

# Research methods of geological structures over hydrocarbon accumulation

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**Abstract.** The article presents the results of research methods of geological structures over hydrocarbon accumulation. Measurements of the characteristics of these structures at the Geological hydrocarbon accumulation of the Republic of Belarus are made. Irradiation with a dual-frequency electromagnetic wave and reception of the reflected wave in modes with the low-frequency signal exceeding 10 times the high-frequency signal and the high-frequency signal exceeding 10 times the low-frequency signal were used. It has been established that measurement of reflection coefficient contrast between a geological structure and a homogeneous underlying profile increases the accuracy of hydrocarbon isolation. Methods of hydrocarbon deposit search based on the measurement of phase components of surface impedance in the mode of amplitude-frequency-modulated signals and determination of reflective properties of the medium over hydrocarbon accumulation in the mode of dual-frequency signals have been developed. The data of the obtained studies can be used to develop methods of hydrocarbon deposits detection.

## 1 Introduction

The development of hydrocarbon accumulation exploration methods and the relevance of such works are caused by the increased requirements for the accuracy of hydrocarbon isolation [1-3]. The use of electromagnetic waves in the frequency modulation mode leads to the expansion of functional capabilities of prospecting works [4]. The data of analysis of geophysical characteristics of the Earth's crust are studied based on the method of depth sounding with the use of powerful explosions and obtaining the dependences of hydrocarbon availability in the selected area on the parameters of the Earth's surface [5]. The use of space imagery is relevant, especially in crisis, when even large oil companies reduce the level of geological exploration tests and sometimes stop investment projects for the development and exploitation of hydrocarbon accumulation [6].

There are experimental data on the use of sensing results for planning the development and production of oil on the oil field in Iraq [7], evaluation of the methodology for prediction of oil and gas occurrence of northwestern Colombia using remote and geophysical data [8]. Long-term geodynamic monitoring of oil and gas fields in Western

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Siberia by satellite radar interferometry is used [9]. All-weather capability of radar data and their independence from illumination allows to receive information on natural and anthropogenic processes occurring on the Earth's surface with guaranteed periodicity (up to several times a day) [10].

Opportunity analysis of using the method of space radar monitoring of earth surface displacements is provided over the Tengiz oil and gas field [11].

Using achievements in modelling and interpretation in near-surface geophysics [12] to analyse the geophysical characteristics of the Earth's crust, it is possible to obtain accurate data on the presence of hydrocarbons along the studied geological profile.

The aim of this research is to develop a method for detecting hydrocarbon accumulation.

## 2 Research methodology

To investigate the properties of the medium over hydrocarbon accumulation, the analysis of the surface impedance of the medium over hydrocarbon accumulation was applied using the formulae

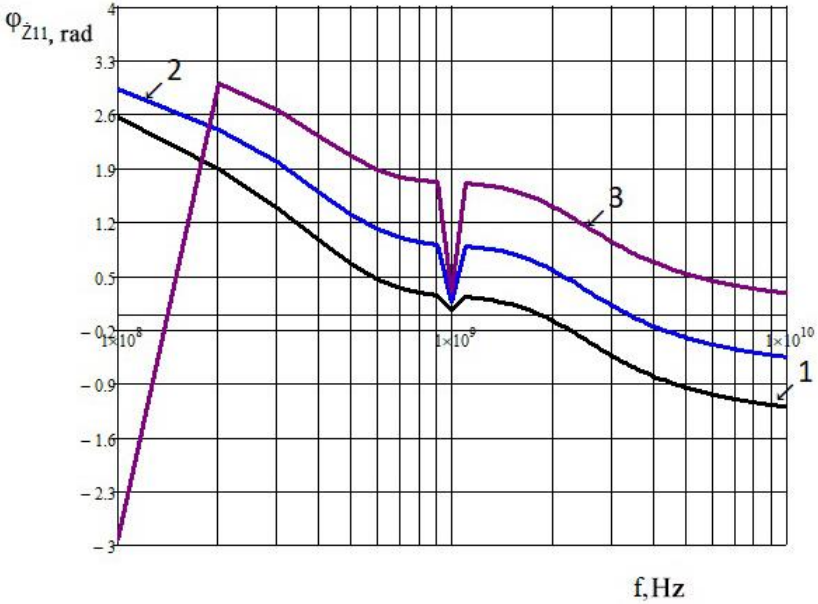
$$\begin{aligned}\varphi_{\dot{Z}_{11}} = \arg \dot{Z}_{11} = \arg \dot{Z}_{22} &= -\arg \left( \frac{1}{j2\sqrt{\dot{\epsilon}_R \dot{\epsilon}_L}} (\dot{\epsilon}_R - \dot{\epsilon}_L) \right), \\ \varphi_{\dot{Z}_{12}} = \arg \dot{Z}_{12} = \arg \dot{Z}_{21} &= -\arg \left( \frac{1}{j2\sqrt{\dot{\epsilon}_R \dot{\epsilon}_L}} (\dot{\epsilon}_R + \dot{\epsilon}_L) \right),\end{aligned}\tag{1}$$

$\varphi_{\dot{Z}_{11}}$  and  $\varphi_{\dot{Z}_{12}}$  – phase components of surface impedance;  $\dot{Z}_{11}$  and  $\dot{Z}_{12}$  – components of the surface impedance of the medium;  $\dot{\epsilon}_R, \dot{\epsilon}_L$  – total and difference components of the dielectric permittivity tensor of geological structures over hydrocarbon accumulation for electromagnetic waves (EMW) with right and left circular polarization.

Expression for the dielectric permittivity tensor is given in [1]. The hydrocarbon detection technique consists in determining the surface impedance for different modes of electromagnetic wave exposure to the investigated profile.

## 3 Discussion of results

Studies of the phase components of the surface impedance (1) when the medium over hydrocarbon accumulation is exposed to amplitude-frequency-modulated (AFM) signals have been carried out. It was found that the phase component of the surface impedance  $\dot{Z}_{11}$  (Figure 1) is most influenced by carrier frequencies (100 – 500) MHz in the variation of modulating characteristics. Not without interest is the carrier signal frequency  $f = 1$  GHz at which there is a sharp decrease in the phase component of the surface impedance  $\dot{Z}_{11}$  for all values of amplitude modulation index  $k_m$  and frequency modulation index  $\beta = 20$ . A sharp increase of phase is typical for amplitude modulation index 1,0 at carrier frequencies (100 – 200) MHz.



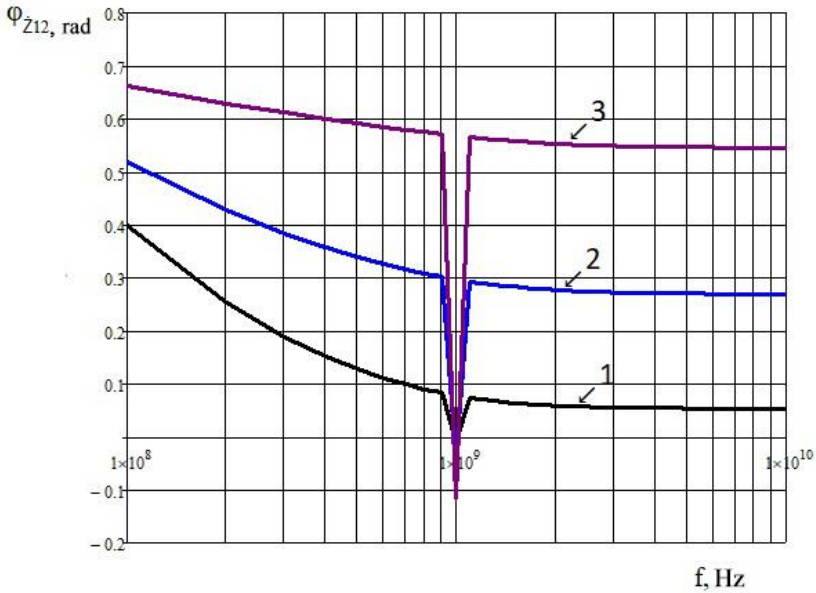
**Fig. 1.** Dependences of the phase component of the surface impedance  $\dot{Z}_{11}$  for  $\varepsilon_r = 10$ , modulation frequency  $F = 10^7$  Hz,  $\beta = 20$ : 1 – for  $k_m = 0.1$ ; 2 – for  $k_m = 0.5$ ; 3 – for  $k_m = 1.0$ .

Table 1 shows the values of  $\Phi_{\dot{Z}_{11}}$  for the variation of modulating characteristics.

**Table 1.** Calculation results of the phase component of the surface impedance  $\dot{Z}_{11}$  for the amplitude-frequency modulation signal.

		<b>f, MHz</b>		<b>500</b>	<b>700</b>	<b>1000</b>	<b>1500</b>	<b>2000</b>
		$k_m = 0.1$	$k_m = 0.5$	$k_m = 1.0$	$k_m = 1.0$	$k_m = 1.0$	$k_m = 1.0$	$k_m = 1.0$
$\Phi_{\dot{Z}_{11}}$ , radian	$\beta = 20,$ $F = 50$ MHz	$k_m = 0.1$		1.28	1.04	0.72	0.75	0.58
		$k_m = 0.5$		2.28	2.15	1.99	1.91	1.72
		$k_m = 1.0$		2.64	2.52	2.37	2.28	2.07
	$\beta = 20,$ $F = 100$ MHz	$k_m = 0.1$				-0.10	-0.36	-0.54
		$k_m = 0.5$				-0.68	-1.05	-1.32
		$k_m = 1.0$				-1.14	-1.38	-1.58
	$\beta = 95,$ $F = 10$ MHz	$k_m = 0.1$				1.90	1.74	1.65
		$k_m = 0.5$				2.28	2.13	2.02
		$k_m = 1.0$				2.38	2.23	2.11

It was found that the phase component of the surface impedance  $\dot{Z}_{12}$  (Figure 2) at variation of modulating characteristics is most influenced by the carrier signal frequency  $f = 1$  GHz at which there is a sharp decrease in the phase component of the surface impedance  $\dot{Z}_{12}$  for all values of amplitude modulation index  $k_m$  and frequency modulation index  $\beta = 20$ .



**Fig. 2.** Dependences of the phase component of the surface impedance  $\dot{Z}_{12}$  for  $\epsilon_r = 10$ , modulation frequency  $F = 10^7$  Hz,  $\beta = 20$ : 1 – for  $k_m = 0.1$ ; 2 – for  $k_m = 0.5$ ; 3 – for  $k_m = 1.0$ .

Table 2 shows the values of  $\varphi_{Z_{12}}$  for the variation of modulating characteristics.

**Table 2.** Calculation results of the phase component of the surface impedance  $\dot{Z}_{12}$  for the amplitude-frequency modulation signal.

		<b>f, MHz</b>	<b>500</b>	<b>700</b>	<b>1000</b>	<b>1500</b>	<b>2000</b>
$\varphi_{Z_{12}}$ , radian	$\beta = 20$ , F = 50 MHz	$k_m = 0.1$	0.34	0.32	0.20	0.29	0.28
		$k_m = 0.5$	0.68	0.67	0.66	0.69	0.66
		$k_m = 1.0$	0.79	0.79	0.78	0.79	0.78
	$\beta = 20$ , F = 100 MHz	$k_m = 0.1$			0	-0.06	-0.09
		$k_m = 0.5$			-0.14	-0.26	-0.35
		$k_m = 1.0$			-0.34	-0.39	-0.43
	$\beta = 95$ , F = 10 MHz	$k_m = 0.1$			0.63	0.64	0.64
		$k_m = 0.5$			0.76	0.76	0.76
		$k_m = 1.0$			0.78	0.79	0.79

This exploration method can be used to highlight the difference in characteristics of geological structures over hydrocarbon accumulation based on surface impedance determination and improved accuracy through the use of a two-channel measurement scheme.

The method of determining the reflective properties of the medium over hydrocarbon accumulation was also applied. The contrast of reflection coefficients between a geological structure and a homogeneous underlying profile when exposed to electromagnetic waves with linear polarization was determined.

This question is solved in this method of hydrocarbon accumulation exploration on the basis of irradiation of electromagnetic waves with vertical polarization of the investigated

profile at fixed frequencies, reception of reflected waves in the measurement points of the given terrain section and determination of the reflection coefficients of the hydrocarbon accumulation boundary by the difference of the contrast value of the reflection coefficients. Irradiation with two-frequency electromagnetic wave and reception of the reflected wave in modes I (low-frequency signal exceeds 10 times the high-frequency signal) and II (high-frequency signal exceeds 10 times the low-frequency signal) is used on the basis of determination of the reflection coefficient contrast between the geological structure and homogeneous underlying profile in the range of high-frequency signal  $f_2 = (700 - 1000)$  MHz with the lower frequency  $f_1 = (1 - 10)$  MHz according to the anomalous values of which the boundaries of the deposit are established.

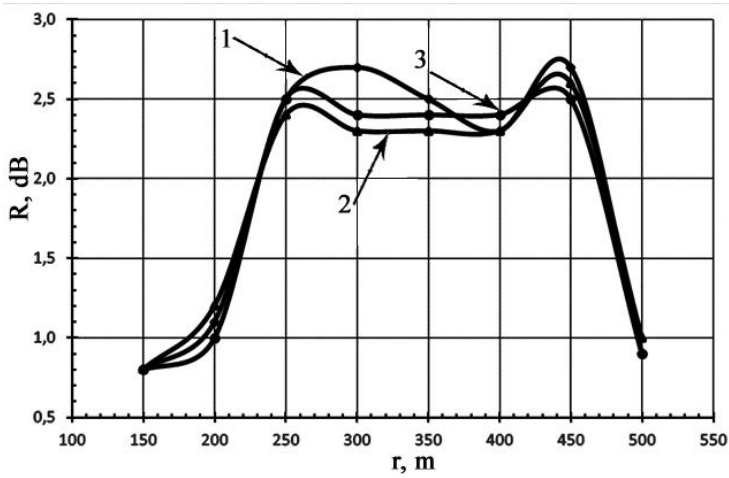
Equipment using a stationary transmitter, receiver and antennas was used. Electromagnetic signal of a two-frequency electromagnetic wave generated by a stationary transmitter in the frequency range  $f_2 = (700 - 1000)$  MHz, with a lower frequency  $f_1 = (1 - 10)$  MHz with vertical polarization in modes I and II comes from the antenna in the area of geological structure over hydrocarbon accumulation. The reflected signal is fed through the received antenna into the receiver. The height of elevation of the antennas used and their diversity value were set from the conditions of convenience of testing and fulfilment of characteristics on electromagnetic compatibility of the equipment. The electromagnetic wave falls at an angle  $\theta = 30^\circ$ . At the measurement points of this profile, the reflection coefficient contrast between the geological structure and the homogeneous underlying profile was measured. Anomalous values of the measured reflectance contrast values indicate the presence of hydrocarbon deposits. The proposed method was tested at the Geological fields of hydrocarbon accumulation in Gomel region.

A certain reference point was set, relative to which the measurements were made along the entire investigated profile. The anomaly of the surface impedance phase was most pronounced when measuring receivers were located over and outside the accumulation.

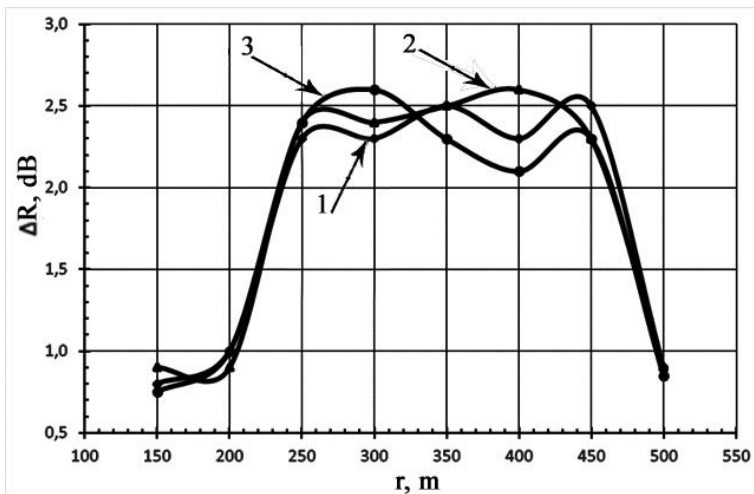
Example 1. Irradiation of geological structures over hydrocarbon fields by a dual-frequency electromagnetic wave at frequency  $f_2 = 700$  MHz with low-frequency exposure frequency  $f_1 = 1$  MHz for vertical polarization of electromagnetic waves in modes I (low-frequency signal exceeds 10 times the high-frequency signal) and II (high-frequency signal exceeds 10 times the low-frequency signal) was carried out.

Example 2. Irradiation of geological structures over hydrocarbon fields by a dual-frequency electromagnetic wave at frequency  $f_2 = 850$  MHz with low-frequency exposure frequency  $f_1 = 5$  MHz for vertical polarization of electromagnetic waves in modes I (low-frequency signal exceeds 10 times the high-frequency signal) and II (high-frequency signal exceeds 10 times the low-frequency signal) was carried out.

Example 3. Irradiation of geological structures over hydrocarbon fields by a dual-frequency electromagnetic wave at frequency  $f_2 = 1000$  MHz with low-frequency exposure frequency  $f_1 = 10$  MHz for vertical polarization of electromagnetic waves in modes I (low-frequency signal exceeds 10 times the high-frequency signal) and II (high-frequency signal exceeds 10 times the low-frequency signal) was carried out.



**Fig. 3.** Caption Research for Geological field of hydrocarbon accumulation, mode I: 1 – Example 1; 2 – Example 2; 3 – Example 3.



**Fig. 4 –** Research for Geological field of hydrocarbon accumulation, mode II: 1 – Example 1; 2 – Example 2; 3 – Example 3.

At the field boundary (points 250, 475 for the Geological field of hydrocarbon accumulation), the contrast increases to values of 2.50 dB (mode I) and 2.40 dB (mode II) at 250 m, to values of 2.50 dB (mode I) and 2.30 dB (mode II) at 475 m. The anomalous behaviour of the reflection coefficient contrast corresponds to the boundary of hydrocarbon accumulation.

## 4 Conclusion

As a result of the conducted research it should be noted:

- Methods of searching for hydrocarbon accumulation based on measuring phase components of surface impedance and determining reflective properties of the medium over hydrocarbon accumulation were developed.

- The exploration method based on the measurement of phase components of surface impedance can be used to delineate geological structures over hydrocarbon fields and leads to improved accuracy due to the use of a dual-channel measurement scheme.
- These studies are relevant for specialists engaged in electrical exploration of hydrocarbon accumulation.

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