

# Formation the radio signal for the system of space-time signal processing

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**Abstract.** The work is devoted to digital information transmission systems using space-time signal processing. The formation of radio signals whose carrier frequencies are determined by the frequency-time matrices is considered. The signal shaper is based on a PLL system with a programmable frequency divider. The analysis of the processes in the phase automatic system under the influence of large destabilizing factors and frequency switching of the generated oscillations is carried out. It is theoretically and experimentally shown that in the above-mentioned conditions the automatic system may lose stability. The algorithm for controlling the PLL has been developed, which ensures the stability of processes under large disturbances. Experimental studies have been carried out that have shown the efficiency of the improved system.

## 1 Introduction

The formation of radio signals, the parameters of which are determined by the frequency-time arrays [1, 2], is considered. The signal shaper is based on a PLL system with a programmable digital frequency divider [3]. The processes in the phase automatic system are analyzed with large changes in the ambient temperature and during the implementation of the program for switching the frequencies of the generated oscillations. The mentioned factors can lead to the functioning of the system with detuning in frequency, close to the limits of the hold band of frequency, which may cause a loss of stability. For the considered PLL system with a periodic characteristic of a pulse-phase detector (PPD), the probable loss of stability is due to the presence of a dangerous attractor in space, which is a limiting cycle that is stable. In the system that has lost its property, stability of stable auto-oscillations developing, the system cannot get out of this undesirable mode on its own. In this connection, the task of controlling the processes in the PLL system, which bring the system into the domain of the target attractor, is of current interest.

## 2 Classic PLL

The differential equation of the PLL system with the periodic characteristic of the PPD and the single-link RC-LPF (the high-order low-pass filters of the high order 3-7 are considered in the work) has the form [3]

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$$\frac{d^2\varphi}{dt^2} + \frac{1}{T_F} \frac{d\varphi}{dt} + \frac{\Omega_h}{T_F} F(\varphi) = \frac{1}{T_F} \Omega_S, \quad (1)$$

where  $\varphi$  - the phase difference of the signals given to the inputs of the PPD;

$T_F$  - time constant RC-LPF;

$\Omega_h$  - hold band of frequency;

$\Omega_S$  - initial detuning;

$F(\varphi)$  - normalized "sawtooth" characteristic of PPD.

The central part of the PPD characteristic is

$$F(\varphi) = \frac{1}{\pi} \varphi, \quad [-\pi \leq \varphi \leq \pi]. \quad (2)$$

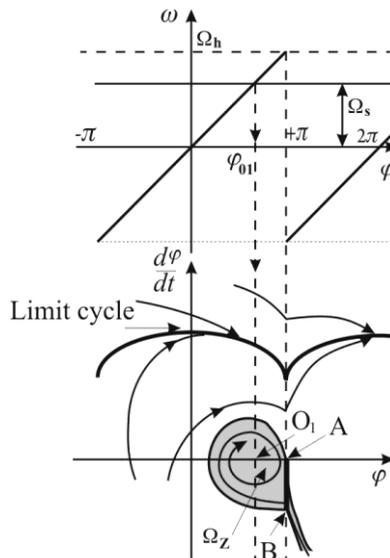
The linearized differential PLL is

$$\frac{d^2\varphi}{dt^2} + \frac{1}{T_F} \frac{d\varphi}{dt} + \frac{\Omega_h}{\pi T_F} \varphi = \frac{1}{T_F} \Omega_S, \quad [-\pi \leq \varphi \leq \pi] \quad (3)$$

In the case when the roots of the characteristic equation

$$\lambda^2 + \frac{1}{T_F} \lambda + \frac{\Omega_h}{\pi T_F} = 0, \quad (4)$$

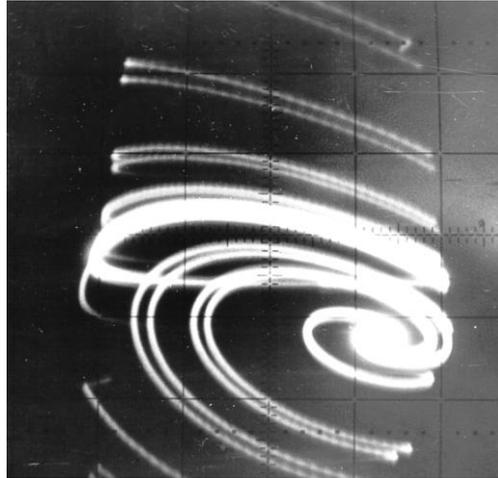
complex-conjugate, the phase portrait in the classical PLL will have the form shown in Fig.1.



**Fig. 1.** Sustainable limit cycle (Limit cycle) and an invariant manifold  $\Omega_Z$  with containing the target attractor  $O_1$  ("stable focus").

From Fig. 1 it is clear that, depending on the initial conditions, the system can with some probability fall into a dangerous self-oscillation mode, or into a desired rest mode.

The results of experimental studies of this system with a third-order low-pass filter are shown in Fig. 2.



**Fig. 2.** Photograph of the phase portrait of the PLL system with a low-pass filter of the 3-d order.

From Fig. 2 it can be seen that with some probability the imaging points on the phase portrait are attracted to the dangerous attractor, and the others to the target attractor.

From the above study it is clear that it is advisable to develop an algorithm for controlling the processes in the PLL system, ensuring the interruption of possible movements of the imaging points to the dangerous attractor and directing them to the target attractor.

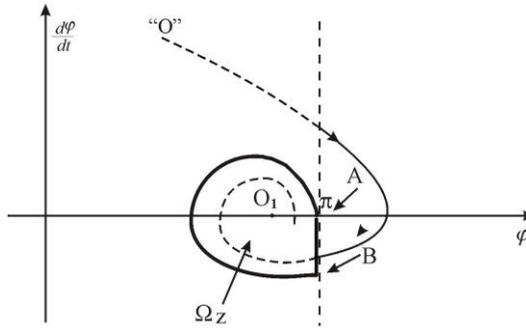
### 3 Formulation of the problem

For the PLL system, the differential equation of which has the form (1), which includes PPD with a “sawtooth” characteristic, the central part of which is described by equation (2), to develop the process control algorithm that interrupts the movements of the imaging points to a stable limit cycle and guides these points to the inner region  $\Omega_Z$  of an invariant manifold containing the target attractor  $O_1$ .

### 4 Process control algorithm in the PLL system

According to Fig. 1 and [4, 5] the sign of that the fact some processes leading to the occurrence of stable self-oscillations can be developed in the system is the exit of the operating point beyond the central part of the PPD characteristic. If the imaging point in the phase portrait of the PLL overcomes the point of discontinuity of the characteristic of the PPD, then in accordance with Fig.1, it is necessary to include an additional control action that provides the change in the sign of the instantaneous frequency detuning to the opposite one. After changing the detuning sign in frequency to the opposite one and re-breaking the break point of the PPD characteristic, additional control must be stopped and the PLL switched to autonomous mode of operation, thus forming phase trajectories entering the invariant manifold  $\Omega_Z$  containing the target attractor  $O_1$ .

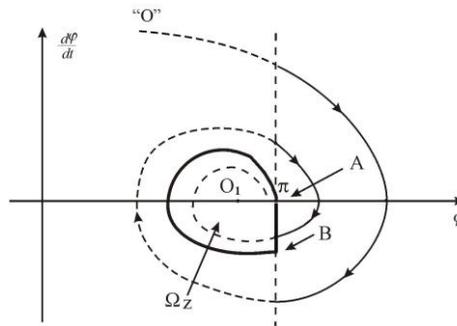
The phase trajectory being realized using the above-mentioned control algorithm is shown in Fig. 3 for the case when the instantaneous frequency detuning is not very large.



**Fig. 3.** Phase portraits in the PLL with additional process control for the case when the instantaneous frequency detuning is not very large.

It can be seen from Fig. 3 that a single application of additional control ensures the movement of the imaging point to the target attractor.

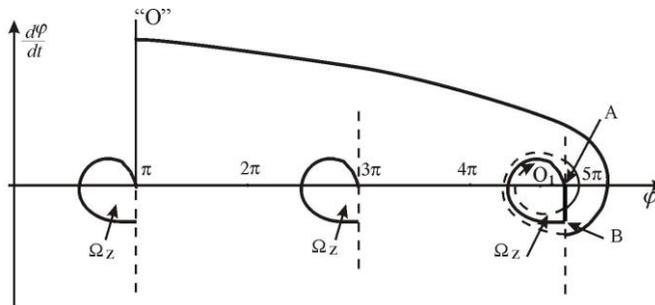
Fig. 4 show a phase portrait of PLL processes with increasing instantaneous frequency detuning.



**Fig. 4.** Phase portraits in the PLL with additional processes with increasing instantaneous frequency detuning.

It can be seen from Fig. 4 that the twofold application of additional control ensures that the imaging point is directed toward the target attractor.

Fig. 5 show the phase portrait of the process in the PLL with a very large instantaneous frequency detuning, when the phase incursion exceeds  $2\pi$  at the stage of applying additional control, which provides a change in the sign of the instantaneous frequency detuning.



**Fig. 5.** Phase portraits in the PLL with additional processes with very large instantaneous frequency detuning.

It can be seen from Fig. 5 that the process of approaching the imaging point to the target attractor begins with a phase shift of  $5\pi$ .

It can be seen from this figures that the imaging points fall into the inner region of the invariant manifold  $\Omega_z$ , and consequently, are attracted to the target attractor  $O_1$ .

## 5 Experimental study of the PLL with additional process control

The paper presents an experimental study of PLL systems built in accordance with the technical solutions [4, 5] with low-pass filter of 1, 3 and 7 orders, which showed the efficiency of these systems with initial frequency distributions close to the limits of the containment band.

Fig. 6, for example, show a photograph of the phase portrait of the processes in the system with detuning in frequency close to 0.9 from the hold band in frequency and 3 orders LPF. The stability margin of the system in phase is deliberately reduced, to such small values that the conservatism of the system manifests itself, i.e. oscillatory transient decays slowly.

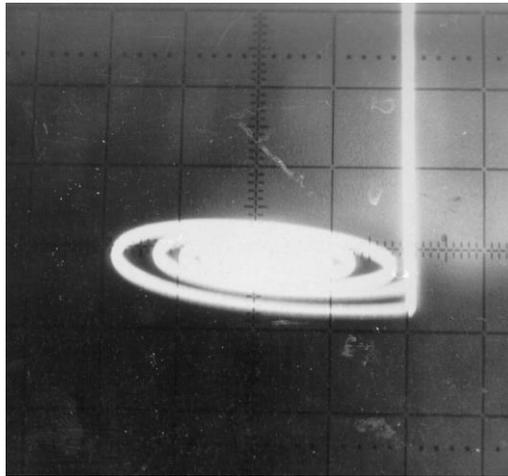


Fig. 6. Photograph of the phase portrait in the system in the PLL with the additional process control.

## 6 Conclusion

PLL systems in which the proposed algorithm of process control is realized, provide the required operation mode of operation under disturbances and interruptions of the main mode operation mode when switching of frequencies in accordance with the programme of time-frequency matrix that increases their efficiency in the radio communication systems with space-time signal processing.

## References

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