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Method for determining characteristics of arbitrary frequency radio channels

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***Abstract*: This paper presents algorithms for data processing of ionosphere sounding chirp signals. These include the algorithms of automatically find and calculate the basic characteristics of an arbitrary frequency radio channel based on the signals and the noise time series separation and subsequent statistical parameters estimation. A feature of these algorithms is to estimate of radio channel parameter based on the signal processing in time rather than in the frequency domain, which can significantly reduce an analysis bandwidth for individual radio channel.**

***Keywords:* chirp sounding, signals detection, HF communications, ionosphere radio channel.**

INTRODUCTION

In recent years, there is a growing interest of specialists to shortwave (SW) communication systems in many countries. The main advantage of which is the possibility of rapid information transmission at the distance of thousands kilometers, without any communication infrastructure by the use of natural ionosphere radio channel. However, the quality and the reliability of SW radio systems depends on the unsteady propagation conditions between a transmitter and a receiver. Therefore, a constant diagnosis of the transmitting frequency channel is needed, which allows to perform an adaptation to the changing environment of the radio signal propagation and a management of SW radio frequency resource.

Widespread use in frequency management system for SW communication found ionosondes with linear frequency modulated (LFM) signal, which have a small size and high noise immunity at a low power level [1]. When ionosphere sounding the chirp signal runs through the entire SW radio waves range from 3 to 30 *MHz*, providing real-time measurement of the signal modal structure, the mode energy and the signal-noise ratio (SNR).

Example of such system is the Tactical Frequency Management System AN/TRQ-35(V) [2]. Major components of AN/TRQ-35(V) are a spectrum monitor, transmitter and receiver of the chirp ionosonde.

Australian system "JORN" includes: bistatic over-the-horizon radar system "Jindalee"; ionosphere monitoring system, known as Frequency Management System and control center Jindalee Facility at Alice Spring (JFAS), where such systems are also used [3].

Russian device [4] and [5] allows to estimate the current state of the radio channel on the basis of the functional connection between the bit error probability, averaged over the random channel parameters and information transmission channel characteristics for the various types of signals.

However, the main disadvantage of the measuring methods in these systems and devices is that the signal parameters estimation carried in the spectral domain at about 100 *kHz* band, while usually SW radio devices operate in radio channels with a bandwidth of unit kilohertz.

The paper aim is to develop methods of measuring signal separation and error probability and communication reliability determination for the arbitrary frequency radio channel with high frequency resolution.

CHIRP SIGNAL PROCESSING METHOD

The signal at the output of the chirp ionosonde receiver, after compression in the frequency domain, represents the sum of the difference frequency signal $A(t)$, fluctuation noise $a_w(t)$ and the sum of station interference $a_n(t)$:

$$A_{out}(t) = A(t) + \sum_{n=1}^{N} a_n(t) + a_w(t),$$

where N is the number of station interference in the frequency bands of signal.

When multipath SW channel, the chirp signal $A(t)$ arriving at the receiver input represents the sum of quasi-harmonic components:

$$A(t) = \sum_{i=1}^{M} a_{0i} \cos(2\pi \cdot F_i \cdot t + \varphi_{0i}),$$

where M is the number of received rays, $a_{0i}, F_i, \varphi_{0i}$ – amplitude, frequency, phase of i th ray.

The instantaneous frequency of the difference signal i th ray is $F_i = \dot{f}\,\tau_i$, where τ_i is the signal time delay of i th ray. The amplitude of the spectral component corresponding to the frequency F_i

proportional to the transmission coefficient H_i through the ionosphere radiochannel for this ray.

For radio channel parameter estimation in a wide frequency band $\Delta f = \dot{f} \cdot T$, the signal $A_{out}(t)$ at the receiver output is divided into elements with the band Δf_{el} and the duration T_{el}. Each k th signal element is subjected to spectral analysis and define the amplitude H_{ki} and the delay τ_{ki} corresponding to the i th ray.

The result of the standard work of the ionosonde is a ionogram (*Fig.* 2a), which characterizes the dependence of the group time delay $\tau_i(f)$ and amplitude $H_i(f)$ of each ray on the frequency f with the frequency resolution Δf_{el} (usually 100 *kHz*).

Ionosphere channel characteristics measurement is performed on the resulting ionogram, by removal of noise components. Separation of signal and noise spectral components allows to evaluate the SNR in the frequency band of signal elements (~ 100 *kHz*), while the SW radio devices usually operate in the channel with bandwidth of a few kilohertz.

The authors propose to perform calculation of SNR in the time domain with high frequency resolution.

For this purpose, by appropriate signal processing $A_{out}(t)$, need to select the difference frequency signals $A(t)$. Difference signals of corresponding modes $a_{difi}(t)$ are harmonic signals and the signals $a_w(t)$ and $a_n(t)$ occupy the entire frequency band. Therefore, the difference signal filtering similar to harmonic signal filtering in white noise. In this method the ray allocation in the received signal $A_{out}(t)$ are invited to perform through the implementation of a spectrum analyzer using band-pass filters [6]. If the signal element duration is T_{el}, the band of each filter is equal $1/T_{el}$. These filters are required to cover the frequency range from $\min(\dot{f}\tau_i)$ to $\max(\dot{f}\tau_i)$. The number of the filters: $L \geq (\max(\dot{f}\tau_i) - \min(\dot{f}\tau_i)) \cdot T_{el}$.

Difference frequency signal of i th mode passes through the p th frequency filter Φ_p $(1 \leq p \leq L)$ and supplied to the adder. At the output of the adder have the signal $A(t)$. Difference signals of i th modes $a_{difi}(t)$ passing through a corresponding frequency filter Φ_i (*Fig.* 1) moves to the ionogram building (i=1,2,…L). Signals from other filters are added. The signal sum restores the signal of noise:

$$A_{NS}(t) = \sum_{n=1}^{N} a_n(t) + a_w(t).$$

Difference frequency signals occupy the band of units and tens hertz, and the signal frequency bandwidth at the ionosonde receiver output takes about 2 *kHz*, so the difference signal filtering does not introduce significant distortions in the signal of noise $A_{NS}(t)$.

To define the average power $P_A(t)$ of the signal $A(t)$ at the receiver bandwidth ΔF_{rec} (usually 2-3 *kHz*), perform integration of the square of the signal, in the time finding it in the receiver bandwidth $t \in \left[t - T_a/2 ; t + T_a/2\right]$:

$$P_A(t) = \frac{1}{T_a} \int_{t-T_a/2}^{t+T_a/2} A^2(t)dt \text{, where } T_a = \frac{\Delta F_{rec}}{\dot{f}}.$$

The average noise power $P_{NS}(t)$ in the frequency band of the receiver is similar:

$$P_{NS}(t) = \frac{1}{T_a} \int_{t-T_a/2}^{t+T_a/2} A_{NS}{}^2(t)dt.$$

Using the samples $P_A(t)$ and $P_{NS}(t)$, we can find a samples of the SNR for the arbitrary working frequency $f_p = f_0 + \dot{f} \cdot t$:

$$(S/N)(f_p) = \frac{P_A(\frac{f_p - f_0}{\dot{f}})}{P_{NS}(\frac{f_p - f_0}{\dot{f}})}.$$

By depending $P_A(t)$, also calculated a value $\beta^2(f_p)$ – the frequency dependence of the power ratio of regular and fluctuation signal component.

For error probability calculation uses the next rules. For Rayleigh channel bit-error probability is calculated according to the formula:

$$P_{er} = \frac{1}{2(h^2+1)},$$

and for quasi-Rayleigh channel by the formula: $P_{er} = \frac{\beta^2+1}{h^2+2(\beta^2+1)} \cdot \exp(-\frac{\beta^2 h^2}{h^2+2(\beta^2+1)})$, where $h^2 = S/N$ – the SNR. According to these formulas is determined $P_{er}(f_p)$ – the value of error probability for each operating frequency.

Communication reliability V in the frequency band $\Delta f_{el} = \dot{f} \cdot T_{el}$ which has the meaning that the error probability P_{er} does not exceed a predetermined threshold P_{tr}, is calculated by the frequency dependence $P_{er}(f_p)$:

$$V(f_p) = \frac{\Delta f_{tr}(f_p)}{\Delta f_{el}} \cdot 100\%,$$

where $\Delta f_{tr}(f_p)$ – the total operating frequency band from the frequency band

$\left(f_p - \frac{\Delta f_{el}}{2}; f_p + \frac{\Delta f_{el}}{2}\right)$ for which the condition $P_{er}(f_p) < P_{tr}$ is performed. This takes into account a list of radio channels occupied by station interference: the reliability of radio channels occupied by station interference is considered to be equal to 0%.

Search of such channels and corresponding list formation are performed using the method which described in [7] on the output of the chirp ionosonde (before the method described above).

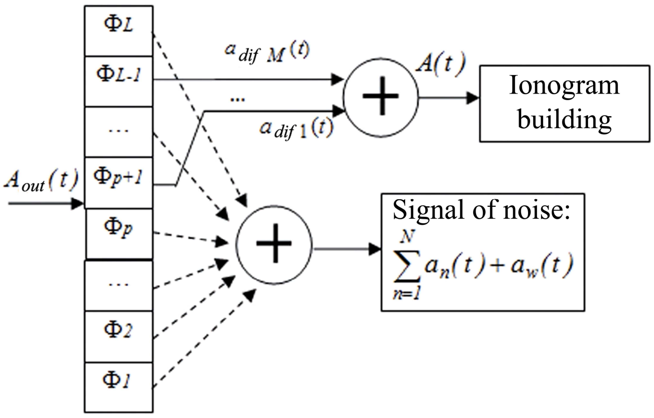


Fig. 1. Scheme to bandpass filter

TABLE I. RADIO CHANNEL CHARACTERISTICS

Frequency band (kHz)	**Reliability (%)**	**Average error probability [band] = value**	**Average SNR (dB) [band] = value**	**Time scattering range (ms)**	**Station interference band (kHz)**
10600-10700	85.71	[10683;10685] = 0.00071 [10687;10689] = 0.00162 [10669;10671] = 0.00166	[10683;10685] = 28.46 [10687;10689] = 24.87 [10669;10671] = 24.75	0.538	no
10800-10900	82.14	[10826;10828] = 0.00048 [10819;10821] = 0.00159 [10824;10826] = 0.00163	[10826;10828] = 30.11 [10819;10821] = 24.94 [10824;10826] = 24.83	0.406	no
8300-8400	75.00	[8384;8386] = 0.00119 [8301;8303] = 0.00170 [8388;8390] = 0.00204	[8384;8386] = 26.21 [8301;8303] = 24.66 [8388;8390] = 23.87	0.203	no
10900-11000	67.86	[10921;10923] = 0.00126 [10973;10975] = 0.00164 [10969;10971] = 0.00222	[10921;10923] = 25.94 [10973;10975] = 24.81 [10969;10971] = 23.49	0.460	[10912 - 10915]

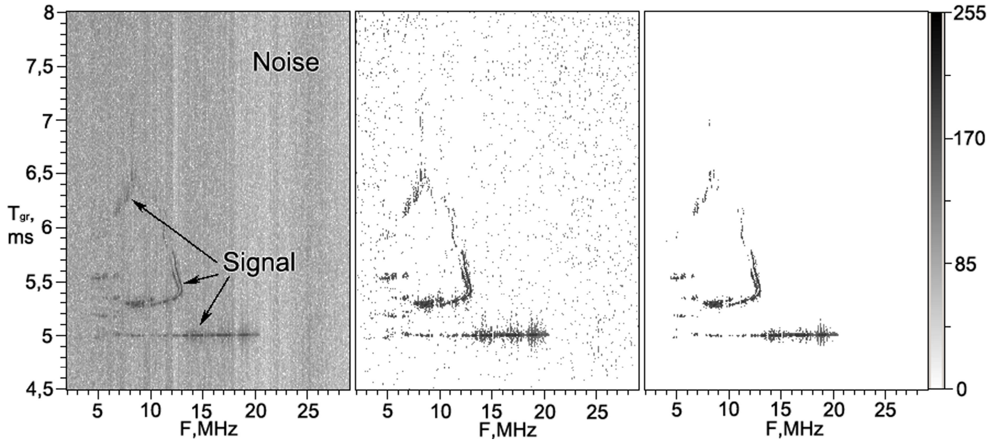
Then, created a list of radio channels of the band Δf_{el} with the highest reliability and showing the sub-channels with a band Δf_K occupied by station interference. Also in each radio channel with the band Δf_{el} with the highest reliability, show sub-channels with the band ΔF_{rec} with the lowest error probability.

According to ionogram also calculated the time scattering of the signal for each frequency band Δf_{el}.

Obtained by these methods data are used to select the optimum operating frequency of SW radio channel.

SIGNAL AND NOISE SEPARATION METHOD

To implement suggested above the measurement methods required the use of appropriate methods of signals separation in frequency and time domains. Reference [8] shown that the selection of ionosonde chirp signals takes place in conditions of a priori nonparametric uncertainty also unknown not only the shape but also the number of the received signals. In this paper, to select the signal is proposed to use method for allocation of anomalous samples in the spectrum of the difference frequency signal.



a) b) c)

Fig. 2. Example of removing noise components on the ionograms obtained on the trace “Lovozero (Russia) - Yoshkar-Ola (Russia),” in June 2, 2015 at 18:17:00 UTC: a) initial b) after applying the method [8], c) after the method [8] and Hough transform

A disadvantage of this method in the signal separation is that after its application to spectra, there are single emissions of noise with intensity, comparable with the useful signal (*Fig.* 2b).

To solve this problem, we propose to use a probabilistic Hough transform [9], which allows to find any curved lines on the image (ionogram).

Using this transformation after applying the method of abnormal samples selection [8], a lot of lines will be accepted as a desired signal, and the another – be considered noise (*Fig.* 2c).

IMPLEMENTATION OF METHODS

On the basis of offered algorithms, a software for the automated data processing of radio sounding was implemented which allows to search for the optimal operating frequency for SW radio systems.

After selecting the desired frequency band, performed estimation of key characteristics of the ionosphere radio channel, which are displayed on the screen in the form of a *Table* I.

For the software implementation has been used C++ programming language and cross-platform framework Qt, allowing to compile the program for Windows, and for UNIX OS.

CONCLUSION

Methods of chirp signals processing of ionosphere sounding which allow to perform expeditious diagnostics of ionosphere radio channels in the automated mode are developed. Also the software for the automation of frequencies management process is implemented. The main feature of these algorithms is possible to define the error probability and reliability of communication for any frequency radio channel with the bandwidth of 2-3 *kHz*.

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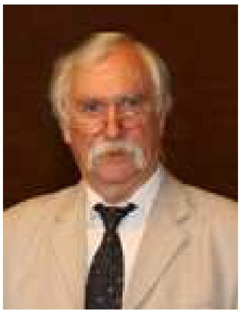

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Методика определения характеристик произвольного частотного радиоканала

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Аннотация: В работе представлена методика обработки данных радиозондирования ионосферы ЛЧМ-сигналом. Она включают в себя алгоритмы автоматического поиска и рассчета основных характеристик произвольного частотного радиоканала на основе разделения сигнала и шума во временной области и последующей оценки статистических параметров. Особенностью этих алгоритмов является оценка параметров радиоканала на основе обработки сигнала во временной области, а не в частотной, что позволяет значительно уменьшить анализируемую полосу частот.

Ключевые слова: ЛЧМ зондирование, обнаружение сигналов, КВ-связь, ионосферный радиоканал.

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