Determination of hydrocarbon boundaries based on changes in field strength at two frequencies

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Abstract. The research is based on the alternative frequency method. Two transition points through zero of the dependences of the dielectric constant tensors of the medium over oil and gas deposits have been established at frequencies that determine the modes of electronic cyclotron and electronic plasma resonances. Pronounced maxima of the modulus of the surface impedance of the medium are determined. A method is proposed to increase the level of reliability in the identification and determination of hydrocarbon boundaries by a jump in the ratio of field strengths at two frequencies, indicating a change in the properties of the medium.

1 Introduction

The urgency of developing methods for searching for hydrocarbons is increasing due to the increasing needs of states to provide their economies with such an important type of fuel. Mobile autonomous devices are being developed, including use for underwater photography, for example, an electromagnetic system using a small loop source [1]. The proposed measurement technologies based on the method of induced polarization significantly increase the level of reliability of polarizability anomalies in determining the oil potential of objects in difficult geoelectric conditions [2]. Solving the issues of three-dimensional visualization of CSEM data with a controlled electromagnetic field source and the problem of high computational costs is currently attracting considerable attention from researchers to map the electrical conductivity of layers of potential offshore oil and gas reservoirs [3]. Compared with seismic and logging data, electromagnetic studies of electrical resistances can provide a better estimate of the total volume fraction of hydrate [4].

Probing signals are used in a wide range of frequencies [5]. Electrical exploration methods, such as electromagnetic sensing by field formation in the near zone, are used in solving oil and gas exploration problems [6]. The specifics of setting up a complex of electrical and seismic surveys are taken into account [7]. The surface electrical exploration (4D) method is used in the development of carbonate deposits with high resistance. The displacement of the flooding front is monitored using multi-time measurements and reservoir pressure maintenance by water injection [8]. Fractured fluid-saturated reservoirs are predicted [9]. The modes of two-frequency interaction of electromagnetic waves with the

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predominance of a powerful low-frequency signal with an anisotropic medium over hydrocarbon deposits are presented with the analysis of the material and phase components of the surface impedance for right and left circular polarizations depending on the dielectric constant and frequency of the probing signals [10].

2 Research methodology

The purpose of the research conducted in this paper is to develop a method for searching for hydrocarbons based on the two-frequency interaction of a signal with amplitudes E_1, E_2 and frequencies $\omega_1 = 2\pi f_1$, $\omega_2 = 2\pi f_2$. The dielectric constant tensors of the medium above oil and gas deposits were modeled, on the basis of which experimental measurements were performed for the two-frequency interaction of electromagnetic waves (EMW) with the medium above hydrocarbon deposits. When calculating the components of the dielectric constant tensors, the values of the medium parameters obtained during field tests over accumulations of hydrocarbons were used [5]:

- the depth of the layers of hydrocarbon deposits $h = 2.0 - 3.5$ km;
- dielectric permittivity of the geological profile $\varepsilon_r = 5 - 30$;
- electrical conductivity of layers $\sigma_r = 10^{-3}$ Cm / m;
- electron concentration $\mathrm{N_e} = 10^{16}$ m^{-3};
- ion concentration $\mathrm{N_i} = 10^{18}$ m^{-3};
- electron-ion effective collision frequencies $\nu_e = 2\pi \cdot 10^9$ rad / s;
- the ratio coefficient of the signal frequencies $k_\omega = 10^{-6}$;
- the ratio of signal amplitudes $k_E = 10$.

The expressions of the components of the dielectric constant tensors were obtained in [5], they allow us to study the propagation of electromagnetic waves over hydrocarbons and identify new patterns of changes in the electrodynamic characteristics of the medium. As can be seen from Figure 1, the real component for the right polarization of EMW is characterized by two zero transition points at frequencies f_{2C} (on the left along the abscissa axis) and f_{2P} (on the right along the abscissa axis), which determine the modes of electronic cyclotron and electronic plasma resonances. With a decrease in the values of the coefficient k_ω, an increase in the frequencies f_{2C} and f_{2P} is observed with a constant value of k_E. When the amplitude ratio is varied by two orders of magnitude, the values of f_{2C}, are further increased, and the electronic plasma resonance of f_{2P} is characterized by a noticeable shift with a decrease in the frequency ratio. For $k_E = 10^{-6}$, the point is shifted to the region of higher frequencies, and for $k_\omega = 10^{-3}$, $k_E = 10^{-6}$, the frequency values of the electron cyclotron and electron plasma resonances are equal. At the same time, f_{2P} can increase to (2÷6) GHz.

Thus, insignificant deviations in the amplitudes and frequencies of the two EMW do not affect the position of the resonant frequencies of the interaction modes and actually characterize the single-frequency mode.

Pronounced maxima of the surface impedance modulus of the medium are observed (Figure 2) at frequencies of (100-400) MHz. As the value of the dielectric constant of an anisotropic medium increases, the resonance frequency shifts to the left along the frequency axis and the value of this component decreases. This behavior of EMW spreading over a deposit can be used to isolate such media among homogeneous objects and develop methods for searching and identifying hydrocarbon deposits.

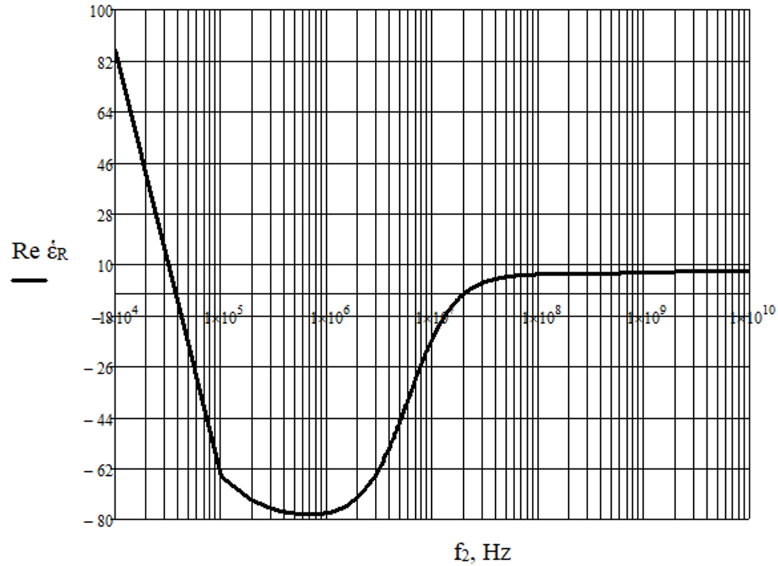

Fig. 1. The dependence of the total component of the tensor on the frequency f_2.

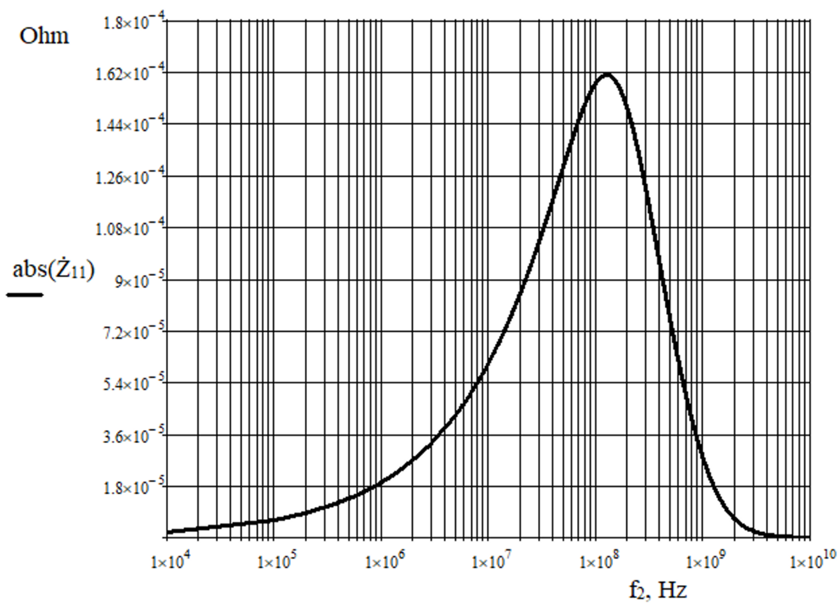

Fig. 2. The dependence of the surface impedance of the medium on the frequency f_2.

3 Results and discussion

The study was conducted on the basis of the method of alternative frequencies established on the basis of the conducted modeling. The zero transition frequencies f_{2C} and f_{2P} (hereinafter referred to as f_1 and f_2 for convenience) characterize the properties of the medium parameters above hydrocarbon accumulations with varying degrees of EMW attenuation, i.e. there are areas where the underlying anisotropic medium will be either absorbing or reflecting. By measuring the ratio of the measured amplitudes of the electric field strengths of EMW E_1 and E_2 at two frequencies f_1 and f_2 when moving along a specific geoprofile:

$$K_E(r) = \frac{E_2}{E_1} \tag{1}$$

the boundary of the hydrocarbon deposit can be determined from the anomalous values of the specified ratio (1). The behavior of the field strength with amplitude E_1 for EMW with values of $K_E \ll 1$ and $K_\omega \ll 1$ in the range of applied frequencies from 1000 Hz to 1-2 MHz in the region of the "outer rocks – hydrocarbon deposits" boundary will be characterized by a sharp decrease.

Experimental testing of the effect of the established nonlinear interaction of signals with frequencies f_1 and f_2 with the medium over hydrocarbon deposits revealed the results shown in Figure 3.

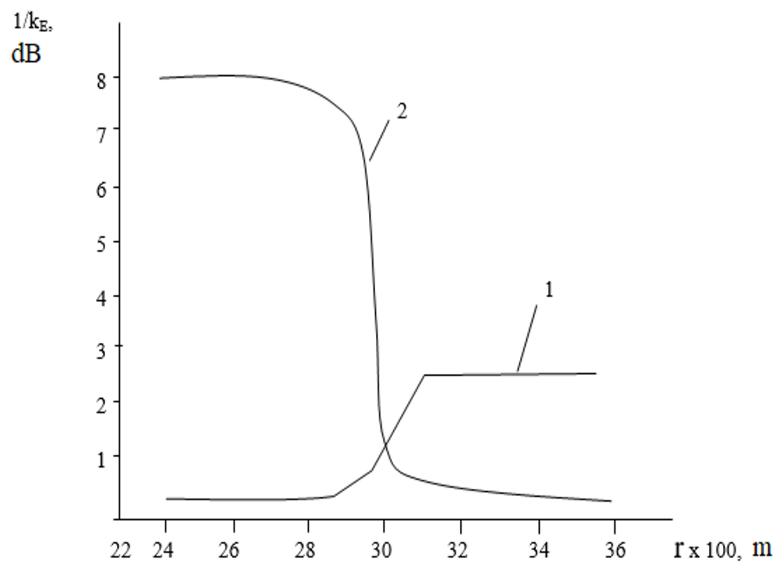

Fig. 3. The results of experimental measurements.

An abnormal jump in the EMW field strength at such frequencies is equivalent to a transformation of characteristics at the boundary of "sea"-"land" type media. At the same time, the use of the so-called alternative frequency f_2 in relation to the frequency f_1 from the calculated subband of 10 ... 100 MHz makes it possible to register at the boundary of the hydrocarbon deposits circuit under study a significant anomaly in the intensity of the EMW electric field E_2 with the opposite character in relation to the first one.

With a constant distance l = 10 m between the receiver and the illumination transmitter, during the tests at frequency f_1 and changing the location of the transmitter operating at frequency f_2, the ratio $\frac{1}{k_E}$ to point 29 of this terrain profile is characterized by uniform behavior, and after passing this picket, it increases to 2.5 dB (so $\frac{1}{k_E} \approx 0.5$ dB at point 27,

$\frac{1}{k_E} \approx 2.5$ dB at point 32). At control points 30-34, the value of the EMW voltage ratio is almost unchanged. When installing transmitters outside the contour of hydrocarbon deposits (curve 2), the ratio of field strengths at points 24-28 is also almost the same.

4 Conclusion

By measuring the ratio of electromagnetic field strengths of EMW at two frequencies at each fixed point when moving along the profile under study, a jump in the ratio of signal strengths at the boundary of the hydrocarbon deposits region is recorded with a significant excess of the field strength anomaly when using a signal at frequency f_2. The tension ratio is constant behind and above the deposit. It is the jump in the ratio at the boundary that determines the change in the properties of the environment and can be used to search for hydrocarbon deposits. This method provides an increased level of reliability in the identification and accuracy of determining the boundaries of the hydrocarbon deposits.

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