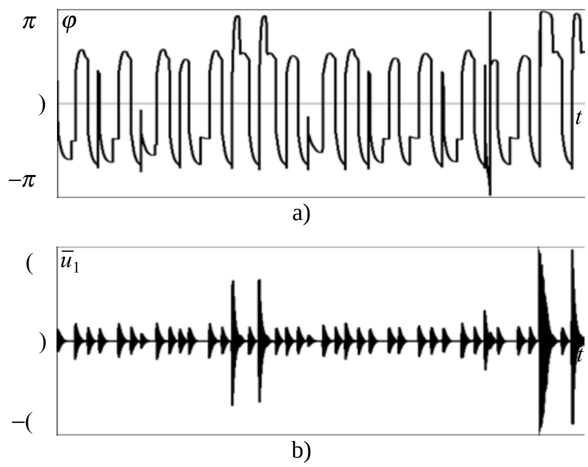

Fig. 6. Waveform of the phase of the output signal and the radio frequency signal of ChPSK generator with APC; $\psi = \pi/,\ ,\ \xi_c =)\,](\,,\ \tau_{(R} =)\,](\,,\ \Omega = -/\ ,\ \overline{\omega}_s = 1)\,.$

4. CONCLUSION

As a result of our investigation of chaotic phase shift keying generator as electronic system with phase control we show possibilities to generate the chaotic oscillations of different types. Single ChPSK demonstrates the phase oscillations in the form of exact phase shift keying to the value, that is to be close to $\pi/2$ at the moments that are chaotically distributed in time. The ChPSK generator with additional phase control loop can produce the signals with more different phase values.

The disadvantage of oscillations presented are in non-constant amplitude of obtained radio frequency signals (Fig. 4, a and 6,b). But for stabilization of the amplitude - Ref.13 we can recommend to use another oscillatory systems in collector circuits of transistors (Fig. 1) with more constant amplitude-frequency and more linear phase-frequency responses as possible.

These are original results that are not been met by us in known literature. Such systems can be useful as a new, non-standard generators for secure communication - Refs.3,5,14-16 with chaotic signals.

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