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Application of Phase Distortion Autocompensation to Improve the Spectral Characteristics of Signal Generators of UAV Radio Transmitters

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Abstract

This article is devoted to the application of the method of automatic phase distortion compensation of direct digital synthesizers (DDSs) to improve the spectral characteristics of signal generators of radio transmitters of unmanned aerial vehicles (UAVs) operating as part of flying ad-hoc networks (FANET) in "smart cities". A block diagram of a universal signal generator for UAV radio transmitters is considered, based on the use of a quadrature modulator and obtaining a carrier oscillation from a reference one using a frequency multiplier based on a phase-locked loop (PLL) and information quadrature components using a DDS. It is shown that one of the key requirements for signal generators of UAV radio transmitters is the spectral purity of the synthesized signals. It is noted that the proposed version of the device has insufficient spectral purity due to the presence of a DDS in the generator, because its output signal spectrum contains a noise component and a set of discrete spectral components of a significant level. It was found that known methods of improving the spectral characteristics are not efficient enough; therefore it was suggested to use the principle of automatic compensation of phase distortion. A block diagram of generating control signals was proposed for its implementation, and analysis of normalized amplitude-frequency characteristics of the proposed scheme was shown.

Keywords: smart cities, ad-hoc networks, unmanned aerial vehicles, signal generators, spectral characteristics, phase distortion, auto-compensation.

1. INTRODUCTION

The management of resources and components of the economy of modern large cities and mega-cities is increasingly based on advanced intelligent technologies from various branches of science and technology, which allows us to call cities that use these principles the term "smart" [1-6]. One of the features of these cities is the active introduction and use of information and telecommunications technologies (Internet-of-things technologies, 3G/4G networks, broadband and mobile Internet access) which are implemented using mobile automated technical means to solve a wide range of tasks.

A promising direction for the development of information and communication technologies in modern "smart cities" is the creation and active use of wireless mobile ad-hoc networks (MANET) and their special case–flying ad-hoc networks (FANET) [7-10], designed for network interaction between small-sized unmanned aerial vehicles (UAVs) [11-13].

The ability to equip communication nodes of FANET networks with additional onboard load (technical equipment, sensors, photo and video cameras, etc.) makes them an effective means of performing various flight tasks involving high-speed data transmission in real time. So the presence of special software and hardware on board the UAV opens up prospects of FANET for the following tasks: access of residents of "smart cities" to high-speed Internet; transmission of video broadcasts from crowded places; shooting topographic plans and maps; monitoring significant objects, location and movement of transport, collecting information about urban traffic jams; monitoring environmental pollution, preventing or reducing the consequences of accidents; searching for people in natural disasters; ensuring public safety, etc.

The successful implementation of these functions is largely determined by technical solutions at the physical level of the open system interconnection (OSI) network model due to the choice of signal generators of UAV radio transmitters, carrier frequencies of transmitted radio signals, as well as modulation and encoding methods [14-21]. At the same time, one of the key requirements for signal generators [22-25] of UAV radio transmitters is the spectral purity of the synthesized signals, which is determined by the level of discrete spurious spectral components (SSC) and the noise component in the output signal spectrum of the device.

1.1. Signal generators for UAV radio transmitters

Signal generators of modern UAV radio transmitters, as a rule, transmit high-speed payload information in the frequency range of 1.2…5.8 GHz using various digital modulation methods (BPSK, QPSK, 8-PSK, 16-APSK, QAM), as well as the encoding mode with orthogonal frequency multiplexing (OFDM). At the same time, the choice of the carrier frequency and modulation method depending on the communication range, the speed of the UAV and the specific interference situation allows to get different data transfer rates of useful information.

To provide the possibility of adaptive changes in the carrier frequency of the transmitted signal and the modulation method used in this case, a universal approach to signal generation in UAV radio transmitters can be used, based on the quadrature modulator (QM), which is a universal device that can be used to receive signals with almost all types of modulation in modern wireless communication systems. In this case, the quadrature components of the carrier oscillation are formed directly by the QM itself, and the quadrature components of the information signal are formed using a direct digital synthesizer (DDS) [26-31] as shown in Fig. 1. The following designations are used in the diagram: RG–reference generator, PLL–frequency multiplier based on a phase-locked loop, FM–frequency multiplier of the reference oscillation (transistor cascade or PLL loop), LPF1 and LPF2–anti-aliasing low-pass output filters for DDS, I and Q–quadrature outputs of the DDS.

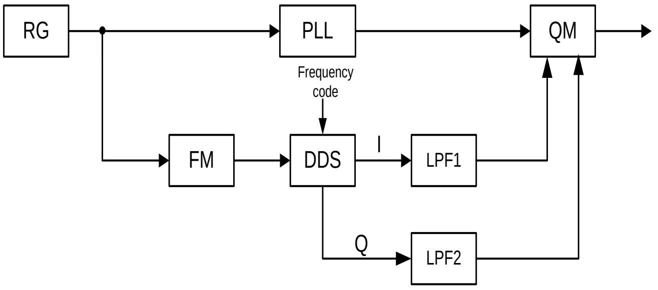


Fig. 1: Block diagram of the signal generator of the UAV radio transmitter

The level of SSC (minus 60 to minus 90 dB) of the synthesized oscillations of the generator is determined by the contribution of DDS. At the same time, the level of phase noise (minus 90 to minus 120 dB at 1 kHz offset from the carrier oscillation for different frequencies) is determined by the PLL and to a lesser extent - by the contributions of DDS and the reference oscillator.

Currently, there are two main methods for improving the spectral characteristics of DDS, which include filtering and randomization, which, however, have limited application and are not effective enough. Thus, when using filtering, there is always an extremely high probability that discrete high-amplitude SSC will fall into the filter bandwidth, and as a result of randomization, the SSC level decreases, but the noise level increases.

1.2. Application of the method of automatic phase distortion compensation to improve the spectral characteristics of signal generators of UAV radio transmitters

The authors' research has shown that an effective method for improving the spectral characteristics of signals synthesized by DDS is automatic phase distortion compensation (APDC) of the DDS [32-35], which reduces both undesirable discrete and noise spectral components present in their output spectrum.

Fig. 2 presents a block diagram of the control signal generator for the APDS of the DDS, which eliminates the differences between the reference and information signal of the APDS in amplitude and shape while preserving phase shifts. The following designations are used in the diagram: RG-reference generator (or clock frequency source), RP–reference path, IP–information path, CP–control path, Tr1 and Tr2 –T-triggers, DC–differentiating circuit, Amp1 and Amp2–amplifiers, FWR–full-wave rectifier, PD–phase detector, CU–control unit.

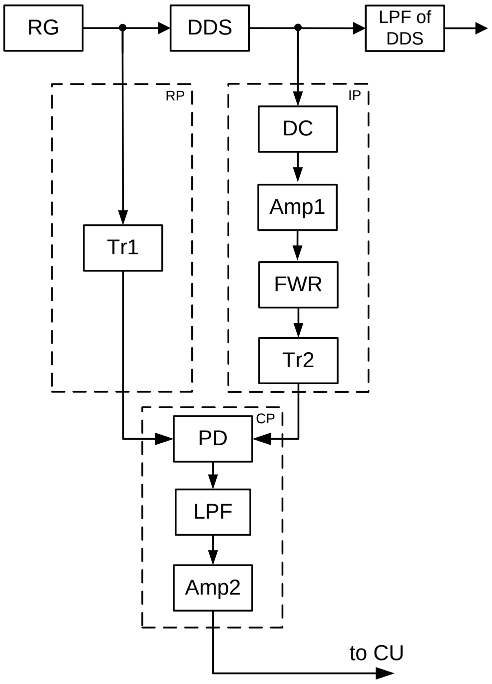
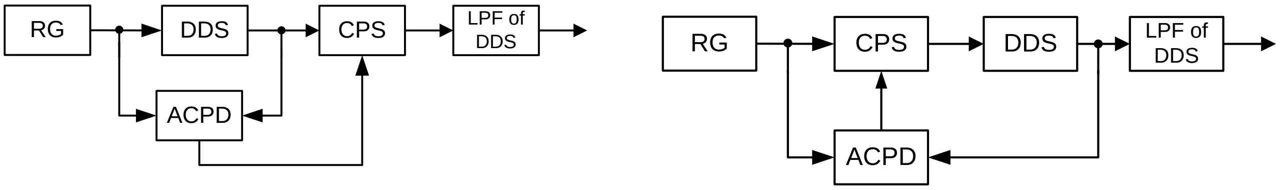


Fig. 2: Block diagram of the control signal generator for the APDS of the DDS

Since the frequency of information signals for a quadrature modulator is an order of magnitude less than the carrier, it is easiest to use a controlled phase shifter (CPS) as an APDS control unit (CU), its decreasing of phase distortion is based on antiphase modulation of the input or output signal of the DDS in accordance with the APDS control signal. In this case, several types of regulation can be used: perturbation, deviation, or combined. Schemes with perturbation control are stable for any characteristics of the components, but full compensation of phase distortions in them is impossible. Ones with deviation control are devoid of this disadvantage, but have a static compensation error. Schemes with combined control combine the advantages of both previous schemes, but have more complicated structure. Figure 3 shows as an example the structural diagrams of the DDS with APDS using regulation by perturbation and by deviation. The scheme with combined regulation is obtained by combining these principles.



(A) (B)

Fig. 3: Structural diagrams of the DDS with APDS and regulation by perturbation (A) and deviation (B)

Figure 4 shows for comparison the normalized amplitude-frequency response of signal generators of UAV radio transmitters with APDS and various types of regulation (here Foffset is offset from the carrier frequency, and Fcut is cutoff frequency of the LPF of DDS). Response was calculated based on the analysis of phase distortions of the constituent blocks (transmission coefficient of DDS is equal to 0.25).

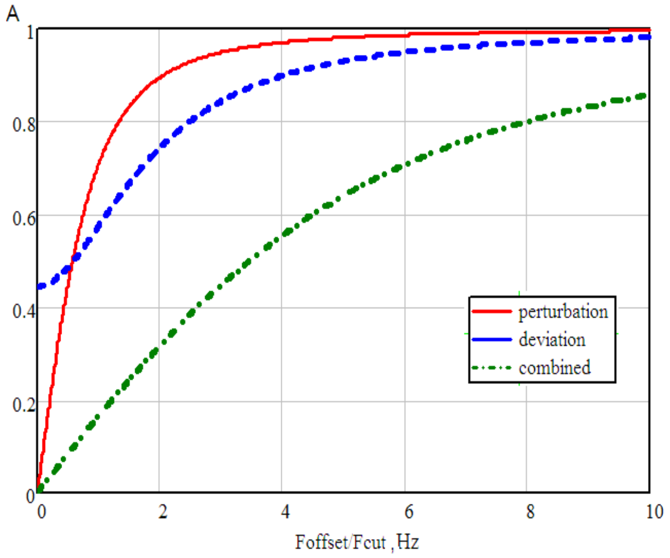


Fig. 4: Normalized amplitude-frequency response of signal generators of UAV radio transmitters with APDC of DDS with regulation by perturbation (red), deviation (blue) and combined regulation (green)

From Fig. 4, it follows that the proposed signal generators provides full compensation for phase distortions of the DDS in the region of small offset from the carrier oscillation (as in the case of perturbation regulation) and better suppression of phase distortions in the remaining frequency range. At the same time, the frequency band in which the main phase distortion suppression is performed is determined by the cutoff frequencies of the low-pass filters of the APDC.

2. CONCLUSION

The method of automatic phase distortion compensation proposed in this work can effectively reduce the level of DDS-caused undesirable discrete and noise components in the output signal spectra of UAV radio transmitter signal generators. At the same time, based on the obtained frequency response, the expected compensation of discrete PSS caused by phase distortions, depending on the type of regulation scheme used, can be about 30 dB (perturbation, deviation or combined regulation). In turn, to assess the decrease of noise of the DCS and the entire signal generator of the UAV radio transmitter, it is necessary analyze equivalent functional models of signal generators taking into account all existing sources of phase noise.

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