Investigation of Methods for Ensuring Electromagnetic Compatibility of Atmospheric Radiosonde Systems

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***Abstract*—Upper-air radiosondes, which transmit coordinate-telemetric information on the main meteorological parameters to the ground station, contain a transmitter and, in some cases, a receiver of GLONASS / GPS satellite navigation systems. The known methods providing electromagnetic compatibility of transmitting and receiving systems cannot be fully applied in this case, taking into account the specifics of the radio sounding system. This paper is devoted to the development and study of methods for reducing the influence of out-of-band emissions from a radiosonde transmitter on navigation signal receivers and other communication systems operating in close frequency bands.**

Keywords*— *radiosonde systems, radiosonde, spread spectrum, Glonass, GPS.

I. Introduction

Atmospheric radio sounding (ARSS) systems are designed to obtain the most accurate upper-air information on the thermodynamic parameters of the free atmosphere, such as temperature, humidity, pressure, wind direction and speed, as well as to measure special parameters (radiation, industrial emissions of gases, aerosols, etc.) p.) at altitudes from the ground level to 35 ... 40 km. ARSSs use the contact sensing method with the help of ballooning radiosondes or radiosondes being dropped on a parachute. The obtained data are necessary for the formation of short-term and long-term weather forecasts, the prevention of natural and man-made disasters, the assessment of their consequences and recommendations for reducing environmental damage in the interests of the national economy, as well as to predict climate variability on a global scale. The upper-air network of the Russian Federation is part of the global world radio-sounding network and conducts upper-air observations in accordance with the requirements set forth in the regulatory documents of the World Meteorological Organization (WMO) [1].

In the last decades, two main methods of determining the location during the flight of the upper-air radiosonde (ARZ) have been established - radar and radio navigation. In the first case, the current coordinates of the ARZ calculates ground radar based on the results of measuring the slant range, the angular direction to the radio probe and its own geographical coordinates. In the second case, the radiosonde determines its coordinates independently according to the data of the onboard receiving module GLONASS/GPS, after which it sends them over the radio to the ground base station (BS). In the SR, a packet method is used to transfer ARZ coordinate-telemetric information to the ground complex.

In the Russian Federation, a radar ARSS developed on the basis of the Vector-M radar, MARL and the MRZ-3, MRZ-3MK type radar probes was created and operated. Radios of the radionavigation type are widely used abroad by such manufacturers as Vaisala, Graw, Modem, Meteolabor, Sippican, etc. In the Russian Federation, a radionavigation ARSS “Polyus” has been established, which is operated at the Baikonur and Vostochny cosmodromes, the aerological network of Roshydromet.

II. Electromagnetic Compatibility Issues

For radio electronic systems (RES), providing tracking of ARZ transmitter signals during flight, frequency bands for radio navigation ARSS in the range 401-406 MHz, for radar ARSS in the range 1670-1690 MHz in [3] are allocated. According to WMO, more than 2000 ARZs are launched per day in various regions of the globe [1]. During the operation of ARSS, a bilateral problem of electromagnetic compatibility (EMC) arises with other RES for various purposes, terrestrial, airborne and space-based. On the one hand, the out-of-band emission of ARZ transmitters may, for example, fall into the reception band of GLONASS/GPS signals in the ranges of 1575-1590 MHz and 1601-1606 MHz, cellular communication systems, on the other hand, out-of-band emissions of other RES may suppress receiving devices of ARZ, land receivers Radar and base stations. To ensure the EMC ground radio electronic systems are developed according to strict requirements for out-of-band emissions of radio transmitting devices and the relevant requirements for the filters of the input circuits of the receiving electronic devices [4]. In the ARZ development also taken constructive and technological measures to improve the EMC performance. However, due to the minimization of the cost and flight weight of the ARZ, these methods cannot be used to the full. Another direction of increasing EMC can be associated with the development of a structural scheme for constructing an ARZ, for example, based on the application of methods of broadband generation of radiated signals and their digital processing in the receiving device of the ground ARSS complex.

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It is necessary to consider in more detail the factors that determine the out-of-band emission of radio electronic devices. Reducing interference caused by unwanted emissions of ARZ transmitters can be implemented by the following technical solutions [5]:

1. Optimization of transmitter architecture;

2. Filtration of transmitter radiation;

3. Modulation methods of transmitter radiation;

4. Improving the linearity of the transmitter characteristics by pre-distortion signal; use of a positive direct connection; use feedback; applying modulation feedback; use of the modulation transfer technology "Polar Loop"; implementation of technology using the Cartesian loop.

Given the wide variety of different architectures and possible methods for reducing radiation, the list presented above should not be considered exhaustive.

Another reason for out-of-band emissions is the non-linearity of the terminal amplifier. The theoretical nonlinearity, which is commonly used in a high-power amplifier model, is a non-memory envelope model. At the amplifier input, the signal in the passband can be represented in a general form with amplitude-phase modulation:

$$s(t) = A(t)\cos(2\pi f_c t + \phi(t)) \qquad for \qquad f_c >> B \qquad (1)$$

Where: f_c is the carrier frequency; B is the bandwidth of the transmitted signal; $A(t)$ is the envelope of the transmitted signal; $\varphi(t)$ is the phase of the transmitted signal.
It is assumed (ideally) that the harmonics of the nonlinear distortion of the signal at the component frequencies of the carrier are suppressed by the first zonal bandwidth of the amplifier. The signal at the output of a high-power amplifier is:

$$s_{fz}(t) = f(A(t))\cos[2\pi f_c t + \varphi(t) + \Phi(A(t))] \qquad (2)$$

The distortions produced by the non-linear amplifier depend on fluctuations of the envelope of the incoming signal and are determined by two functions of the transfer of the envelope:

$f(A(t))$: AM/AM conversion

$\Phi(A(t))$: AM/PM conversion.

These distortions can be divided into four types:

- additional non-linear interference in the receiver;
- interference between the in-phase and quadrature components caused by the AM/PM transformation;
- spectral expansion of the signal;
- intermodulation effects.

Another way to reduce out-of-band emission may be methods associated with the use of the extended spectrum, implying an increase in the bandwidth of the transmitted signal in order to achieve one or several advantages, such as reducing multipath propagation of radio waves, providing multiple station access, reducing power spectral density, and a number of other [6,7,16].

III. The use of spread spectrum signals.

Spread spectrum can have six basic forms [16]:

- Direct spread spectrum systems based on pseudo-random sequences, including code division systems (DSSS);
- Frequency hopping (slow and fast) (FSSS);
- Systems of multiple access with spread spectrum and carrier control (CSMA);
- Systems with realignment of the temporary position of the signals (Time-hopping TH)
- Systems with linear frequency modulated signals (chirp spread spectrum - CSS)
- Systems with mixed spreading methods.

. For the purpose of reducing out-of-band emissions, the expanded sequence of the direct sequence seems to be more important: since the effect of the jumps in frequency depends mainly on the speed of the jumps and is fixed either by the influence of frequency modulation or amplitude modulation, depending on the actual performance. With the spread spectrum of the direct sequence, the modulated signal is distributed in the frequency domain by remodeling with a pseudo-sampling digital sequence, as a rule, through the use of PM modulation. Further implementation of this method in ARSS is considered.

The output power of ARZ transmitters, as a rule, does not exceed 200 mW [8]. In the case of using narrowband modulation of the transmitter radiation by a coordinate-telemetric signal with a frequency (Δf = 2.5-5.0 kHz), the spectral power density of the main lobe will be 40-80 μW/Hz. In the case of using spread spectrum signals, the same power will be distributed over a wider frequency band (Δf = 6-20 MHz) and the power spectral density will be 0.2/6·106 = $3.33 \cdot 10^{-8}$ W/Hz for the 6 MHz band and 0.2/20·106 = $1 \cdot 10^{-8}$ W/Hz, which is three orders of magnitude less. This result indicates that the out-of-band emission density will also be significantly reduced. Given the availability and low cost of the element base for the implementation of methods for expanding the emission band of ARZ transmitters with respect to ARSS, this approach is most preferable.

Phase-shift keyed signals are often used as spread spectrum signals (SSS) [7].

Of course, phase-shift keyed signals - not the only ones that can be used in this capacity - can be used for this purpose and amplitude-pulse and frequency-modulated signals. At the same time, the use of phase-shifted signals has several advantages over the above. First, with balanced modulation, the $A\cos w_C t$ carrier signal is multiplied with the $B\cos w_M t$ baseband signal, the resulting signal looks like this:

$$AB\cos\omega_C t\cos\omega_M t = AB\cos(\omega_C \pm \omega_M)t \qquad (3)$$

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Theoretically, such a signal does not contain components with carrier frequency, practically with this kind of modulation, carrier suppression can be achieved up to 60 dB. This gives some energy gain, but makes it difficult to ensure synchronization mode. In addition, technologically the use of a two-phase balanced modulator does not cause any particular difficulties, unlike other modulators.

A modulating signal consisting of N square-wave pulses can be written as follows [4]:

$$U(t) = \sum_{n=1}^{N} a_n \cdot u_0\left[t-(n-1)\right]\tau_0 \tag{4}$$

a.

where $u_0\ (t) = 1$ while $0 \le t \le \tau_0$ is a square wave.

Each n-th pulse has an amplitude a_n and is late from the origin of coordinates by a time $(n-1)\tau_0$ equal to the total duration of all previous pulses.

It is known that the optimal reception of a signal with fully known parameters against the background of white Gaussian noise is carried out using a correlator or a matched filter [6, 7, 16]. The correlator calculates the correlation integral of the form.

$$z = \int_0^T x(t) \cdot y(t) dt \tag{5}$$

where $x(t)$ is the signal at the input of the receiving device (RD), equal to the sum of the useful signal $y(t)$ and white Gaussian noise.

Define the spectrum of the phase-shift (PM) spread spectrum signal through the spectrum of a single rectangular pulse $u_0(t)$ and code sequence A, which we define as

$$A = \{\alpha_1 \alpha_2 \ldots \alpha_n \ldots \alpha_N\} \tag{6}$$

where α_n - elements of the sequence.

The complex envelope spectrum is determined by the Fourier transform [4]:

$$G(\omega) = \int_{-\infty}^{\infty} U(t) \cdot e^{-i\omega t} dt \tag{7}$$

where $U(t)$ is the complex envelope of the signal $u(t)$. The spectrum of a rectangular pulse $u_0(t)$ with a unit amplitude and a duration of τ_0 is equal to:

$$S_0(\omega) = \int_0^{\tau_0} u_0(t) \cdot e^{-i\omega t} dt = \tau_0 \cdot \frac{\sin(\omega \cdot \tau_0 / 2)}{\omega \cdot \tau_0 / 2} \cdot e^{-1\omega\tau_0/2} \tag{8}$$

The spectrum of the complex envelope of a phase-shifted signal has the following form:

$$G(\omega) = S_0(\omega) \cdot \sum a_n \cdot e^{-i(n-1)\omega\tau_0} \tag{9}$$

The sum on the right-hand side is the spectrum of the coding sequence A and is denoted as $H(\omega)$. Therefore, the spectrum of the PM signal can be represented as a product, i.e.

$$G(\omega) = S_0(\omega) \cdot H(\omega) \tag{10}$$

Where $S_0\ (\omega)$ is the spectrum of impulse (8), and

$$H(\omega) = \sum a_n \cdot e^{-i(n-1)\omega\tau_0} \tag{11}$$

is the spectrum of code sequence.

The energy spectrum $S(\omega)$ is equal to the square of the modulus of the spectral density $G(\omega)$. The spectrum of the phase-shifted signal formed by the M sequence of 63 elements in length, constructed in accordance with (6) - (11), is shown in Fig. 1.

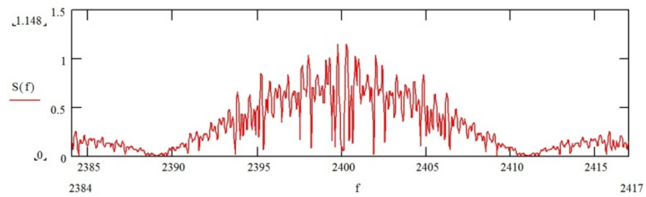

Fig. 1. The spectrum of a phase-shifted signal formed by an M sequence of length 63 elements.

IV. Radiosonde Transmitter Design

On the basis of the analysis carried out, a block diagram of the ARP transmitting device is shown in Fig.2.

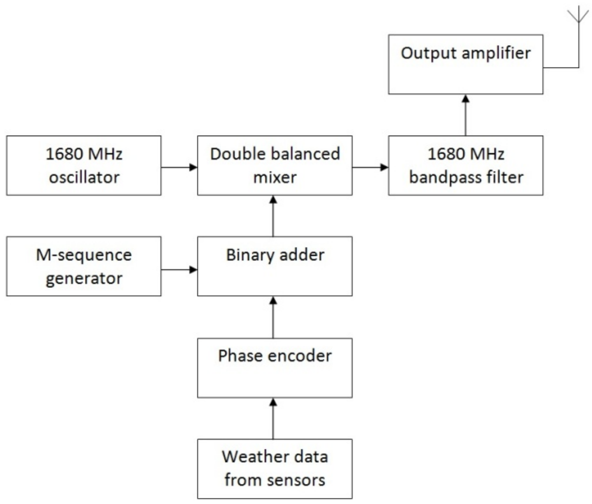

Fig. 2. Block diagram of the ARZ transmitter with a spread spectrum signal of a radar ARSS at a frequency of 1680 MHz.

In the proposed scheme of the transmitter ARZ used the following technical solutions and components. The M-sequence generator is designed to form an M-sequence with a length of 127 elements. The modulo-2 modulator adds the information sequence to the M-sequence, thereby ensuring spreading of the spectrum. A relative phase encoder is used to eliminate phase uncertainty in the transmission of a useful signal, since the quadrature method is not used in this case. In

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this case, a double balanced mixer acts as a phase modulator of a carrier signal, which is formed by a master oscillator. From the output of the double balanced mixer, the modulated signal is fed to a 1680 MHz bandpass filter. The bandpass filter [9, 10] provides additional suppression of out-of-band emissions relative to the signal level in the passband of 1680±10 MHz by minus 40 dB. In this case, the spectral density of out-of-band emissions of the PSS is lower than minus 120 dBW / Hz. The measured spectrum of the output signal of the prototype broadband transmitter ARZ is shown in Fig.3

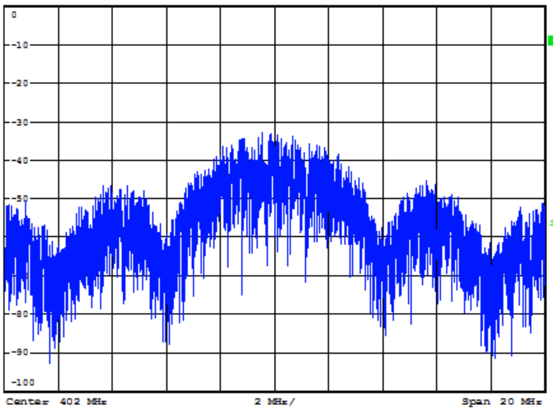

Fig. 3. The spectrum of the noise-like signal, the frequency of the m-sequence is 4 MHz, the transmission speed of the useful information is 5 kb/s.

In order to further reduce the level of out-of-band emissions, it is advisable to use Gaussian [16, 17] or quasi-harmonic [15] instead of rectangular information pulses. Figure 4 shows the spectral density of signals with phase modulation of PSK and signals whose information pulses passed through a Gaussian filter, GPSK.

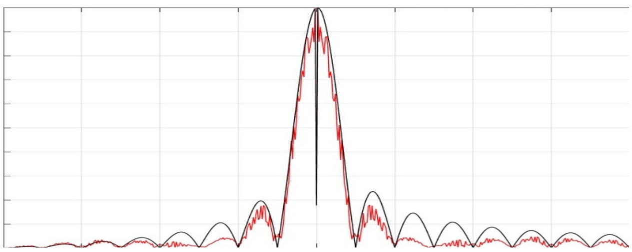

Fig. 4. Spectral density of PSK (black) and GPSK (red) signals.

V. Conclusion

1. When operating airborne radiosonde systems, there is the problem of electromagnetic compatibility of radiosonde transmitter transmitters with electronic devices of various purposes.

2. To improve electromagnetic compatibility, three possible methods for implementation were considered: optimizing the shape of modulating information pulses using Gaussian filtering, using the technology of noise-like communication channels, filtering the output radiation of the transmitter ARZ SAW filter.

3. The use of the proposed methods makes it possible to reduce the level of out-of-band emissions from ARZ transmitters to less than minus 120 dBW/Hz.

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