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Development of a Block Diagram of a Signal Generator of a UAV Radio Transmitter based on Auto Compensation of Phase Distortions

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Abstract:

A block diagram of a signal generator of a UAV radio transmitter with an auto compensator for phase distortion of a digital computational synthesizer with improved spectral characteristics compared to known solutions has been developed. The simulation of the operation of each link of the device in the clock area is carried out. The conditions for selecting the parameters of the shaper to achieve the greatest compensation of phase distortions are formulated.

Keywords: unmanned aerial vehicle, signal generator, direct digital synthesizer, phase distortion auto compensator.

Introduction

The successful operation of unmanned aerial vehicles (UAVs) of various classes and applications requires the implementation of a reliable communication channel with the ground control unit (GCU). The main tasks solved by the specified communication line are [1,2]:

− from the GCU to the UAV – transfer of UAV flight control commands and the use of third-party equipment;

− from the UAV to the GCU – transfer of the collected information with the help of targeted equipment (photography, video and audio recordings, etc.) and its further transfer to the GCU.

These radio lines vary significantly in bandwidth:

− The radio link from the GCU to the UAV is a narrow-band communication channel, because the amount of information transmitted even during the full flight time of the UAV and the operation of its equipment is small. The information transfer rate required in this channel, in any case, does not exceed several tens of Kbit/s (usually no more than 56 Kbit/s).

− The radio link from the UAV to the GCU should have, as a rule, much greater bandwidth. The specific value of the required transmission speed is largely determined by the purpose of a particular device and the indicators of the target equipment installed on it (usually 1-20 Mbit/s).

The effectiveness of information exchange using UAVs mostly depends on the characteristics of radio transmitters and their signal generation systems, which should provide reliable radio communication both between UAVs and between UAVs and GCU [3,4]. It follows from this that the primary task is to optimize the parameters of signal generation systems for data transmission lines, since they contribute to the growth of communication range and the quality of transmission of useful information by choosing the carrier frequency of data transmission, modulation methods, coding and other technical solutions.

One of the parameters of the signal generators of UAV radio transmitters is the spectral characteristics that need to be improved, and to be more precise, for reliable transmission and reception of information, it is necessary to have high values of the signal-to-noise ratio.

One of the methods for improving spectral characteristics is the method of phase distortion autocompensation, which is implemented by adding an autocompensator to the circuit, the principle of its operation which is as follows: a signal with phase distortion is applied to one of the inputs of the autocompensator, and a reference signal is applied to the other [5-9]. As a result, a compensating signal is formed, which is then used to suppress phase distortions.

The development of this device for the signal generator of a UAV radio transmitter on a modern element base and the analysis of its characteristics and effi-

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ciency is an urgent task, which is the purpose of this work.

Quadrature signal generator of a UAV radio transmitter based on a direct digital synthesizer (DDS)

We consider the following signal generation option. In this case, the block diagram of the signal generator of the UAV radio transmitter can have the form shown in Figure 1. The reference generator (RG) must operate at a frequency not higher than 30 MHz for optimal power consumption of the radio transmitter. This role will be filled by a highly stable reference frequency source based on a high-precision quartz oscillator. Also, the provided solution allows you to link the input signals of the quadrature modulator for each of the channels of the circuit. FM1 and FM2 are frequency multipliers of the reference generator: the first is needed to obtain the desired value of the carrier frequency and can be carried out by an indirect frequency synthesizer based on a phase-locked loop (PLL), the second is designed to obtain the clock frequency of a direct digital synthesizer (DDS), which must be at least twice higher than the upper frequency of its output spectrum [10-14]. LPF DDS1 and LPF DDS2 are anti-aliasing low-pass output filters for DDS, they perform the function of eliminating side spectral components that are above the clock frequency of the synthesizer in its output spectrum. I and Q are the quadrature outputs of the DDS. A quadrature modulator (QM) is necessary for generating signals with many modulation options that are relevant today in wireless communication systems [15].

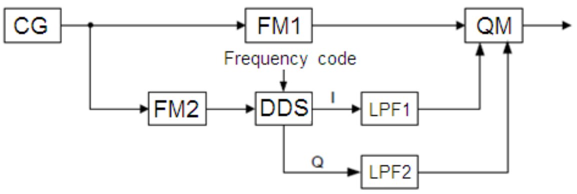

Figure 1 - Block diagram of the signal generator of the UAV payload radio transmitter

The disadvantage of this method of formation is the low spectral purity of the synthesized signals, due to the contribution of DDS.

The discrete part of the spectrum is a peak at the output frequency of the synthesizer and parasitic spectral components at certain detuning from the carrier. The formation of parasitic components in the output spectrum of the DDS is due to phase distortions caused by the nonlinearity of the digital-to-analog converter (DAC), the truncation of the phase code, the effect of destabilizing factors and the multiplicity of the input and output frequencies of the synthesizer.

The noise part of the spectrum is continuous, and fluctuations are called phase noise, which is random in nature and is determined by the magnitude of the spectral power density of phase noise. The cause of such fluctuations are the effects of quantization and the intrinsic noise of the semiconductor elements that make up the DDS.

To improve the spectral characteristics of the shapers, it is necessary to add an auto compensator of phase distortion (ACPD) to the DDS based on the isolation of an antiphase interference signal based on phase detection, subsequent amplification of this signal and low-frequency filtering.

Formation of signals of a UAV radio transmitter with an auto compensator of phase distortions

The operation of the ACPD control signal generation path consists in the isolation of phase distortions of the DDS output signal and their subsequent processing. Direct suppression of phase distortions is performed in accordance with the selected control (compensating) signal, which is formed in the control path of the ACPD (Fig. 2).

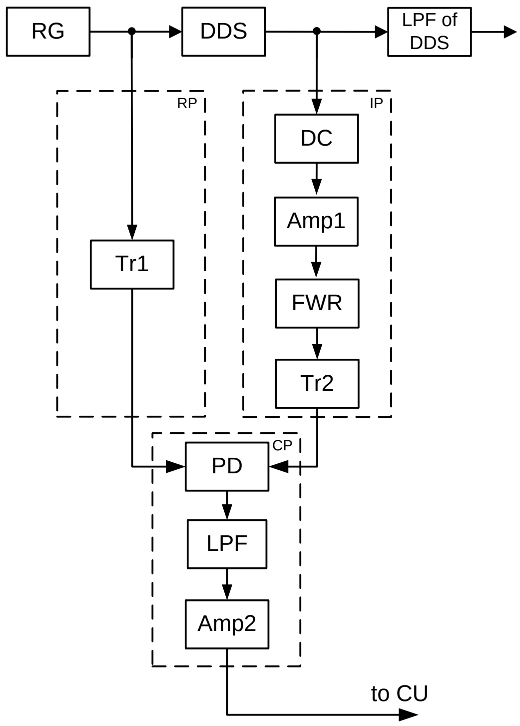

Figure 2 - Block diagram of the ACPD control signal generation path

The following designations are accepted in the scheme: CG - reference clock generator, DDS - direct digital synthesizer, LPF - low-pass filter, DC - differentiating circuit, Tr - trigger, FWR - full-wave rectifier, PD - phase detector, RP - reference path, IP - information path, CP - control path.

The signal from the output of the DDS with phase distortions enters the information path IP of the autocompensator, from the input of the DDS – to its reference path PR. At the inputs of the reference and information paths, the signals differ not only in phase, but also in amplitude and shape. Signal processing in both paths allows you to align their shapes and amplitudes. At the same time, the phase shifts of the signals are preserved.

To obtain an information signal, the output signal of the DDS is differentiated in the DC, amplified and fed sequentially to a full-wave rectifier FWR, an amplifier A and a trigger Tr2. The purpose of the triggers Tr1 and Tr2 is to switch abruptly from one stable state to another at the moment of the appearance of the control edge of the signal with positive polarity.

The control path CP receives signals from the reference and information paths where subsequent processing is carried out, which consists in comparing the phases of the signals produced by the phase detector PD. As a result, rectangular pulses are obtained at the detector output, describing the difference between the time parameters of the reference and information signals, in other words, phase distortions at the output of the DDS. Further processing of pulses from the PD output is carried out in the low-pass filter LPF, where the constant component of the signal is isolated and the Amp3 amplifier is used to convert the control signal to the required level. The principle of operation of various blocks of the ACPD control path in the form of transient diagrams is shown in Figure 3.

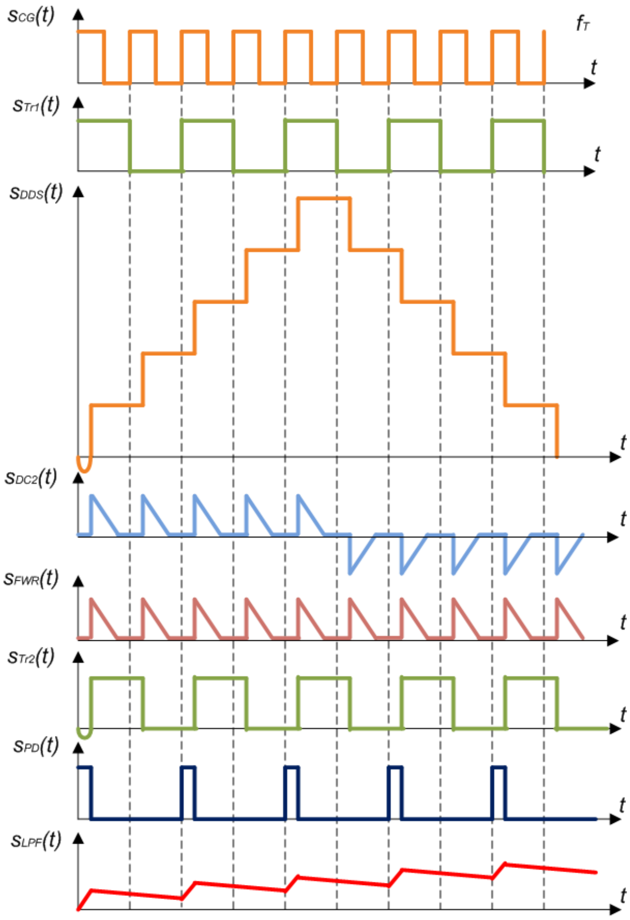

Figure 3 - Transients of signals at the outputs of various blocks of the ACPD control signal generation path

For the output frequencies of the DDS no more than 30 MHz, perturbation control and the simplest control based on a controlled phase shifter (CPS) can be used. Auto-compensators with forward adjustment do not have a static compensation error. They are stable under any characteristics of the constituent units, which facilitates the construction of ACPD with complex selectivity characteristics. The disadvantage of autocompensators with such an adjustment is the fact that the phase of the output signal is not controlled by the feedback circuit and full compensation of phase distortion is possible only with an accurate selection of the characteristics of the component links.

Since the DDS has two quadrature outputs, it is necessary to compensate for each output signal. To do this, we use a control device of two CPSs and a 90-degree phase shifter (Fig. 5).

When combining the signal generator circuit (Figure 4) with the circuit of the formation path of the ACPD control signal (Figure 2), we obtain the resulting circuit of the signal generator of the UAV radio transmitter with an autocompensator of phase distortions, shown in Figure 6.

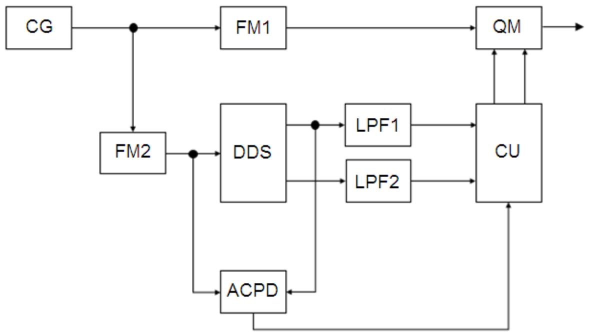

Figure 4 – Diagram of the signal generator of the UAV radio transmitter with an autocompensator of phase distortions

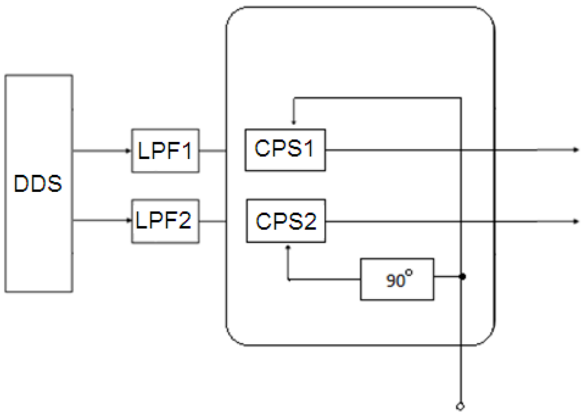

Figure 5 – Communication circuit of the DDS with the control device

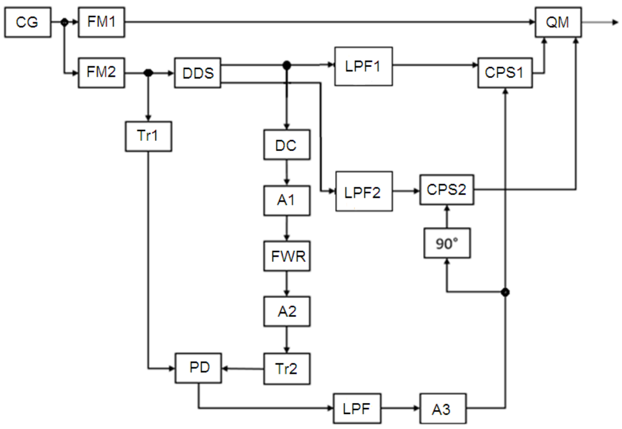

Figure 6 - The resulting circuit of the signal generator of the UAV radio transmitter with an autocompensator of phase distortions

Simulation of the signal generator

Using the obtained block diagram of the phase distortion autocompensator of the payload signal generator of the UAV radio transmitter, we will conduct its simulation. The signal of the clock generator is set as a meander with a frequency of 4 MHz and an amplitude of 4 V. The limiting thresholds of the amplifier U1 are set to -1.39 V and 1.39 V.

Figure 7 shows the spectrograms of the DDS output signal at an output frequency of 12 MHz when the conditions of full compensation are met, with a deviation of 25% from these conditions, with a deviation of 50% from these conditions, with a deviation of 75% from these conditions and with an open autocompensation loop.

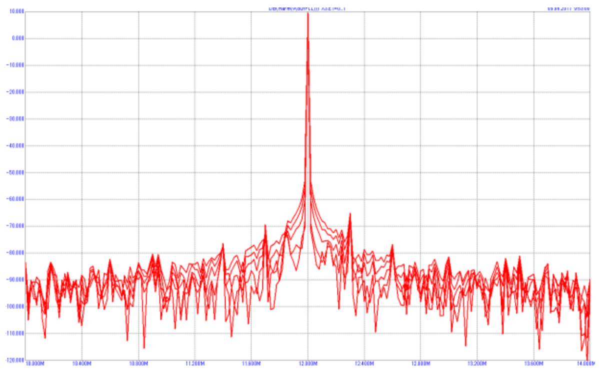

Figure 7 – Spectrograms of the DDS output signal at a frequency of 12 MHz at various gain coefficients of the amplifier A3

It follows from the obtained graphical dependencies that the closer the values of the coefficients of amplifier A3 are to the conditions of complete suppression, the higher the compensation of phase distortions of the DDS is observed. At the same time, the greatest compensation is observed when the coefficient is adjusted to 25% relative to the specified conditions.

Conclusion

The structural scheme of the signal generator of the payload of the UAV radio transmitter based on the phase distortion autocompensator was developed and its study was carried out in the Micro-Cap circuit modeling program in the frequency domain. It is established that the reference generator of the shaper should not operate at frequencies above 30 MHz, which is due to the optimal power consumption of the radio transmitter. This condition is fulfilled by using a highly stable reference frequency source based on a high-precision quartz oscillator with subsequent multiplication of its output frequency. According to the specified range of output frequencies of the direct digital synthesizer, it was concluded that the elements of the device can be implemented on high-speed transimpedance amplifiers. The conditions for selecting the parameters of the shaper to achieve the greatest compensation of phase distortions are formulated.

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