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The Real-time Diagnostics of HF Radio Channel on the Base of Ionospheric Backscatter Sounding Data

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Abstract

The method of real-time diagnostics for decameter radio channel on the base ionosphere backscatter sounding data by continuous chirp signal is presented. The method is based on the extraction of the backscatter signal leading edge under processing and interpretation of experimental ionograms. The interpretation of signals on an ionogram is carried out by the results of calculation for minimum group path of the backscatter signal leading edge within waveguide approach using the IRI model. The low variability property of the minimum group path for a signal scattered by the Earth's surface on a scaled frequencies grid under ionosphere parameters change is used. The results of the extraction of the backscatter signal leading edge on the backscatter ionogram are used to calculate the maximum usable frequencies and group path characteristics for the oblique propagation on the specified radio paths in the sounding sector. The scheme for inversion of the backscatter signal leading edge into parameters of the quasi-parabolic profile of electron concentration is given.

1 Introduction

One possible way for real-time prediction of radio communication characteristics is the method of direct diagnostics of HF radio channels, when propagation characteristics are determined from a sounding signal, without recovery of ionosphere parameters [1]. Under backscatter sounding (BS), the signal is influenced by the same factors that affect the signals of the main radio paths. Therefore, it is natural to expect that the parameters of the backscatter signal and their changes can predict the propagation conditions on the communication lines. As a rule, the sounding signal delays corresponding to the leading edge of the backscatter signal are used as measured characteristics. The allocation of the backscatter signal leading edge on the ionograms allows the real-time prediction of the maximum usable frequencies and the path characteristic calculation of the oblique propagation for the specified radio paths in the sounding sector. In addition, the backscatter signal carries information on the state of the ionosphere at a distance of several thousand kilometers from the observation point in any given direction. This greatly complements the possibilities offered by vertical sounding (VS) ionospheric stations for ionosphere study and prediction of the ionosphere parameters. The methods of inversion for the backscatter signal leading edge allow determining the parameters of the ionosphere and restoring the spatial distribution of electronic concentration in the sounding sector.

2 Method of direct diagnostics for radio channel

During the simulation of BS and oblique sounding (OS) signal characteristics and the analysis of experimental data, it had been found that the following ratios change slightly under variations of the ionospheric parameters [1]:

- the ratio of the group way P_m, corresponding to the leading edge of BS signal, to the distance of the skip zone border D_m at a given frequency, (P_m/D_m);
- Group path $P(f)$ and angle of arrival $G(f)$ of oblique sounding on the normalized grid of frequencies $\beta = f/f_m$, where f_m is the maximum usable frequency for the considered distance, $(P(\beta))$;
- $P_m(f)$ of a backscatter signal by the leading edge on the normalized frequency grid $\nu = f/f_m$, where f_m is the maximum usable frequency (MUF) for the maximum propagation distance of a BS signal, $(P(\nu))$.

These ratios allow us to solve the following problems of real-time diagnostics for a decameter radio channel on the basis of the BS ionogram current data:

- automatic interpretation of the registered signals on BS experimental ionograms and constructing the backscatter leading edge [2];
- real-time determination of MUFs, $P(f)$, and $G(f)$ for the given radio path on BS data.

3 Real-time diagnostics

Input data are the results of automatic processing and interpretation of BS ionograms - the leading edge of the BS signal [2]. Experimental ionograms are processed based on data filtration with further compression using the cellular automaton method. Interpretation of signals in a backscatter ionogram is carried out by calculating the backscatter leading edge. The simulation of BS signal characteristics is carried out within waveguide approach using the IRI model [2, 3]. The experimental BS ionogram received on the basis of chirp ionosonde located in ISTP SB RAS [4] is given in Figure 1.

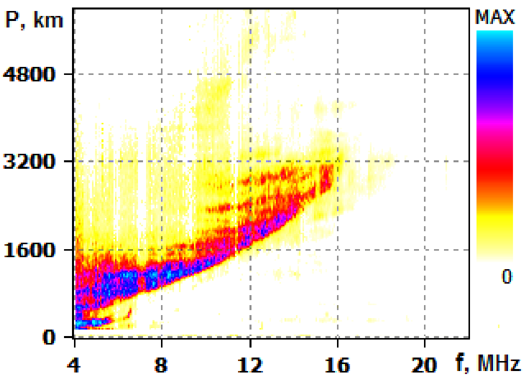

Figure 1. The experimental BS ionogram.

Figure 2 presents the results of processing, simulating of the minimum group path and skip zone border, and the results of BS ionogram interpretation. Gray points in Figure 2 are BS signals with significant amplitude that were detected after the processing. Solid blue line depicts the results of simulating frequency dependence of minimum group path $P_m(f)$ of 1F2 propagation mode. Black line in Figure 2 shows the results of simulating distance to the skip zone border $D_m(f)$. Solid red line in Figure 2 shows the results of interpretation, $P_m^{exp}(f)$, for BS signals arriving at the receiving point by means of primary reflection from F2 layer. Intrinsically, frequency dependence $P_m^{exp}(f)$ is a scaled $P_m(f)$, hence, it is close to the leading edge of BS signal in the ionogram.

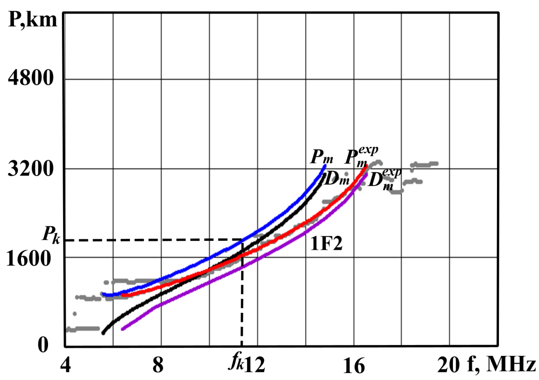

Figure 2. The results of processing and interpretation of the BS ionogram.

The calculation of MUF for a OS signal with fixed distance is based on an adiabatic ratio P_m/D_m. At the first stage for forecasting ionosphere parameters we calculate the leading edge of the BS signal $P_m(f)$ and the distance of the skip zone border $D_m(f)$. For radio path with distance D_0, the ratio $\eta = P_m/D_0$ is calculated. Further, we use P_m^{exp} to determine the frequency f_m that corresponds the group path $P_m^{exp}(f_m) = \eta D_0$. The frequency f_m is the real maximum usable frequency for the distance D_0.

After definition of MUF f_m for given distances with a help of BS data, one can restore real group path $P^r(f)$ and angle of arrival $G^r(f)$ of oblique sounding by the results of the long-term forecast. Oblique sounding characteristics, $P(f)$ and $G(f)$, for distance D_0 on forecast values of ionosphere parameters on the relative grid of frequencies $\beta = f/f_m^d$ are calculated. Here, f_m^d is maximal usable frequency for simulating OS. The real OS sounding characteristics, $P^r(f)$ and $G^r(f)$, at current time moment is restored from forecast characteristics by multiplying β on f_m.

The results of automatic processing and interpretation of the BS ionogram given on Figure 1 and results of OS $P^r(f)$ restoration on the grid of distances corresponding to MUF values calculated with a help of the BS leading edge are given in Figure 3.

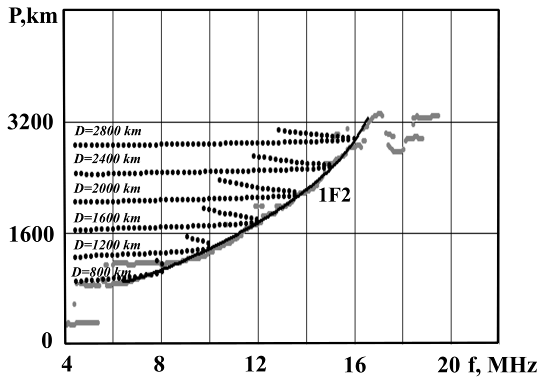

Figure 3. The results of $P^r(f)$ calculation on the distance grid using interpretation of the BS ionogram.

The results of restoration of signal arrival angles $G^r(f)$ from a source of the radio waves located on different distances from the receiver in the sector of backscatter sounding are given in Figure 4.

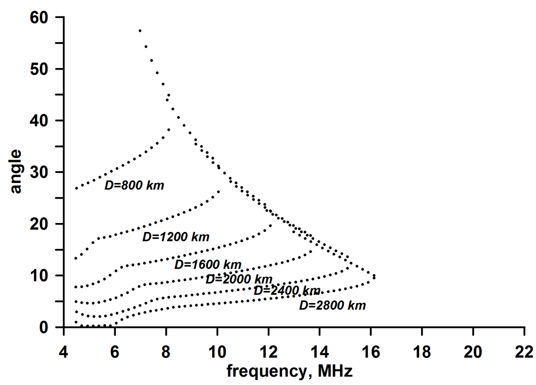

Figure 4. The calculation results of arrival angles $G^r(f)$ on the distance grid using interpretation of the BS ionogram.

4 BS ionogram inversion

The input parameters are frequency dependencies of minimum group way for signal propagation obtained as a result of processing and interpretation of backscatter ionograms. The identified signal leading edge $P_m^{exp}(f)$ allows computing the relevant frequency dependence of the skip zone border $D_m^{exp}(f)$ using adiabatic ratio P_m/D_m on the relative grid of frequencies $\nu = f/f_m$, which changes slightly at variations in the ionospheric parameters. Here, f_m is the maximum usable frequency for the hop extreme distance. For a given group path P_k, relationship $\eta = P_k/D_m$ is calculated using dependences $P_m(f)$ and $D_m(f)$ (see Figure 2). Then, from P_k on real $P_m^{exp}(f)$, we determine frequency f_k and relevant distance to the skip zone border $D_k^{exp} = P_k/\eta$. Figure 2 shows frequency dependence $D_m^{exp}(f)$ with violet line.

Below, we suggest the algorithm of BS ionogram inversion to determine the ionospheric parameters, such as a critical frequency f_{cr} and a maximum height h_m of the 1F2 layer:

1. On a frequency grid $f_k, k = \overline{1,N}$, functions $D_m^k(f_{cr}, h_m)$ and $P_m^k(f_{cr}, h_m)$ are calculated for different admissible pairs of ionospheric parameters (f_{cr}, h_m) with quasi-parabolic dependence of profile $N_e(r)$. Parameters of quasi-parabolas, h_b and h_0, are derived from h_m:

$$h_b = h_m \frac{c_b - 1}{c_b}, \quad (1)$$

$$h_0 = h_m \frac{c_0 - 1}{c_0}, \quad (2)$$

   where c_0 and c_b are some coefficient. To inverse the ionogram on Figure 1, we set $c_b = 1.5$ and $c_0 = 8$.

2. From given frequency f_k we determine group path P_k using $P_m^{exp}(f_k)$, and distance D_k to the skip zone border using $D_m^{exp}(f_k)$. It will be correspond to set of parameters (f_{cr}, h_m).

3. A single pair of the ionospheric parameters (f_{cr}, h_m) is determined from equations

$$D_k = D_m^k(f_{cr}, h_m), \quad (3)$$

$$P_k = P_m^k(f_{cr}, h_m), \quad (4)$$

   as a pierce point of two curves representing solutions of (3) and (4).

The skip zone border corresponding to distance D_k is formed by the ionospheric region at distance $D_k/2$ from the transmitter. This assumption are based on geometry of caustic curve in the waveguide for descending trajectories of one hop mode of propagation. That is why determining the ionospheric parameters using the algorithm of BS ionogram inversion on the frequency grid $f_k, k = \overline{1,N}$, with relevant P_k and D_k, allows us to plot the two-dimensional distribution of electron density along backscatter sounding.

5 Conclusion

We present the methods of real-time diagnostics HF radio channel by the results of automatic processing and interpretation of backscatter ionosphere sounding received by the chirp ionosonde developed in ISTP SB RAS. The results of the BS registered signal interpretation and track constructing are basic data for definition of MUFs and OS characteristics on given radio path in the sounding sector. The inversion scheme of the backscatter signal leading edge into parameters of the quasi-parabolic profile of electron concentration is presented on the basis of comparison of experimental and calculated minimum delays of scattered signals and corresponding distances to the skip zone border. For a fixed sounding frequency, the ionosphere parameter pair, the critical frequency and height of the maximum of the F2 layer, defines as the intersection point of the two curves corresponding to the solutions of minimization problems for discrepancy functional of the minimum group path and the distance to the skip zone border.

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