CZU: 621.391.81

OPERATING PRINCIPLES OF LFM IONOSONDES

Eugeniu Plohotniuc
(State University “Alecu Russo”, Republic of Moldova)

The operating principles, technical characteristics and advantages of LFM ionosondes utilized for vertical, oblique, and vertical-oblique sounding of the ionosphere with respect to the pulse ionosondes are discussed.

At present, there is no strict self-consistent theory of propagation of extremely-wideband signals of Linear Frequency Modulated (LFM) ionosondes in the ionospheric plasma as a dispersive medium. Only a few approximate approaches of mathematical description of operational functions of the LFM ionosonde were developed accounting for specific features of processing of registered signals by the receiver, as well as based on well-known behaviour of narrowband signals in the ionosphere [1]. The influence of dispersion distortions in the ionosphere on the structure of the complicated signals (including LFM signals) during vertical sounding (VS) and oblique sounding (OS) of the ionosphere was analysed using theoretical frameworks described in [2, 3-6].

The basic principle of LFM ionosonde operation can be explained by using a simple functional scheme shown in Figure 1.

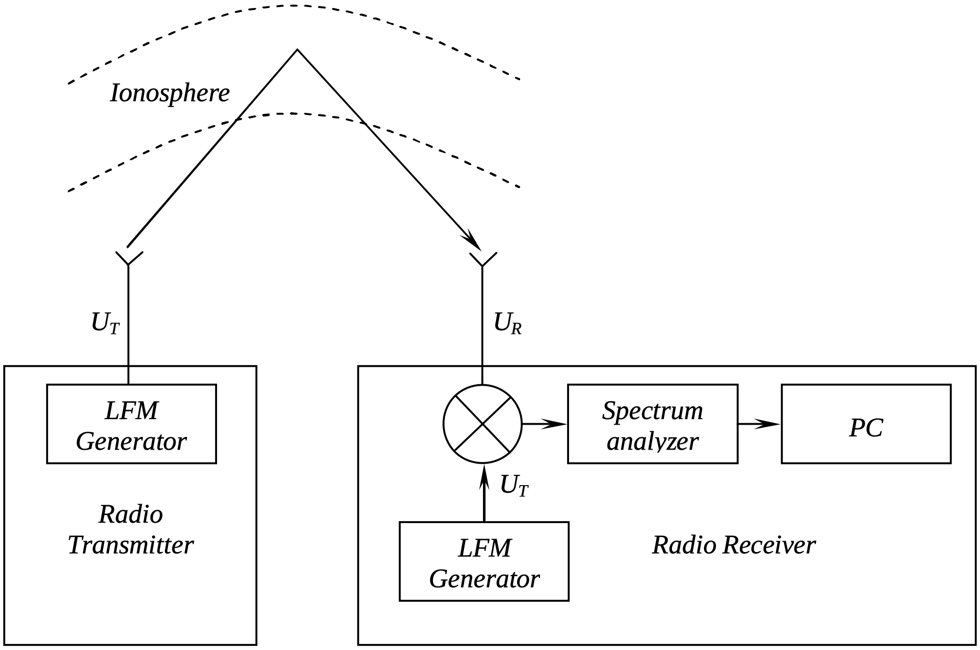

Fig. 1. Functional scheme of the LFM ionosonde.

Let us suppose that at the transmitting channel of an ionosonde the transmitter radiates a continuous signal with linear modulation of its frequency:

$$u_T(t) = u_0 \cos\left(w_S t + b\ t^2 / 2\right), \tag{1}$$

where u_0 is the signal amplitude, $w_S = 2p\ f_S$ is the initial circular frequency, $b = 2p\dot{f}$ is the velocity of changes of the circular frequency. Then, the current radiated frequency, $f = d(w_S t + b \cdot t^2 / 2) / 2pdt$, changes according to linear low at the range from f_S to f_E with the velocity which has fixed values in the limits from 25kHz/s to 1MHz/s depending of the regime of sound and the problem that is being solved. Usually, f_S ~ 2–3 MHz and f_E ~15–30 MHz, and therefore the radiated signal has a period of several minutes and occupies a frequency bandwidth of several tens megahertz, i.e., it is extremely-wideband.

We also suppose that the LFM signal formed by the transmitter arrives at the input of the radio channel, containing the receiving-transmitting antenna-fider devices, the input of the receiver and the “land-ionosphere” waveguide, has all the elements of the channel to be coincided mutually with each other in the whole frequency band $[f_S, f_E]$. Let’s assume for simplicity that in equation (1) u_0 = 1. In assumption of linearity of the characteristics of radio channel, a signal at its input can be presented as an integral product of the radiated signal $u_T(t)$ and the pulse characteristic of the channel $h(t\ )$:

$$u_R(t)=\int_0^{\infty} h(t\ )u_T(t-t\ )dt\ . \qquad (2)$$

The signal $u_R(t)$ passes the input circuits of the receiver, is then affected by first processing procedure using the method of its compression. Compression of spectrum is realized by the consistent filter at the receiver, in which the signal $u_R(t)$ is producted with the signal of the basic generator shifted with respect to radiated generator at the time t_0 and having the time dependence presented by (1). The result of this product contains low-frequency (difference between frequencies) and high-frequency (sum of frequencies) components. The latter component can be then filtered with low-frequency filter.

From the continuous signal of low frequency, using the corresponding analysis, the sets with period T_D are selected by the “window” $w(t)$ with time duration around their centres of $t_k = t_0 + (k-1/2)T_D$, $k=\overline{1,N}$. We should note that the window in the time domain with time period T_D corresponds to the segment of the input LFM signal with the frequency band of $\Delta f_D = \dot{f}\cdot T_D$. Therefore, the frequency band of this segment has to be not larger than the frequency band of the receiver’s selector.

Then the selected sets of the initial LFM signal enter at the input of the spectrum analyzer. The result of its work is described by the Fourier transform, where the spectrum of the k-selected set has the form:

$$\mathrm{S_k}(\Omega)=S_k(F)=\frac{1}{4p}\int_{-\infty}^{\infty}\int_0^{\infty} w(t-t_k)h(t\ )\cos\left[\frac{b}{2}(t\ -t_o)^2-bt(t\ -t_o)\right]e^{i\Omega t}dtdt\,, \qquad (3)$$

where $\Omega = 2pF$.

The form of the window $w(t)$ in the device is realized in such a manner that its Fourier transformance $W(F)$ has a narrow band, of about 1-10 Hz (in most cases ~1 Hz) with total elimination of the side loops. The selected sets with time period, T_D, correspond to segments of the LFM signal with basis $B_D = \Delta f_D \cdot T_D$ in the frequency domain. For the case of $\dot{f} = 10^5$ Hz/s and T_D = 1s, we get $\Delta f_D \cong 100\,\mathrm{kHz}$ and $B_D \cong 10^5$.

Expressing the pulse characteristic of the radio channel $h(t\ )$ via its Fourier transformance, called transferred function $H(w)$, the following approximate expression of the registered spectrum at the input of the spectrum analyzer can be obtained [7]:

$$S_k(\Omega)=\frac{p}{2}e^{iy}\int_{-\infty}^{\infty} H(w)B(b\ \ (t_k-y_0)+w+w_H)e^{-iwy_0}dw\,, \qquad (4)$$

where $y = b\left(y_0^2 - t_0^2\right)/2 - w_S\left(y_0 - t_0\right)$, $y = \Omega/b - \left(t - t_0\right), y_0 = \Omega/b + t_0$, $B(b\,(t_k - y_0) + w + w_S)$ - and the Fourier transform of the function equals

$$b(y) = e^{ib\ y^2/2} W\left(b\ \ y\right). \tag{5}$$

The term $b(y)$ is defined as a range of the argument values where the function differs essentially from zero. According to (5), it is close to the term describing spectrum of the window of selections, $W(b\ \ y)$. In this case, it is also supposed that the lower limit of frequency band Ω_0, measured by the analyzer exceeds the frequency band of the window spectrum. In these definitions, the expression for spectrum of the k-selected set is the same as that for the response of the radio channel against any equivalent signal $b(y)$ with the spectrum $B(w)$.

According to (5) the time duration of the pulse signal $b(y)$ is defined by the frequency resolution of the spectrum analyzer $d\Omega$ and by the velocity of frequency changes according to the formula $dt\ \ \cong d\Omega/b$.

Usually, the time duration of the equivalent pulse is of the order of 10^{-5}-10^{-4}*s*, and the band of its spectrum is of the order of 10–100 kHz. In the short-wave range in most cases such a spectrum can be considered narrowband. In the conditions mentioned here the scheme of modeling the characteristics of continuous LFM signals when sounding the ionosphere is reduced to a simple problem of propagation with narrowband signals. It is well known [8, 9] that when sounding the ionosphere with narrowband pulse signals, several responses of the radio channel are registered by the receiver with the frequency band equal to the frequency band of the signal (in conditions of full coincidence).

As a rule, $H(w)$ can be presented as a sum of transferred functions $H_l(w)$, corresponding to different modes of propagation:

$$H(-w) = H^*(w) = \sum_l H_l^*(w) = \sum_l \left|H_l(w)\right| e^{-iwP_l(w)/c}\ , \tag{6}$$

where $P_l(w)$ is a phase trajectory of the l-th mode at frequency w .

Let us expand $H_l^*(w)$ at the proximity of the frequency

$$w_k = w_S + b\left(t_k - y_0\right), \tag{7}$$

which is a central frequency in the spectrum $B(w)$. Within the limits of the examined band, the value $\left|H_l\ (w)\right|$ can be taken as constant, and the function $P_l(w)$ as a smooth function. Therefore we can limit the Teylor expansion of the signal phase by using only its second-order term:

$$\frac{wP_l(w)}{c} = \frac{w_k P_l(w_k)}{c} + \left(w - w_k\right)t_l + \left(w - w_k\right)^2 \frac{t_l'}{2}\ , \tag{8}$$

where

$$t_l = \left.\frac{d\left[wP_l(w_k)\right]}{c\,dw}\right|_{w_k} \tag{9}$$

is the group delay of the l-th mode at the frequency w_k, and

$$t'_l = s_l / 2p = \left.\frac{dt_l}{dw}\right|_{w_k} \qquad (10)$$

After submission of (8) into the right part of (6), the expression for the output spectrum $S_k(\Omega)$ can be obtained in the following form [10]:

$$S_k(\Omega) = S_k(F) = \frac{p}{2} e^{i(y + w_k y_0)} \sum_l H_l^*(w_k)\, q(y_0 - t_l), \qquad (11)$$

where $q(y_0 - t_l)$ is the inverse Fourier transformance of $Q(w_k - w) = B(w_k - w) e^{-i\frac{(w - w_k)^2 t'_l}{2}}$.

From these current derivations it follows that without accounting for frequency dispersion (i.e., for the second-order term in the expansion (8)), the non-distorted signals are registered at the output of the spectrum analyzer. This case corresponds to propagation of various modes during the sounding of the ionosphere with narrowband pulse with envelope $b(y_0)$.

Actually, the pulse envelope is the function $W(by_0)$, since the power in the exponent of expression (11) for the case of consideration is very small. Therefore, the form of pulses is defined by the form of the window $w(t)$ of the spectrum analyzer. The position of the centre of l-th signal at the axis Ω is determined from the constraint $y_0 = t_l$ and corresponds to the frequency

$$\Omega_l = b(t_l - t_0) \text{ or } F_l = \dot{f}(t_l - t_0) \qquad (12)$$

Expression (12) gives relation between time delay of the registered signal of mode l and the variable of the analyzer Ω (or the difference F), and allows also to coincide the interval of group delays of interest with the working band of the analyzer $[F_0, F_{\max}]$ by using the corresponding selection of the parameter t_0.

To obtain record of all modes of the signal with delays $t_1,...,t_n$, it is necessary that the frequency band of the receiver exceeds the value $\Delta F = \dot{f}(t_n - t_1)$. For example, if $(t_n - t_1) = 5ms$ and $\dot{f} = 100$ *kHz/s*, then $\Delta F = 500$ *Hz*. This means that for the given velocity of rearrangements of the frequency at the receiver, its working frequency band of 500*Hz* corresponds to the time window, which equals 5*ms*.

The spectrum analyzer divides the band of the receiver into m equal sub-bands of value dF. The latter characterizes errors in estimating the time of group delay, which is defined by the time of the equivalent pulse, dt, and has to be smaller than the expected minimum difference of signal delays for different modes of propagation.

By using fast Fourier transform for derivation of the signal spectrum at the difference frequency, the corresponding quadrature components should be outlined. Using these components, the amplitude and phase spectra can be calculated. The amplitude spectrum is used for performance of the corresponding ionograms. Index k in formula (11) determines the current frequency w_k, at which the characteristics of LFM signal of mode l are calculated. Changes of the index k from 1 to N, correspond to the frequency of the LFM signal running along the whole frequency band used for sounding.

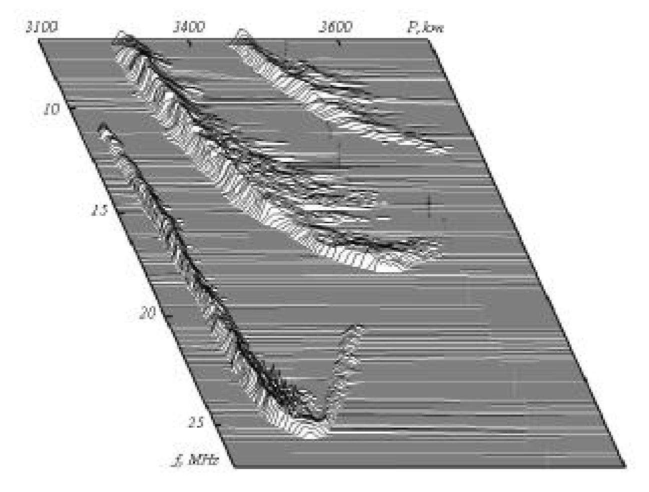

Fig. 2. The experimental amplitude spectrum obtained on the trace Ioshkar-Ola-Bălți.

As an illustration, in Fig. 2 the experimental amplitude spectrum $|S_k(t)|$ is presented during sounding on the trace Ioshkar-Ola-Bălți on December 10 1991. The group path $P = ct$ is arranged along the axis of delays. The registered signals correspond to bottom and top rays of one-, two- and three-hop modes of propagation. The graphical imaging of the cross-section of $|S_k(\Omega)| = |S_k(t)|$ at the given level presents an actual ionogram of oblique sounding. The dependence $|S_k(t)|$ at the time t_k presents the amplitude relief of the signal at the current frequency f_k for all the registered modes of propagation.

In works [3, 11, 12], the radiated continuous LFM signal was performed in the frequency domain (unlike the above described approach operating with signal in the time domain). For this case, the method of stationary phase was used, giving a good approximation for the real spectrum.

In our further discussions we suppose that the obtained solution of the problem of propagation of the harmonic signal in the ionosphere is found and known. Then, it defines the transfer function of the ionosphere containing the amplitude-frequency characteristic (AFC) and phase-frequency characteristic (PFC) for the wave frequency under consideration. If so, the product of radiated signal and the transfer function of the ionosphere finally gives the spectrum of the signal at the input of the receiver, and the Fourier transform of this product gives us the desired signal.

Further mathematical derivations of the signal can be done according to the scheme described above. As a result of such an approach, we can obtain analytical dependences for the amplitude spectrum on difference frequency accounting for dispersion in propagation of radio signal in the ionosphere.

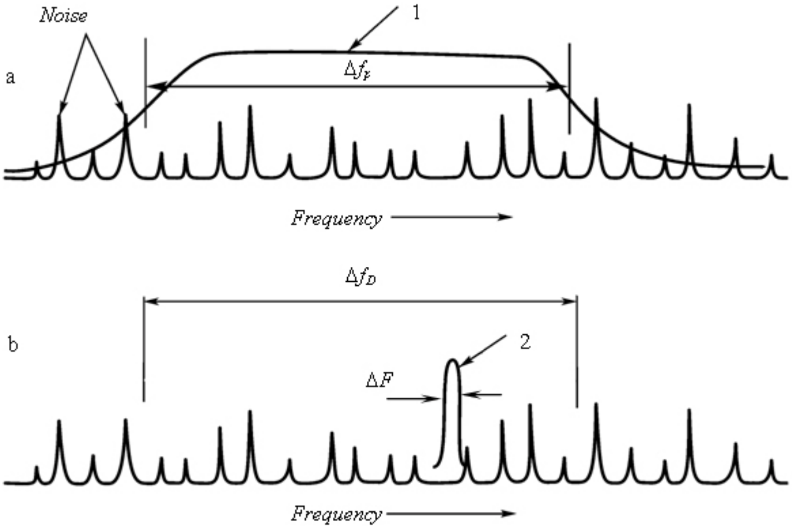

Fig. 3. The frequency band of the pulse ionosonde (curve 1) and the LFM ionosonde (curve 2).

Concluding this paragraph, we will consider the question of stability of LFM ionosonde against noises with respect to the pulse ionosonde described in [2, 13]. The main sources of noises in the short-wave frequency band are the operating radio broadcasting stations. In Fig. 3 according to [14] the frequency band of the pulse receiver is shown (curve 1).

We should stress that the band of the pulse ionosonde has to be not less than $\Delta f_p \sim 1/T_p$, where Δf_p and T_p are the band of radio frequencies and the time duration of the sounding pulse, respectively. For typical values of $T_p = 50\,ms$ we easily estimate Δf_p~20 kHz, i.e., the band of a pulse ionosounde is much bigger than the band ΔF of an LFM ionosonde. All noises from radio stations can be hit simultaneously inside the bandwidth of the impulse ionosonde, and practically cannot be rejected from this wide bandwidth.

The receiver of an LFM-ionosonde has much less frequency band ΔF (curve 2, Fig. 3) and selects signals from radio stations continuously, step by step, transforming them into impulse noise, the spectral density of which is sufficiently small and which can be rejected by several technical methods, namely, either by frequency rejecting at the input filter of the receiver, or by time rejecting of the signal at difference frequency.

If, for example, at the input of the receiver the noise signal arrives in the form of:

$$u_n(t) = u_0 \cos w_n t\,, \tag{13}$$

then, after product operation with the signal (8.1) in the receiver, this signal has the form:

$$u_n(t) = u_0 \cos\left((w_n - w_S)t - \frac{b}{2}\cdot t^2 \right). \tag{14}$$

At the same time, the difference signal during the time T can be assumed to be harmonic, that is, its power is concentrated on the element dF. During the time T_D the noise power P_n is distributed along the band Δf_D in such a manner that the spectral density of its power equals:

$$N_n = \frac{P_n}{\Delta f_D}\,. \tag{15}$$

Hence, at the element dF will be concentrated the noise density recorded at the output of the receiver, which equals:

$$(P_n)_{exit} = \frac{P_n}{\Delta f_D}\cdot dF = \frac{P_n}{B_D}\,, \tag{16}$$

where $B_D = \Delta f_D / dF = \Delta f_D T_D$ is the basic parameter of the signal with noise. In this case, the ratio of signal power to noise power at the input and output of the receiver is described by the following formula [15]:

$$(\frac{P_{sign}}{P_n})_{exit} = B_D (\frac{P_{sign}}{P_n})_{ent}\,. \tag{17}$$

Thus, during broadcasting stations activity and influences of noises arriving at the input of LFM receiver, we get according to (17) that the signal-to-noise ratio (SNR) at the output of the receiver exceeds the SNR at the input of the receiver in B_D times (for $B_D >> 1$), which allows to decrease significantly the transmitted power of the LFM ionosonde. It should be pointed out that using the narrow beam antenna grid with the dimensions of 2.5*km*, the ionograms of oblique sounding can be easily obtained at power of radiation of the order of units of milliwatt [16, 17].

Further we shall formulate briefly the main requirements for the parameters of an LFM ionosonde used to investigate the ionosphere and to diagnose short-wave communication ionospheric channels. The transmitting part of an LFM ionosonde can be built on the basis of industry-produced broad-band power amplifiers and elaborated program-run synthesizers of LFM signals [18-24]. The main requirement for the transmitting part refers to the spectral purity of the formed LFM signal and to frequency stability of the LFM signal synthesizer reference generator, which must be not less than 10^{-8} Hz (brief instability leads to the appearance of mistakes in LFM signal synthesis and to deviation from linear law which drives the transmitter, and long instability leads to deviation of frequency absolute values of the forming LFM signal). Frequency range of an LFM ionosonde is determined by the length of usable radio-traces. For the years with high solar activity, maximum-suitable frequencies can reach 40 MHz; therefore an LFM ionosonde should have a frequency range not less than 2÷40 MHz. Radiation power of a power amplifier shouldn't be too strong not to interfere with other short-wave communication systems.

Usually, a transmitter's power shouldn't exceed 100 W. The requirements for the receiver bandwidth of an LFM ionosonde are contradictory: on the one hand, it should be big enough to transmit without distortion all the signal propagation modes; on the other hand, an increase of the bandwidth leads to an increase of noise that gets into the receiver tract and to its masking of the useful signal. The width of the receiving tract band pass is closely connected with the speed of LFM signal frequency change and with the range of the signal mode group delay. The necessary range of group delay is calculated taking into account radio-route length with some reserve, which compensates the influence of the instabilities of the receiving and transmitting tracts, temporary lack of synchronization of the time scales of the receiving and transmitting parts, daily and annual variations of group delays under the influence of the Sun radiation. When sounding on short and middle radio-routes, the calculated range of group delays doesn't exceed 3-4 ms. Thus, when using an LFM signal with the frequency change speed $df/dt = 100$ kHz/s, the receiving tract transition band should be not less than 500 Hz.

When working in an automatic regime on different radio-routes with a big difference of the levels of received signals, insufficient dynamic range of the system can influence the quality of received ionograms. A signal that exceeds the boundary of a dynamic range may cause distortions in non-linear circuits of the receiving tract (frequency changers, amplifiers). The problem can be solved by using variable step-switching attenuators connected at the input of the radio-receiving installation.

An LFM ionosonde should work on both long (more than 3000 km) and short (up to units km) routes. This requires the use of at least two antenna systems for long and short radio-routes and of antenna commutators for their quick switching. To ensure the possibility of receiving signals of the world net of LFM-ionosondes, the receiving antennas should have a circle radiation pattern in a horizontal plain. The required exactness of synchronization of the time scales of the receiving and transmitting parts of an LFM ionosonde (not less than 20-30 μs), can be reached by constructing a subsystem of exact time on the basis of GPS receivers and rubidium frequency standards. A frequency standard can also serve as a source of oscillation for the LFM signal synthesizer. The parameters of an LFM signal formed by the synthesizers in the receiving and transmitting parts of the complex should meet high requirements: a wide range of frequency change, high linearity of the frequency change law, spectral purity, coherence. LFM signal synthesizers constructed by using the method of direct digital synthesis answer such requirements. The choice of the LFM signal frequency change speed is defined by the necessary frequency resolution and delay as well as by the necessity of compatibility with the LFM ionosondes of the world net. It should be noted that by changing the speed of the LFM signal frequency change, the width of the signal spectrum of difference frequency grows too, which requires an increase of the receiver transmission band, that is, of the transmission in signal-to-noise ratio. The positive factor here is that in this case decreases the influence on the communication systems working in DKMB range. A decrease of the sounding speed, on the contrary, improves signal-to-noise ratio, reduces the receiver transmission band, but increases the duration of the sounding session, and increases the influence on DKB of the communication system. Most transmitters of the world net of LFM ionosondes use the LFM signal change speed of 100 kHz/s, when the receiver transmission band is sufficiently wide within the limits of permissible duration of the sounding d which constitutes 280 s. when sounding in the range 2 - 30 MHz.

The technical characteristics of LFM ionosondes for vertical, oblique, and vertical-oblique sounding of the ionosphere are represented in the table.

With the help of LFM ionosondes, extensive data on the condition of natural and artificially-disturbed ionosphere were received; formation peculiarities of the field of short-wave signals on middle-latitude, sub-auroral, trans-equatorial routes of different length were investigated. High effectiveness of using LFM sondes as part of adaptive short-wave radio communication system was experimentally shown.

Technical characteristics of LFM ionosonde operating with continuous signals

Main Characteristics	**VS**	**OS**	**BOS**
Radio Transmitter			
Frequency range of radiated LFM signal, MHz	2–16	2-40	2–40
Velocity of LFM signal frequency changes, kHz/s	50	100–1000	25–100
Radiated power, Watt	2–10	2–100	10–1000
Radio Receiver			
Frequency range of received LFM signal, MHz	2–16	2–40	2–40
Velocity of LFM signal frequency changes, kHz/s	50	100–1000	25–100
Frequency band of the receiver, Hz	500	500	1000
Dynamic band, dB	80	100	120
Approval of the device on delay, *ms*	20	10	10–40
The range of the observed delays, *ms*	10	5	5–20

In order to implement the potential possibilities of using LFM sounds when solving fundamental and applied problems in the field of ionosphere physics and radio wave propagation, it is necessary to widen the world net of LFM sondes and to place them, first of all, in high-latitude regions, where the effects of Sun – Earth connection in the system of magnetosphere – ionosphere – atmosphere are most strongly manifested. Besides, the placement of LFM sondes in the Arctic and in the Antarctic regions will allow us to receive in real-time regime information about the conditions of radio wave propagation in regions strongly exposed to the influence of magneto-ionospheric disturbances. This data can be used to solve the practical problems of providing effective functioning of short-wave radio communication systems, above-the-horisont short-wave radio-location, radio-navigation and radio direction-finding.

Further development of hardware-software devices of an LFM complex presupposes inclusion into the data base of geophysical information received from sputniks in on-line regime and exchange of sounding results over the Internet.

Thus, we can quite definitely assert that the development of an LFM sondes network, software improvement, their inclusion into a single world network of LFM ionosondes will allow us to control and forecast on a new technological level the effects of space weather, that play such an important role in life support on the Earth.

Conclusion

The main requirements for the parameters of an LFM ionosonde used to investigate the ionosphere and to diagnose short-wave communication ionospheric channels are the following:

1. the transmitting part of an LFM ionosonde can be built on the basis of industry-produced broad-band power amplifiers and elaborated program-run synthesizers of LFM signals;
2. the main requirement for the transmitting part refers to the spectral purity of the formed LFM signal and to frequency stability of the LFM signal synthesizer reference generator, which must be not less than 10^{-8} Hz (brief instability leads to the appearance of mistakes in LFM signal synthesis and to deviation from linear law which drives the transmitter, and long instability leads to deviation of frequency absolute values of the forming LFM signal);
3. an LFM ionosonde should have a frequency range not less than 2÷40 MHz;
4. when using an LFM signal with the frequency change speed $df/dt = 100$ kHz/s, the receiving tract transition band should be not less than 500 Hz;

In order to implement the potential possibilities of using LFM sounds when solving fundamental and applied problems in the field of ionosphere physics and radio wave propagation, it is necessary to widen the world net of LFM sondes and to place them, first of all, in high-latitude regions, where the effects of Sun – Earth connection in the system of magnetosphere – ionosphere – atmosphere are most strongly manifested.

Bibliography

1. Ivanov, V. A., V. I. Kurkin, V. E. Nosov, V. P. Uryadov and V. V. Shumaev, “Chirp ionosonde and its application in the ionospheric research, *Radiophysics and Quantum Electronics*, vol. 46, 2003, pp. 821-851.
2. Ureadov, V., V. Ivanov, E. Plohotniuc, L. Eruhimov, N. Blaunshtein, and N. Filipp, *Dynamic Processes in Ionosphere and Methods of Investigation*, Iasi, Romania, Tehnopress, 2006, 284 p.

3. Ivanov, V. A., “Peculiarities of propagation of short-wave LFM radio signals in the regular ionosphere”, Moscow: VINITI, No. 3064-85. 1985, 41 p.
4. Namazov, S. A., “On dispersion distortions of signals with the limited spectrum during reflection from the ionosphere”, *Radiotechniks and Electronics*, vol. 24, 1984, pp. 1280-1288.
5. Orlov, Yu. I., “On geometrical theory of dispersion distortions of signals with the limited spectrum”, *Izv. Vuzov, Radiophysika*, vol. 25, 1982, pp. 772-783.
6. Terina, G. I., *Radiotechniks and Electronics*, vol. 12, 1967, pp.124-132.
7. Ilyin N. V., Khakhinov V. V., Kurkin V. I., et al., *Proc. of the International Symposium on Antannas and Propagation*, Chiba, Japan, vol.3, 1996, pp. 689-692.
8. Budden K.G. Radio Waves in the Ionosphere, Cambridge: Cambridge University Press, 1966, 542 p.
9. Ginsburg, V. L., Propagation of Waves in Plasma, Moscow: Phys.-Math. Literature, 1967, 684 p.
10. Davydenko, M. A., N.V. Ilyin, and V. V. Khakhinov, “On the shape of measured spectra of the ionosphere sounding by an FMCW signal under dispersion case”, *Journal of Atmospheric and Solar-Terestrial Physics*, vol. 64, 2002, pp. 1897-1902.
11. Brynko, I. G., I. A. Galkin, V. P. Grozov et al., “Automatically controlled data gathering and processing system using an FMCW ionosondes”, *Adv. Space Res.*, vol. 4, 1988, pp. 121-124.
12. Ivanov, V. A., D. V. Ivanov, and A. A. Kolchev, “Study of peculiarities of dispersive characteristics of radio channels with help of LFM ionosonde”, *Izv. Vuzov., Radiophysika*, vol. 44, 2001, pp. 241-253.
13. Erukhimov, L. M., V. A. Ivanov, N. A. Mityakov, et al., *LFM-Method of Diagnostics of the Ionospheric Channel*, Moscow: VINITI, No. 9027-1386, 1986, 94p.
14. Barry, H. G. “A low-power vertical-incidence ionosondes”, *IEEE Trans. on Geoscience Electronics*, vol. GE-9, 1971, pp. 86-89.
15. Lynch, J. T., R. B.Fenwick, and O. G. Villard Jr., “Measurement of best time-delay resolution obtainable along east-west and north-south ionospheric paths”, *Radio Science.*, vol.7, 1972, pp. 925-929.
16. Sweeney L. E., Jr., “Experimental measurements of amplitude and phase distributions across a 2.5-km HF array”, *Proc. of URSI Spring Meeting*, Washington, D.C., Apr 1968.
17. Sweeney, L. E., Jr., “A new swept-frequency technique for matching feedline lengths”, *Proc. of the IEEE*, vol. 59, Issue 8, 1971, pp. 1281-1282.
18. “The new VOS-1 vertical/ oblique sounder”, *Prospect “Barry Research” Palo Alto*, Calif., USA, 1970.
19. “Chirpsounder receiver systems”, *Prospect “Barry Research” Palo Alto, Calif.*, USA, 1972.

20. “Ionospheric chirpsounder transmitter TCS-4”, *Prospect “Barry Research” Palo Alto*, Calif., USA, 1973.
21. “HF chirpsounder receiver dodel RCS-5”, *Prospect “BR Communications”*, USA, 1985.
22. “HF chirpsounder transmitter model TCS-5”, *Prospect “BR Communications”*, USA, 1990.
23. Poole, A. W. V., “Advanced sounding (1): The FM-CW alternative”, *Radio Science*, vol. 20, 1985, pp. 1609–1616.
24. Poole, A.W.V., and G. P. Evans, “Advanced sounding (2): first results from an. advanced chirp ionosondes”, *Radio Science*, vol. 20, 1985, pp. 1617–1623.

PRINCIPIILE DE LUCRU ALE IONOSONDELOR DE TIP MLF

Eugeniu Plohotniuc
(Universitatea de Stat “Alecu Russo”, Republica Moldova)

În lucrare sînt prezentate principiile de lucru, parametrii tehnici şi avantajele ionosondelor cu modulare liniară a frecvenței, utilizate pentru sondarea verticală, oblică şi vertical-oblică a ionosferei, în comparație cu ionosondele de tip impuls.

Prezentat la redacție la 24.07.08