The Survey of Ionospheric Scattering Function

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Abstract

Because of its advantages, such as broad sounding range and real-time sounding, etc, ionospheric oblique back sounding has been regarded as one of the most important ionospheric sounding means. Ionospheric oblique back sounding is capable to get features of HF back scattering channel and the sounding data will be shown by the Frequency-Time delay-Amplitude 3D graphics in the form of scattering function. The Doppler frequency shift \( f_d \), the multidiameter spread according to time and channel fading can be obtained directly by surveying the scattering function of the HF channel.

The new type ionospheric oblique backsounding system (IOBSS) developed by Wuhan University has been put in use and got many sounding data.

Introduction

Although the traditional ionospheric oblique backscattering sounding radar [1][2], which adopts system of Pulse Doppler (PD) [3][4] or Frequency Modulation Continuous Wave (FMCW) [5], has the advantage of dependable technology, the great transmitted power, perhaps the power of thousands kilowatt, is necessary, however other HF devices nearby will be interfered by the great power, the HF band which is not so broad are not able to be put in full use and the ionosonde adopting this kind of working system must be of complex buildup and high cost. At the same time because of the restriction of radar system, the backscattering echo includes a little information and only the echo front edge can be continuously gotten by sounding. But the front edge of backscattering echo itself can’t provide enough information, in the respect that most of the marked character of ionosphere though affects the echo in specified manner, has little effect on front edge., for example the increase of electron concentration interlayer almost has no effect on front edge. So the absence of enough understanding and right interpretation for the information of sounding echo, as well as on more information can be gotten by the existing radar system, all this restrict the wide application of oblique backscattering sounding technology. This paper has introduced the sounding principle, IOBSS and some results.

Ionospheric Scattering Function

Ionosphere is a kind of randomly delaminating medium, and temporal and spatial variation of which will directly affect the ionospheric channel and the transmission of HF radio wave. The ionospheric channel could pass for time-varying system. As for the low power sounding, the ionospheric channel can be regarded as linear time-varying system and be described by its pulse response function \( h(t, \tau) \). In the function \( h(t, \tau) \), the time variable \( t \) is used to describe the change of system with time and the variable \( \tau \) is used to describe the pulse response with relative delay time \( \tau \), which is group propagating time \( t_p \) in ionospheric survey, therefore the pulse response of ionospheric channel can be written as \( h(t, t_p) \) which is called “bi-time response” function. Fourier transforming the bi-time response along variable \( t \), the scattering function [6] of the ionospheric can be gotten as follows:

\[
D(f_d, t_p) = \int_{\mathbb{R}} h(t, t_p)e^{-j2\pi f_d t} dt
\]

In order to take the full advantage of the power of transmitter and prevent the circuit cell in transmitter from the nonlinear affection of AM signal, the transmitted wave is always phase modulated and so the transmitted wave could be expressed as,

\[
e(t) = u(t) \cdot e^{j2\pi f_0 t}
\]

The \( u(t) \) represents the modulating signal, and \( f_0 \) is the carrier frequency. Because this is a narrow-band signal, after being synchronously demodulated and low-pass filtered, the received signal could be expressed as,
\[ \hat{r}(t) = \int_{\mathbb{R}} h(t, \tau)u(t-\tau)d\tau \quad (3) \]

In the general system model of pseudo-random codes radar sounding the ionospheric channel parameters, the transmitted signal \( u(t) \) is time-delayed by \( t_p \) and then correlation operated with received signal (the length of correlation operation is \( T_0 \)). So at the time \( t_c \), the crosscorrelation of the two signals are shown as follows:

\[ C_{\hat{r},u}(t_c, t_p) = \frac{1}{T_0} \int_{t_c-T_0}^{t_c} \hat{r}(t)u(t-t_p)dt \]
\[ = \frac{1}{T_0} \int_{t_c-T_0}^{t_c} \int_{\mathbb{R}} h(t, \tau)u(t-\tau)u(t-t_p)d\tau dt \quad (4) \]

From the formula (4), we can find that if the autocorrelation of the PN codes in the system model has the feature of Dirac figure, the autocorrelation function of the pseudo-random codes serves as impulse function and acts on linear system. Therefore by collecting the impulse response data of the whole channel, the system model of the channel can be acquired. If the crosscorrelation function of two pseudo-random codes is of the Dirac figure, the survey is also able to be realized by the crosscorrelation function of the two pseudo-random. Applying the crosscorrelation of two different pseudo-random codes to the survey of ionosphere, the formula (4) can be changed as follows:

\[ C_{\hat{r},v}(t_c, t_p) = \frac{1}{T_0} \int_{t_c-T_0}^{t_c} \hat{r}(t)v(t-t_p)dt \]
\[ = \frac{1}{T_0} \int_{t_c-T_0}^{t_c} \int_{\mathbb{R}} h(t, \tau)u(t-\tau)v(t-t_p)d\tau dt \quad (5) \]

In order to get an estimation of scattering function, we assume that the ionospheric channel is smooth in a certain time (this assumption is according to the real physical nature of the ionosphere, and the experiment led up to the fact that the stability of ionospheric channel can continue for 10s, or so far as to 600s in most cases.), so the time \( T_0 \) of correlation operation, which impulse compression takes, must be less than stable time of ionosphere to ensure \( h(t, \tau) \) in (3) effective, namely, ensure that the ionosphere can be regarded as an linear time-invariant system for the each code in a sequence of one period. Based on this hypothesis, we can take that \( h(t, \tau) \approx h(t_c, \tau) \) in the time \( T_0 \).

Change the integral order of (4), we get:

\[ C_{\hat{r},u}(t_c, t_p) \approx \int_{\mathbb{R}} h(t, \tau) \left[ \frac{1}{T_0} \int_{t_c-T_0}^{t_c} u(t-\tau)u(t-t_p)dt \right] d\tau \]
\[ = \int_{\mathbb{R}} h(t, \tau)C_{u,u}(t_c, t_p-\tau)d\tau \]
\[ = \int_{\mathbb{R}} h(t, \tau)C_{u,u}(t_p-\tau)d\tau \]
\[ = h(t_c, t_p) * C_{u,u}(t_p) \quad (6) \]

If \( C_{u,u}(t_p) = \delta(t_p) \), \( C_{\hat{r},u}(t_c, t_p) = h(t_c, t_p) \). Replace \( t_c \) by \( t \), we get:

\[ h(t, t_p) = C_{\hat{r},u}(t, t_p) \quad (7) \]

Therefore if only the pseudo-random code modulating signal with favorable autocorrelation [7] is applied to modulate the transmitted carrier wave, the “echo ~ distance function” of single frequency and the whole path of the ionospheric channel in a certain time \( t \) is capable to be acquired directly at each survey.

The Ionosonde, IOBSS

IOBSS developed by ionosphere lab in Wuhan University has adopted phase coded pulse compression system, can sound the ionosphere by sweeping the whole frequency band in real time, and then gain the changing state of ionospheric parameters and transmitting characters of HF channel. The Ionosonde is a monostatique system applying phase-modulated PN codes and the alternating receiving and transmitting timing. The simplified block diagram of IOBSS is shown in figure 1.
Figure 1: The simplified block diagram of IOBSS.

Sounding Result

The sweeping frequency oblique backscattering sounding result gained by IOBSS in real time at 9:44 AM LT on 27 Oct 2004 in Wuhan China is shown in figure 2. On the left is the $p' - f - A$ graph showing the relationship between distance, frequency and amplitude of ionospheric backscattering echo and the amplitude is expressed colorfully; on the right is the $p' - f - f_d$ graph gotten by synchronous Fourier transformation of the ionospheric bi-time response function shows the relationship between distance, frequency and Doppler frequency shift of ionospheric backscattering echo, and the magnitude of Doppler is expressed by different colors. From figure 2 we can find that the Doppler of near ground wave is 0Hz, undulation of ionosphere is between ±1Hz, and the real-time change of ionosphere is shown in the figure. It is the radio-frequency interference caused the discontinuous point in frequency sweeping in most conditions. It is clear that there are vertical sounding echo near 350km and secondary echo tracking in figure 2, as the beam width of transmitting and receiving antennas are both wide. So at the same time the system receives oblique backscattering echo, it can also get the vertical sounding echo.

Figure 2: An example of digital ionogram obtained on 27 Oct 2004 at 9:44 LT

Conclusion

Making use of the favorable autocorrelation of PN sequence and adopting pulse compression technology, the oblique backscattering echo from far away is able to obtain in a low transmitted power. IOBSS, compared with traditional FMCW oblique backscattering sounding radar, can not only get general ionospheric oblique backscattering sounding data, more important, but also get ionospheric bi-time response, scattering function, and the valuable engineering information about ionospheric Doppler frequency shift in real-time. Because the transmitted power has been reduced greatly, in one hand the complexity and cost of the system have been cut down largely, in the other hand its interference to other radio system has been decreased and the spectrum utilization ratio has been improved. It is of great significance to ionospheric dynamical conformation sounding,
evaluation of ionospheric real-time channel parameters and adaptive diagnosis and managing system for electric wave circumstance of HF radio channel.

REFERENCES