

SELECTIVE EXCITATION OF CHARACTERISTIC WAVES IN THE IONOSPHERE

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A method is developed and experiments are carried out for studying the possibility of selective excitation of characteristic waves in the ionosphere. The results of the experiment indicate that one characteristic wave can be excited steadily, and the ratio of the mean power values of the damped and undamped waves can be brought to 10. It is shown that the gain in the noise immunity when receiving such a single-mode signal, compared with the double-mode one, is 10-20 dB.

The physical specific features of the ionosphere are such that radio waves reflected from it are partially polarized. In the ionospheric communications channel the radio waves propagate from the point of emission to the point of reception along several paths simultaneously, and the frequency spectra as a result of the Doppler effect are shifted for a different value. These two circumstances cause interference fading of the overall field and, consequently, lowering of the noise immunity in reception.

It is known that only two, characteristic waves (CW) differing, in particular, by polarization, can propagate in the anisotropic ionosphere. Theoretical solution of the problem of the polarization of the CW emerging from the ionosphere involves considerable difficulties for a number of reasons [1, 2]. The results of experimental investigations, carried out in vertical sounding of the ionosphere, show that the polarization of the CW, measured near the Earth's surface, is elliptical and almost orthogonal (on the average) [3].

The sharp difference in the polarization of two CWs and a physical inhibition of the propagation of differently polarized waves in the ionosphere suggest that only one CW can be excited in the ionosphere. For solving this problem it is necessary to match the polarization of the radiated wave with the polarization of one of the CWs.

The method of selective polarization excitation of one CW is based on two assumptions concerning the physical properties of the ionosphere and of the electromagnetic waves propagating in it:

(1) the value of the permittivity of the ionosphere does not depend on the power of the electromagnetic wave propagating in it;

(2) the polarization parameters of the CW at the exit from the ionosphere do not depend on the kind of the polarization of the wave radiated by the transmitting antenna.

These two assumptions are substantiated theoretically and supported by physical experiments [1, 3, 4].

The possibility of selective excitation of individual CWs was tested experimentally in vertical sounding of the ionosphere by pulsed signals. The frequency of sounding radio signals was selected so that the pulsed signals corresponding to two CWs and reflected from the ionosphere should be time-separated in terms of group delay.

Observation sessions lasted for about ten minutes, and each session with selective excitation of the characteristic wave was preceded by a test session of observation, during which both CWs were excited and their power was measured.

The results of measuring the ratio of the CW power values during the test sessions are presented in Fig. 1. The ratio of the power values of two CWs, averaged over the session, was measured: $Q_t = P_m/P_s$, where P_m is the more powerful wave, P_s is the "weak" wave, irrespective of its (ordinary or extraordinary) type.

It is seen that all the Q_t values lie within the range of 1 to 5; this points to the absence of predominant excitation of any CW under the conditions of the given experiment.

The test session was always followed by the session with selective excitation of a CW, during which the power of two received waves was also measured. Fig. 2 shows the histogram of the ratio of mean power

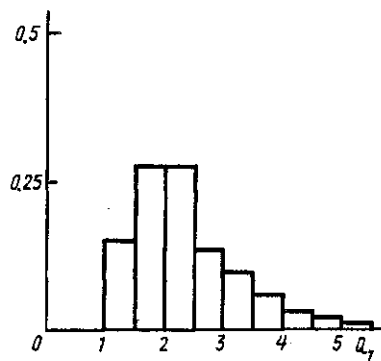


Fig. 1

Ratio of CW power values in radiation of linearly polarized wave.

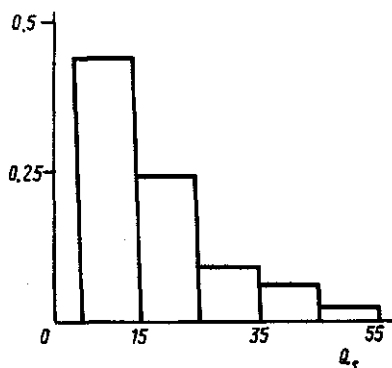


Fig. 2

Ratio of power values of undamped and damped CWs in selective excitation.

values of the selectively excited (undamped) and damped CW $Q_s = P_{np}/P_p$.

For a number of reasons ideal excitation of only one CW is not feasible: the other, damped, wave (having an appreciably smaller power) is always present, and therefore the value Q_s is never infinite. The histogram in Fig. 2 indicates that in selective excitation the ratio of the power values of two CWs has changed materially: the value Q_s ranges within 5-55 (it should be recalled that Q_t ranges within 1-5).

Thus, comparing the histograms in Figs. 1 and 2, we can conclude that the employed method of selective excitation of characteristic waves in the ionosphere allows one to change the ratio of the power values of these waves on the average by an order of magnitude, i. e., to make one wave ten times less powerful than the other. Experiments showed that this effect is stable with time: the mean value Q_s practically does not change during 10-15 min.

The results presented in Figs. 1 and 2 pertain to measuring the power of vector field $P = |E_\xi|^2 + |E_\eta|^2$, where $E_{\xi,\eta}$ are the projections of the vector of the received field in a system of coordinates, associated with the receiving antenna, and, as a consequence, they are invariant to the chosen system of coordinates.

The obtained results, pointing to the possibility of exciting only one characteristic wave in the ionosphere, allow one to estimate the gain in the noise immunity of reception, which can be provided by this effect.

The probability of an error in reception of discrete information transmitted with the help of fluctuating signals, is defined by the formula

$$P_{\text{err}} = \int_{-\infty}^{\infty} W(A)f[h^2(A)] dA, \quad (1)$$

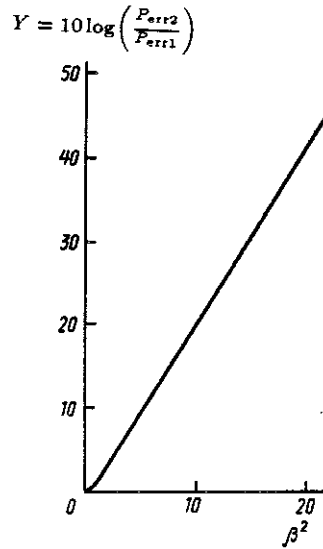


Fig. 3

Gain in noise immunity in selective excitation.

where $W(A)$ is the function of the distribution of the amplitude A of the received signal, f is the function which depends on the method of reception,

$$h^2 = A^2(t)h_0^2/\langle A^2(t) \rangle, \quad h_0^2 = P_c T/\nu^2,$$

P_c , T denote the mean power and duration of the signal element, respectively, ν^2 is the spectral density of noise in the reception band [5].

In non-coherent reception by the method of relative phase telegraphy formula (1) takes up the form

$$P_{\text{err}} = \frac{1}{2} \int_0^{\infty} W(A) \exp\{-h^2(A)\} dA. \quad (2)$$

If the signal being received consists of two partially scattered partial waves with mixed spectra, then in accordance with formula (2) the probability of error is defined by the expression

$$P_{\text{err}} = \frac{1}{2} \frac{1 + k_0^2}{1 + k_0^2 + h_0^2} \exp\left\{-\frac{k_0^2 h_0^2}{1 + k_0^2 + h_0^2}\right\} \cdot I_0\left(\frac{2k_{10} k_{20} h_0^2}{1 + k_0^2 + h_0^2}\right), \quad (3)$$

where $k_0^2 = k_{10}^2 + k_{20}^2$; $k_{i0} = A_{i0}^2/2\sigma^2 = \beta_i^2 \alpha_i^2/(\alpha_1^2 + \alpha_2^2)$, $\alpha_i = \sigma_i^2/\sigma_1^2$; $\beta_i = A_{i0}^2/2\sigma_i^2$, A_{i0}^2 is the power of the non-scattered component of partial fields E_i , $2\sigma_i^2$ is the mean power of the scattered components of the fields, $i = 1, 2$. By definition α_1^2 is always equal to 1, and

$$\alpha_2^2 = \langle A_2^2 \rangle (1 + \beta_1^2) / (\langle A_1^2 \rangle (1 + \beta_2^2)).$$

In reception of the single-beam field the probability of error is defined by the formula

$$P_{\text{err}} = \frac{1}{2} \frac{1 + k_{10}^2}{1 + k_{10}^2 + h_0^2} \exp\left\{-\frac{k_{10}^2 h_0^2}{1 + k_{10}^2 + h_0^2}\right\}, \quad (4)$$

which follows from expression (3) in the presence of the second wave (for example, $A_2 = 0$).

Formulas (3), (4) were used for estimating the gain in the noise immunity during exciting one characteristic wave in the ionosphere. The parameters β^2 and α^2 were determined from the experimental results, h_0^2 was assumed to be equal to 200.

Fig. 3 shows the gain $Y = 10 \log(P_{\text{err}2}/P_{\text{err}1})$ as a function of the parameter β^2 . The plot in Fig. 3 points to the fact that for the most probable values $\beta^2 = 5-10$ the value of the gain Y lies within the range of 10-20 dB.

The developed method of selective excitation of CWs in the ionosphere was experimentally tested with the help of a special computerized diagnostic complex.

We shall now formulate the experimental results.

Only one characteristic wave can be excited in the ionosphere: the method and a specially developed device provide the opportunity to excite any characteristic wave optionally.

The time of stable excitation of only one characteristic wave exceeds 10–15 min.

The quality of excitation of one characteristic wave is sufficiently high and allows one to bring the ratio of mean power values of two characteristic waves to 10; with such Q , value the interference fading of the overall field is practically absent.

The gain in the noise-immune reception of the single-mode signal propagating in the ionospheric communications channel, obtained as a result of lowering the interference fading, is equal to 10–20 dB.

These results indicate that selective excitation of one characteristic wave in the ionosphere is a new and very powerful tool for raising the quality and reliability of information transmission along the ionospheric communications channel.

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