Sounding Signal Generator for Geodynamic Monitoring Systems of the Geological Environment Based on Geoelectric Control Methods

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Abstract To generate sounding signals for geodynamic monitoring systems of the geological environment based on geoelectric control methods, various generating equipment is currently used, which has a number of characteristic disadvantages that significantly reduce their effectiveness to ensure the desired technical characteristics. Based on the features and requirements imposed on the radiating paths of geodynamic monitoring systems based on geoelectric control methods, it is proposed to implement a universal signal generator based on digital computational synthesizers (DDS), which allows high accuracy of synthesized signals, extremely high frequency resolution, high switching speed, ease of control and the possibility of forming complex signals. To improve the spectral characteristics of the DDS, it is proposed to use the method of automatic phase distortion compensation. Two original algorithms have been developed to isolate phase distortions and form a compensating signal. A block diagram of a signal generator and transfer functions for the main impacts were proposed. The amplitude-frequency characteristics of the signal generator based on the phase distortions of the DDS for an autocompensator with deviation control are obtained, as well as the compensation degree at different scheme parameters.

Keywords–agro-industrial complex, signal generators, digital computing synthesizers, automatic compensation.

Introduction

Modern geodynamic monitoring systems [1-3] of the geological environment, implemented on the basis of geoelectric methods [4-9] can assess and monitor the state of resources of the agro-industrial complex, are complex software and hardware complexes. The generated electric fields can be divided into infrasound, sound, radio wave and microradiowave, and the measured parameters in most cases are the amplitude and phase components of the field. When using infrasound radiation, the sounding frequency is within 1 MHz - 1 Hz at a depth of about 1000 m; when using sound radiation within 1 kHz at a depth of about 100 m; when using radio wave radiation within 1 MHz at a depth of about 10 m; when using microradiowave radiation within 1 GHz at a depth of about 10 cm . Accordingly, various generating equipment is currently used to generate probing signals in these ranges.

The currently used methods and devices have a number of characteristic disadvantages that significantly reduce their technical characteristics. The formation of noise-resistant sounding signals for geodynamic monitoring systems will allow:

- to develop a single universal approach to the formation of sounding signals with the possibility of controlling their parameters, suitable for various methods of geodynamic monitoring based on geoelectric methods;
- to increase the sensitivity of detecting small geodynamic changes in the near-surface zones and the initial signs of the development of possible catastrophic geo-technical processes by forming probing signals with increased spectral characteristics;
- to increase noise immunity when detecting small geodynamic changes in near-surface zones and initial signs of the development of possible catastrophic geotechnical processes and to reduce the power of probing signals to increase their secrecy due to the formation of modulated probing signals with a broadening of their spectra;
- to identify weak signs of geodynamic activity caused by natural and man-made factors (landslides, landslides, karst-suffusion processes).

Selection of a method for generating probing signals for geodynamic monitoring systems of the geological environment based on geoelectric control methods

The sounding signal generator [10-13] is one of the main elements of any modern geodynamic monitoring system based on geoelectric methods. It is designed for the formation and operational change of parameters of probing signals with the required resolution in a given frequency range of the system. Depending on the type of probing signals, the design of the transmission path and the geoelectric methods used, this unit can be either single-channel or multi-channel. At the same time, in the case of a multichannel signal generator, one highly stable reference frequency source should be used, which will ensure the coherence of the synthesized signals for each of the formation channels separately and, accordingly, coherent processing of the received signals.

The main requirements for each of the signal generation channels of the geodynamic monitoring system based on geoelectric methods are:
- wide frequency range of output signals (in some cases up to tens of megahertz);
- high frequency resolution (hertz – fractions of hertz);
- acceptable speed when switching to a new frequency (as a rule, units – hundreds of microseconds).

The requirement to change the probing frequency in a wide range and with a low frequency resolution is due to the need to register, based on the skin effect, even minor changes in the state of the probed geological environment in the geodynamic monitoring zone, the presence of vertical and spatial inhomogeneities in it, as well as the fact that the complex permittivity of most media has seasonal and geographical dependence.

In addition, one of the most important parameters of any signal generator is the permissible spectral characteristics that determine the sensitivity of the receiving paths and the difficulty of isolating a useful signal against the background of interference. These characteristics are determined by two components - the level of discrete parasitic spectral components and phase noise. Typical requirements for discrete parasitic spectral components are a level of no more than minus 60 – minus 75 dB in the near zone of the generated oscillation and a spectral power density (SPD) of phase noise of no more than minus 90 - minus 110 dB when detuning 1 kHz from the carrier frequency.

The specified requirements for modern signal generators of geodynamic monitoring systems based on geoelectric methods are quite stringent and lead to the need for continuous improvement of the methods of constructing their nodes to ensure the required characteristics.

Theoretically, signal generators of geodynamic monitoring systems based on geoelectric methods can be implemented on the basis of one of three methods of frequency synthesis: direct analog, indirect based on phase-locked frequency systems (PLL) and direct digital synthesizers (DDS). Each of these synthesis methods has both advantages and characteristic disadvantages that limit their use.

Advantages of synthesizers of the direct analog synthesis method: short time and small step of frequency tuning, low level of phase noise. Disadvantages: significant weight and size indicators, large power consumption.

Advantages of PLL-based synthesizers: small dimensions and power consumption, small number and low level of discrete side components of the output signal spectrum. Disadvantages of PLL-based synthesizers: low speed, broadening of the spectral line near the carrier.

Advantages of DDS: a wide range of output frequency tuning, high frequency resolution, small dimensions, short adjustment time. Disadvantages of DDS: relatively low output frequencies, a significant level of discrete parasitic spectral components of the output signal.

Based on the features and requirements imposed on the radiating paths of geodynamic monitoring systems based on geoelectric control methods, it is proposed to implement a universal signal generator based on DDS, which allows for high accuracy of synthesized signals, extremely high frequency resolution, high switching speed, ease of control and the possibility of forming complex signals [14-18]. In this case, the formation of probing signals with the required parameters will be achieved by operational changes in real-time control codes of amplitude, frequency and phase coming from a computer, a microcontroller (MC) or a programmable logic integrated circuit (FPGA) on a DDS in the form of an integrated circuit containing a phase accumulator (PA), read-only memory (ROM), digital-to–analog converter (DAC), external reference clock generator (RG) and low-pass filter (LPF) - Fig. 1.

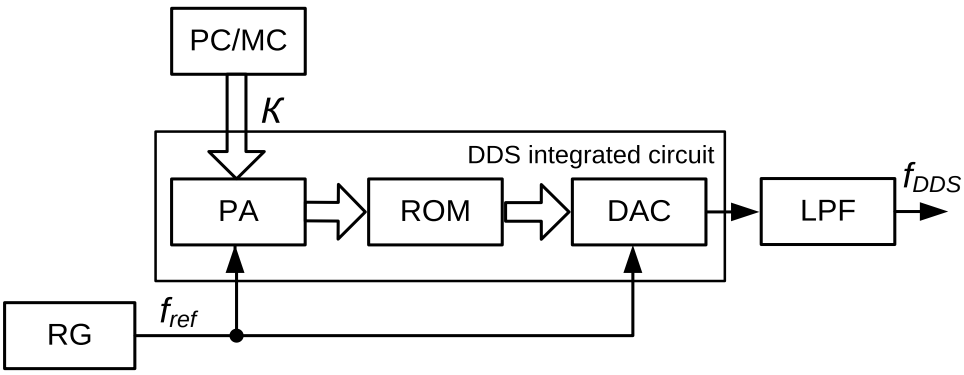

Fig. 1. The block diagram of the DDS

Automatic phase distortion compensation based on direct digital synthesizers

To improve the spectral characteristics of DDS, the method of automatic phase distortion compensation (ACFI) is proposed [19-21]. Two original algorithms have been proposed to isolate phase distortions and form a compensating signal of the autocompensator (Fig. 2,3).

The main stages of the first algorithm are illustrated by time diagrams explaining the features of processing the output signal of the clock generator.

The idea of the proposed algorithms is that in the presence of a parasitic phase modulation of the output signal of the DDS, all components of the spectrum are modulated according to the same law as the synthesized frequency, but with different modulation indices (Fig. 2). Since the clock frequency is constant, then highlighting it in the output In the DDS spectrum, it is possible to automatically compensate for phase distortions of the synthesizer output signal at a given frequency.

The differences between the algorithms are that in the first case, phase distortion detection is carried out at a frequency two times less than the clock frequency, and in the second - directly at the clock frequency. To do this, in the first case, the processing of the output signal of the clock generator involves the formation of a reference signal for phase detection using a T-trigger, which divides the frequency of this signal into two and an information signal obtained by synthesizing the signal in the DDS, differentiating, amplifying, nonlinear conversion in a full-wave rectifier and dividing the frequency of this signal into two. In the second case, the output signal of the clock generator is initially a reference signal for phase detection, and the information signal is obtained by signal synthesis in the DCS, differentiation, nonlinear transformation in a full-wave rectifier, bandpass filtering and amplification. Further processing of the detected signals for both algorithms is the same and consists of phase detection and low-frequency filtering with subsequent amplification.

The most important advantage of the first algorithm is the implementation of phase correction at a reduced frequency of the clock generator by half, the second is the simplicity of implementation. However, in the second case, the change in the clock frequency of the DCS requires a reconstruction and correction of the bandpass filtering parameters.

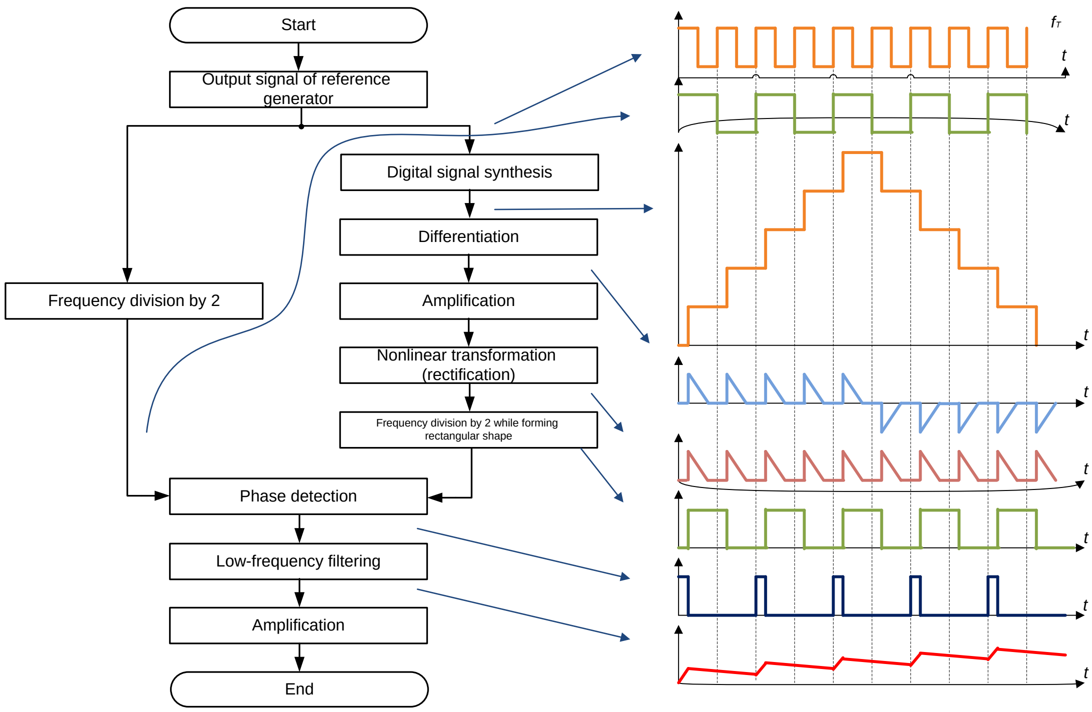

Fig. 2. Algorithm and time diagrams of the formation of the control signal of the DDS ACFI with detection at a frequency two times less than the clock signal

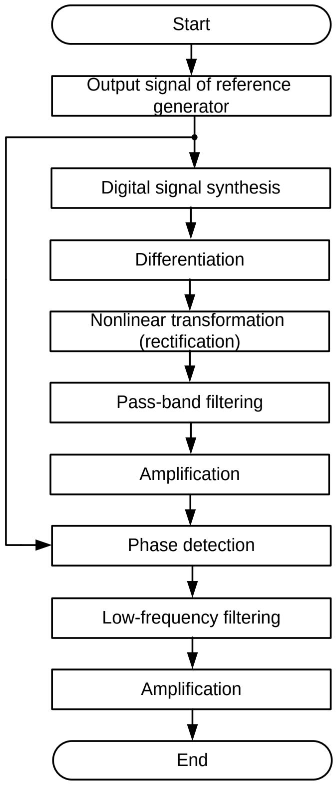

Fig. 3. Algorithm for generating the control signal of the DDS ACFI with detection at the clock signal frequency

Sounding signal generator for geodynamic monitoring systems of the geological environment based on geoelectric control methods

As an autocompensator control device in the frequency range up to several tens of MHz, it is easiest to use a controlled phase shifter. The reduction of phase distortion in it is based on the antiphase modulation of the input or output signal of the CVR in accordance with the control signal of the autocompensator. Depending on where information about phase distortions is allocated in the circuit, several types of auto-compensators can be developed depending on the type of regulation, each having characteristic advantages and disadvantages.

Figure 4 shows a block diagram of a signal generator f based on DDS with automatic phase distortion compensation, supplemented by a power amplifier (Amp) to convert the output signal to the required level. The following designations are adopted in the scheme: DC - differentiating circuit, Tr - trigger, FWR - full-wave rectifier, PD – phase detector, Amp - amplifier, CPS - controlled phase shifter.

The functioning principles and the block diagram of the control path are similar to the one described above. In this scheme, the output voltage of the control path is proportional to the phase deviation of the output signal of the automatic phase distortion compensation, and an accurate selection of the characteristics of the component links is not required. The disadvantage of feedback in these schemes is the presence of a static compensation error; its elimination requires the scheme adjustment. In addition, there is the possibility of self-excitation and inertia. This is due to the fact that the suppression of phase distortions starts only after they pass to the output of the autocompensator.

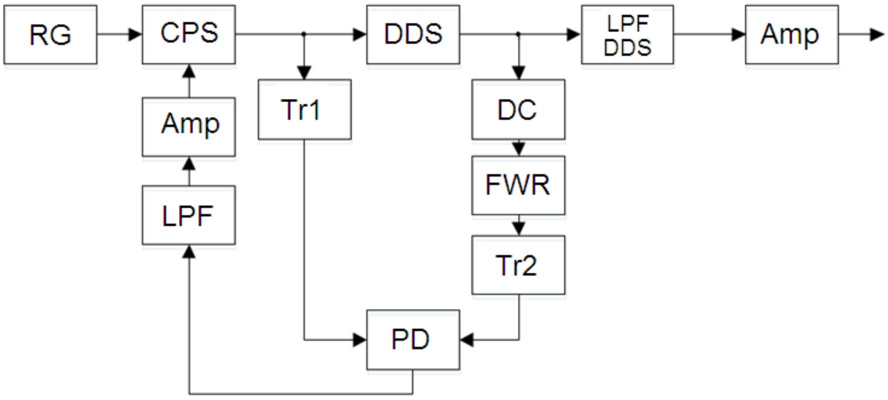

Figure 4 – Block diagram of the sounding signal generator for geodynamic monitoring systems of the geological environment based on geoelectric control methods

Modeling of the characteristics of the sounding signal generator for geodynamic monitoring systems of the geological environment based on geoelectric control methods

On the basis of this functional scheme, the transfer functions of the shaper for the main impacts are determined. Phase deviation of the DDS Δε has the following form:

$$H_{\Delta\varepsilon} = \frac{K_{п} K_{Amp}}{1 + K_{CPS} K_{PD} M_A(p) n_{Amp\_ACPI} \frac{1}{2}}$$

where K or n – transfer coefficient of the correspondent block for phase deviation, $M_A(p)$ - transfer function of the ACPI filter.

It follows from this transfer function that in order to fully compensate the deviations of the phase of the DDS, its denominator must strive to infinity, i.e. the values of n_{Amp_ACPI} should be the maximum possible.

An important property of the proposed variant of the signal generator is the selective suppression of phase distortion of the output signal of the DDS in a given range of the frequency spectrum, which is ensured by the introduction of a low-pass filter with the corresponding selectivity characteristic into the control paths of the ACFI. Figure 5 shows the amplitude-frequency characteristics of the signal generator according to the phase distortion of the DDS for ACFI with deviation control and the first-order low-frequency control path with normalized device parameters and $K_{DDS} = 0.25$.

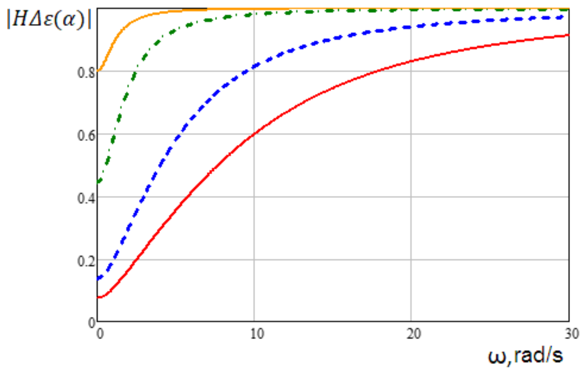

Figure 5 – Amplitude-frequency characteristics of the signal generator by phase distortion of the DDS for the device with deviation control (orange at $n_{Amp\_ACPI} = 2$, green at $n_{Amp\_ACPI} = 10$, blue at $n_{Amp\_ACPI} = 50$, red at $n_{Amp\_ACPI} = 100$)

Figure 6 illustrates the dependence of the degree of maximum achievable automatic compensation of discrete parasitic spectral components of the DDS output signal on the gain of the ACFI control path amplifier with deviation control.

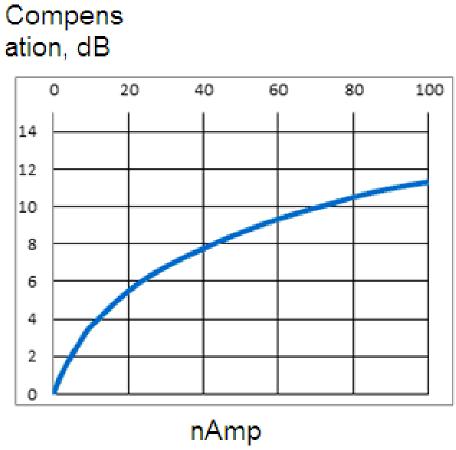

Figure 6 – Dependences of the maximum degree of automatic compensation of the output signal of the DDS on the amplifier gain of the control path of the ACFI

Conclusion

From the Fig. 6, it is clearly seen that the higher the gain of the amplifier in the control path of the ACFI, the lower the transmission of phase distortion of the DDS to the output of the signal generator. As a result, it can be concluded that ACFI with deviation control does not allow to obtain complete suppression of phase distortions (due to the impossibility of implementing infinitely large gain coefficients in practice). For all the amplitude-frequency characteristics shown in Figure 6, the frequency band in which the main suppression of phase distortion of the DDS is carried out is determined by the cutoff frequency of the ACFI filter used. This conclusion allows to choose the parameters of the ACFI signal filtering device from a compromise between the desired reduction of phase distortion of the DDS and the required selective properties.

Thus, the degree of automatic compensation of phase distortions present in the output signal of the DDS of the sounding signal generator for geodynamic monitoring systems of the geological environment based on geoelectric control methods is determined by two factors: the amplitude-frequency characteristic of the phase distortions of the DDS and the conditions of full compensation. When these conditions are reached, the phase distortions of the DDS output signal are compensated, and the corresponding parasitic spectral components and noise components are completely eliminated from the spectrum of both the DDS and the entire signal generator, respectively. However, in practice this is not achievable, so the parameters of the autocompensator links will have values close to the conditions of full compensation. The more the values of these parameters approach these conditions, the lower the transmission of phase distortions of the DDS to the output of the device.

Based on curve 7, it is possible to select the gain coefficients of the amplifiers of the control paths of the ACFI.

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