CZU 621.391

RECEIVING-MEASURING COMPLEX FOR DOPPLER OBLIQUE SOUNDING OF IONOSPHERE

Plohotniuc E.F. – dr., ass. prof., Botnariuc S.B. – researcher, Ţîganaş I.P. – researcher
(Alecu Russo Balti State University, Republic of Moldova)

This paper describes the receiving-measuring complex for Doppler oblique sounding of the ionosphere and the results of the first data processing. The complex is located in the city of Balti (47.75° N, 27.92° E) and is designed to study the propagation properties of decameter radio waves in the ionosphere.

INTRODUCTION

One effective method for remote monitoring of the ionospheric communication channel is the method of recording the Doppler frequency shift of HF radio signals propagating in inhomogeneous nonstationary ionosphere. The main advantages of this method are the relative ease of implementation, high sensitivity to small perturbations, and the time resolution, the possibility of selection of different modes, arising from the spatial-temporal heterogeneity of the ionosphere and radio wave propagation characteristics in the decameter range.

Multichannel reception and synchronized registration parameters of HF radio signals propagating on the fixed network radio paths of different orientations and lengths significantly extend the method, especially in terms of the solution of inverse problems of remote diagnostics of the ionosphere.

This paper describes the receiving-measuring complex for Doppler oblique sounding of the ionosphere and the results of the first data processing. The complex is situated in the city of Balti (47.75° N, 27.92° E) and is intended for the study of the propagation of decameter radio waves in the midlatitude ionosphere.

DESCRIPTION OF THE RECEIVING-MEASURING COMPLEX

The system is designed for the detection and recording of magneto-ionospheric disturbances of natural and artificial origin (solar flares, earthquakes, geomagnetic storms, sudden impulses of the geomagnetic field, etc.).

The complex works in the receiving mode of radio waves reflected from the ionosphere HF band and records Doppler frequency shift of the reference radio stations signals on transient inhomogeneities of the ionosphere.

Block diagram of the receiving and measuring complex is shown in fig. 1. As the receiving antenna (A1) is used an antenna of the "diamond" type with the suspension height of 20 m.

Registration of the current radio spectrum is made by the receiver of "КАТРАН". The signals of the second intermediate frequency (215 kHz) are mixed in the converter and mixer unit (see fig. 2), with a reference signal from the frequency synthesizer Ч6-31 (215 kHz + Δf), where Δf – the support frequency of about 10 Hz are filtered and fed to a computer audio input, which records the signal.

To stabilize the generators of the receiver, synthesizer and clock, the FS725 Rubidium Frequency Standard with a frequency of 5 MHz and erors $\pm 5\times 10^{-11}$ is used. To calibrate the receiving-measuring circuit a standard signals generator Г4-158 is used.

For the operational management of the complex, formation, processing and storage of experimental data a software is developed. Visualization of signals passing along the routes of the receiving-measuring system is performed by a virtual oscilloscope and spectrum analyzer.

The recording of the signal fed to the PC audio input is preformed by a record program that allows to make the record at the time when the reference radio station emits a continuous signal.

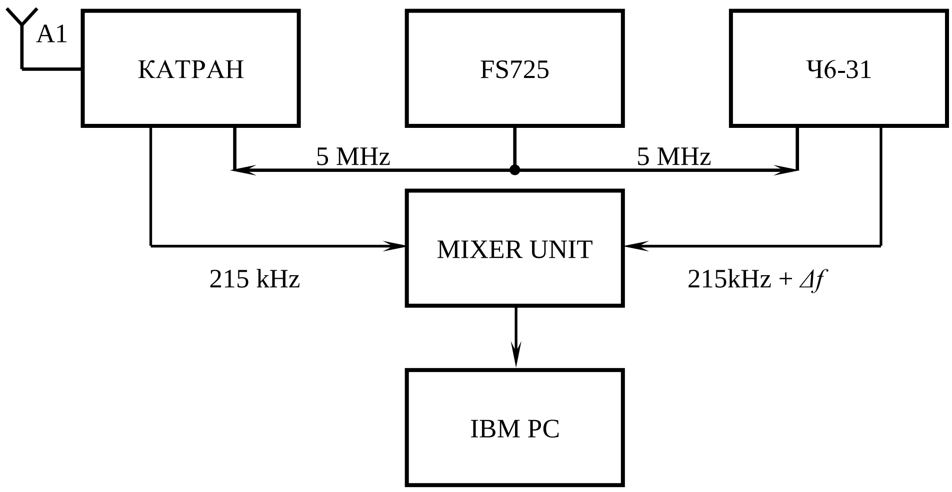

Fig.1. A block diagram of the receiving and measuring Doppler complex.

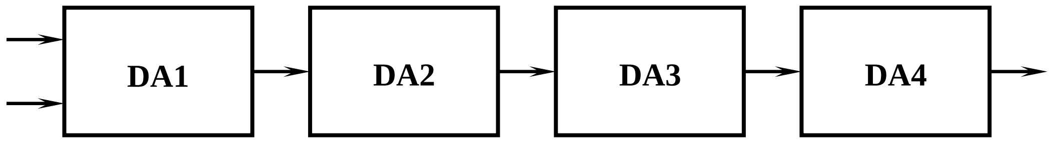

Fig.2. A block diagram of the converter and mixer: DA1 - balanced mixer; DA2 - amplifier with adjustable gain and bandwidth; DA3 - voltage amplifier; DA4 - active low-pass filter.

PROCESSING OF OBLIQUE DOPPLER SOUNDING DATA

We present the major approaches to processing oblique Doppler sounding implemented in the research of nonstationary ionosphere. Primary data processing of Doppler oblique sounding consists in getting the current radio spectrum and sonogram in the frequency-time coordinates. Sonograms can detect variations in the amplitude-frequency characteristics of the HF signal and provide feedback signals oblique of Doppler probe under the effects of non-stationary processes in the ionosphere in the form of the characteristic variations of the Doppler frequency shift. However, processing of the current spectrum is difficult, because each of the Doppler spectrum is a group of partial waves. The spectrum of the signal may contain E and F modes that carry information about the various regions of the ionosphere, the effect of not one, but several non-stationary processes, which have different physical nature. For example, the range of the radio signal can contain both mirror and diffuse components. As a rule, all processes are non-stationary against the regular diurnal variations in the ionosphere. All of these factors greatly complicate the processing and interpretation of the results obtained by the Doppler oblique sounding. Thus, it is necessary to eliminate ambiguity associated with the inherent property of the ionospheric propagation of short-wave signals - multipath.

Therefore, digital signal processing of oblique Doppler probe was based on the idea of the amplitude of the Doppler spectrum as the distribution of energy of the electromagnetic wave at the receiving frequency. For example, the use of such statistical characteristics of the Doppler spectrum, as the center of gravity *P*, enabled us to reduce the variation of the spectral components in frequency to the time dependence of one variable - *F(T)*. This approach is justified because, in the first place, it does not lead to loss of the original data and, secondly, the developed computer software for receiving and measuring system allows us to apply this idea of the amplitude of the Doppler spectrum not only to the entire spectrum as a whole but to its individual components (modes) as well.

As with any distribution [1,2], the Doppler signal spectrum can be characterized by its mean value F (center of gravity of the distribution):

$$F = \sum_{i=1}^{N} x_i p_i \,, \qquad (1)$$

x_i - Doppler frequency, p_i - normalized amplitude of the *i*-th component, $(\sum_{i=1}^{n} = 1), N$ - the length of the sample, as well as the central moments M_k:

$$M_k = \sum_{i=1}^{N} (x_i - F)^k p_i \sum_{i=1}^{n} (x_i - F)^k p_i \,, \qquad (2)$$

of which the first three are commonly used.

We can also define the following parameters of the signal:

- integrated amplitude,

$$A = \sum_{i=1}^{N} A_i \,, \qquad , (3)$$

- sum of the squares of the amplitudes,

$$A^2 = \sum_{i=1}^{N} A_i^2 \,, \qquad (4)$$

- frequency dispersion,

$$\delta_f^2 = M_2 \,, \qquad (5)$$

- asymmetry coefficients

$$k = \frac{M_2}{\sqrt{M_2^2}} \qquad (6)$$

and excess

$$\gamma = \frac{M_4}{M_2^2} \,. \qquad (7)$$

Time series of moments of the of the integral amplitude distribution and the coefficients k and γ are used to study the dynamics of the HF signal parameters, to establish quantitative and qualitative connections of response signals of oblique Doppler sounding data carried out simultaneously on different tracks with each. For this purpose were developed algorithms for the selection of the desired signal from the background noise, regression, correlation and spectral analysis [3-8].

Doppler method allows to separate the adjacent HF signal modes, if these modes are fΔ separated in frequency by an amount greater than the width of the spectrum of one of the modes. According to [9], the width of the HF signal in the calm conditions in the mid-latitude ionosphere is not more than 0,1 Hz. By our data, this value in similar conditions is in the range 0,05-0,2 Hz. Application of this approach to data processing of oblique Doppler sounding of an individual selected mode allows to get time series of the center of gravity variations, amplitude, frequency deviation, etc. and to apply to these series regression, correlation and spectral analysis algorithms.

The next important aspect of signal processing of oblique Doppler sounding signals is to separate the useful signal from the background noise. It should be noted that, depending on the test conditions, the noise may be a response signal to other time-dependent processes that contribute to its shape and spatial-temporal dynamics.

To separate the useful signal from the background noise the method proposed by the authors was used [4, 6], and the filtering and detection procedure were implemented on a computer, depending on the purpose of processing, both of the source and processed data of oblique sounding.

To remove high-frequency noise component triangular filter was used [7].

Low-frequency filtering was performed with a filter defining the velocity:

$$z_i = (y_i - y_{i-1}) \,. \qquad (9)$$

Detection of rapid variations of the Doppler frequency shift was calculated as follows:

$$f_{gi}^d = ABS(z_i) \,. \qquad (10)$$

The above given approach to the recording, processing and storage of the initial information largely determined the ability to carry out research of trasient processes in the Earth's ionosphere of different space-time scales by analyzing the parameters of the response of HF radio signal to ionospheric disturbances.

MEASUREMENT METHODOLOGY

Test observations on the complex started in August 2011. To work out methods of observation and carry out data processing, a fiducial radio station based in Moscow - RWM: 55° 48' N 38° 18' E has been selected that broadcasts the exact time signals, presented in the table. The trajectory of radio trace is shown in fig. 3.

The recording of a given radio signal is done when the radiostation RWM emits unmodulated continuous signals in the time period 00 min.00 sec. - 07 min.55 sec. and 30 min.00 sec. - 37 min.55 sec of every hour. Signal frequency of 10 Hz, is taken from the output of the converter and the mixer and fed to the audio line input of on computer, which records the signal at the set periods of time, in a file format *. wav.

For visual control of the signal fed to the input of the computer, a software batch is used that represents a virtual oscilloscope and spectrum analyzer (see fig. 4).

Hour program of radio RWM Moscow

Time of signal transmission. Start	Time of signal transmission. End	View of the signal
00 min.00 sec.	07 min.55 sec.	Unmodulated wave carrier signals
08 min.00 sec.	09 min.00 sec.	Radio transmitter off
09 min.00 sec.	10 min.00 sec.	Signals of radiostation recognition
10 min.00 sec.	19 min.55 sec.	A1X signals, containing second, minute labels and DUT1 + dUT1 information
20 min.00 sec.	29 min. 55 sec.	A1N signals with a repetition rate of 10 Hz
30 min.00 sec.	37 min.55 sec.	Unmodulated wave carrier signals
38 min.00 sec.	39 min.00 sec.	Radio transmitter off
39 min.00 sec.	40 min.00 sec.	Signals of radiostation recognition
40 min.00 sec.	49 min.55 sec.	A1X signals, containing second, minute labels and DUT1 + dUT1 information
50 min.00 sec.	59 min.55 sec.	A1N signals with a repetition rate of 10 Hz

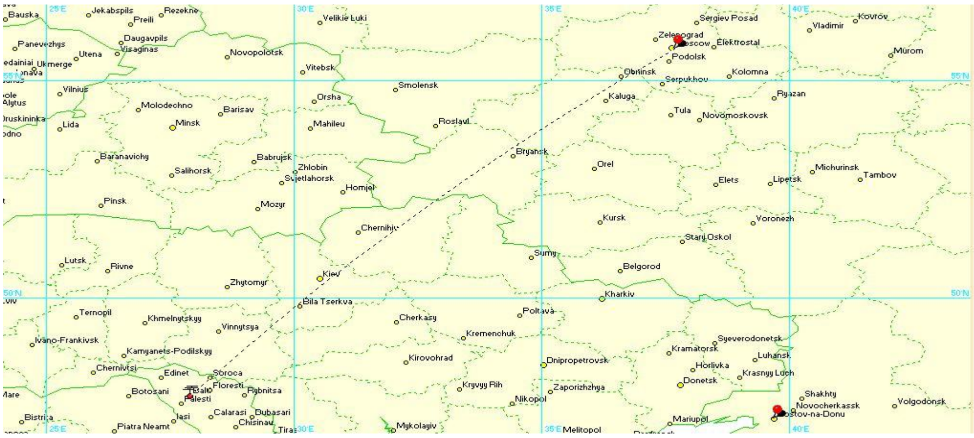

Fig. 3. The trajectory of radio trace.

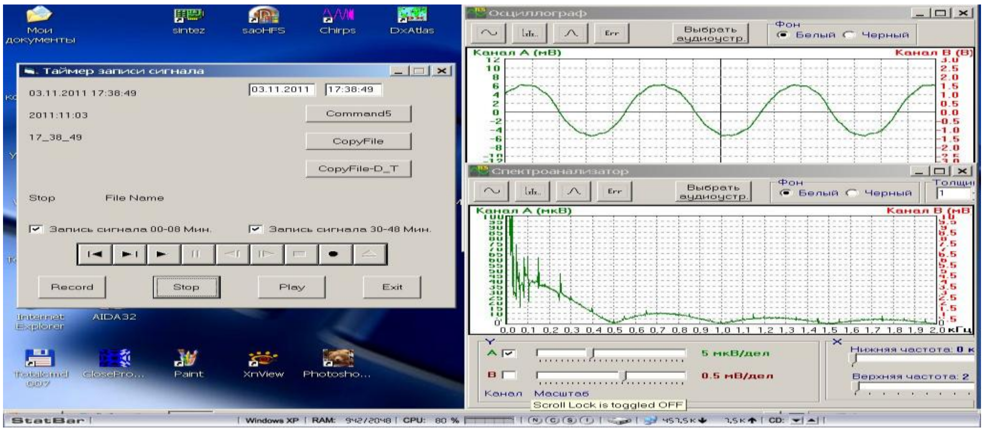

Fig. 4. The program interface, signal recording oscilloscope and spectrum analyzer.

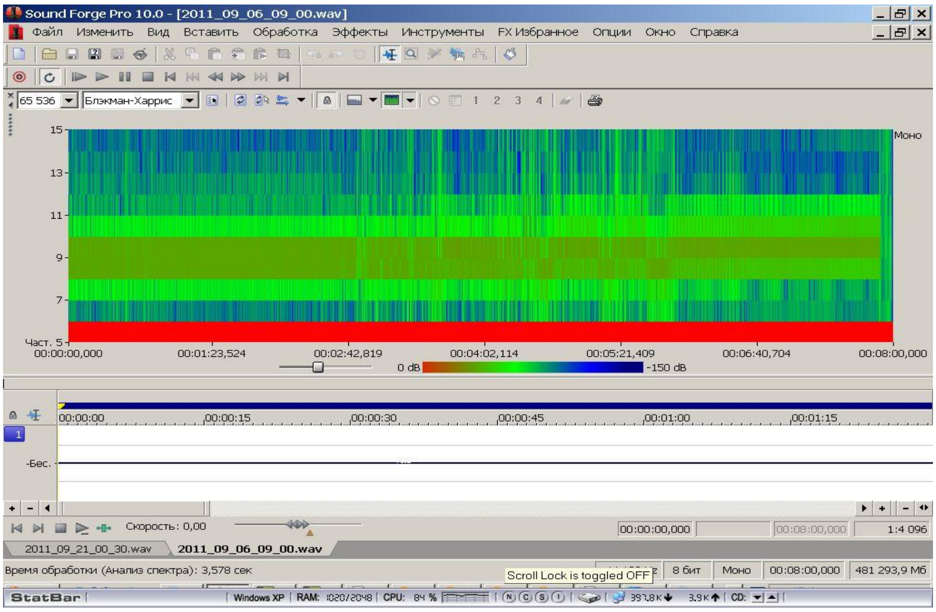

Fig. 5. The program interface "Sony Sound Forge" with sonogram signal.

To observe the diurnal signal changes, hourly eight-minute cuts of the signal are connected into one - the daily file. The processing of the file with the signal is produced by the program - "Sony Sound Forge", which gives the signal spectrum and sonogram in frequency-time coordinates, where one can trace the Doppler frequency shift (see fig. 5).

CONCLUSION

The created complex allows for a continuous monitoring of the dynamics of ionospheric processes in any area of the middle latitudes, depending on the choice of transmitting stations. It should be noted that a significant limitation of the choice of reference stations is the almost complete lack of access to the wave transmitting schedule of both here and abroad.

The results of Doppler measurements can be used to detect and record the magneto-ionospheric perturbations of natural and artificial origin (solar flares, earthquakes, geomagnetic storms, sudden impulses of the geomagnetic field, etc.).

BIBLIOGRAPHY

1. ЛЕВИН, Б.Р. Теоретические основы статистической радиотехники. Книга первая. М.: Сов. Радио, 1974. 552 с.
2. РЫТОВ, С.М.; КРАВЦОВ, Ю.А.; ТАТАРСКИЙ, В.И. Введение в статистическую радиофизику. Часть II. Случайные поля. М.: Наука, 1978. 464 с.
3. БЕНДАТ, Дж.; ПИРСОЛ, Л. Применение корреляционного и спектрального анализа. М.: Мир, 1983. 312 с.
4. ДЖЕНКИНС, Г.; ВАТТС, Д. Спектральный анализ и его приложения. М.: Мир, 1972. Вып. 2. 288 с.
5. ДЬЯКОНОВ, В.П. Справочник по алгоритмам и программам на языке Бейсик для персональных ЭВМ. М.: Наука, 1989. 240 с.
6. МАКС, Ж. Методы и техника обработки сигналов при физических измерениях. М.: Мир, 1983. Т.1. 312 с.
7. МАРПЛ, С.Л. Цифровой спектральный анализ и его приложения. М.: Мир, 1990. 584 с.
8. РАБИНЕР, Л.; ГОУЛД, Б. Теория и применение цифровой обработки сигналов. М.: Мир, 1978. 848 с.
9. АФРАЙМОВИЧ, Э.Л. Интерференционные методы радиозондирования ионосферы. М.: Наука, 1982. 198 с.

CZU 621.391

COMPLEXUL DOPPLER DE SONDARE OBLICĂ A IONOSFEREI

Plohotniuc E.F. – dr., conf., Botnariuc S.B. – c.ş., Ţîganaş I.P. – c.ş.
(Universitatea de Stat “Alecu Russo” din Bălți, Republica Moldova)

În articolul dat este descris complexul Doppler de sondare oblică al ionosferei şi sînt prezentate rezultatele primelor măsurări. Complexul Doppler este plasat în mun. Bălți (47.75° N, 27.92° E) şi destinat pentru cercetarea propagării undelor radio scurte prin ionosferă.

Prezentat la redacție la 17.03.2011