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MATHEMATICAL SIMULATION OF ULTRA WIDEBAND SIGNALS SCATTERED BY MINES BURIED IN GROUND. ALGORITHMS OF MINE DETECTION AND IDENTIFICATION

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Method of mathematical simulation of ultra wideband signals scattered by metal or dielectric mine and other subsurface objects located in ground or other medium is described. Method allows for getting electromagnetic signals reflected from subsurface objects with arbitrary substance, shape, orientation, parameters of the environment the object is in, and scanning with various polarity waves. Results of metal and plastic mine ultra wideband response calculation are discussed. Also algorithm of mine detection and identification based on determination of object natural complex resonances is considered.

1. Introduction

At present the radar systems take a wide application for the detection of mines and other subsurface objects (SO) located in the ground or other dielectric medium at small distance from medium interface. Advantages of electromagnetic method for mine detection are conditioned by good penetrability of electromagnetic waves at the frequency band from 0.1 to more then 2 GHz in the ground, wide progress in generation, reception technique, and processing of radar signals at last decade.

The mine detection is accompanied with several difficulties: 1) mine detection is accomplished of strong medium interface reflection, which masked the signal reflected by mine; 2) electrical parameters of ground (permittivity and conductivity) significantly depend on frequency, humidity, and density of a ground; 3) ground is a nonuniform medium containing stones, bricks, remains of pipes and other foreign objects. This fact stimulate the necessity of identification algorithm using for reducing of conditional probabilities of false solutions; 4) plastic mine detection is essentially complicated by small difference between mine permittivity and ambient ground one. Moreover mines are generally located in near-field zone of radar antenna system.

Problems stated above denote necessity of ultra wideband (UWB) signal using for mine detection and identification.

At the state of creation the SO detection radar it is important to dispose of information about the features of signals scattered from such objects located in a dispersive medium. In report the method of calculation of UWB signals scattered by mine and other SO located in the ground (or other medium) is described. Developed method is based on solving of integral equations for the current densities on the object surface and allows calculating of UWB responses of metal and dielectric objects of arbitrary shape and orientation, for the various sounding conditions.

2. Mathematical Simulation of Ultra Wideband Signals Scattered by Mines Buried in the Ground

In papers [1, 2, 3] mathematical expressions for calculating the electromagnetic fields scattered by metal and dielectric SO are described in detail.

In the case of metal SO surface Fredholm integral equation of the second kind for the electric current densities on the SO surface was obtained. For dielectric SO the system of surface Fredholm integral equations of the second kind for the equivalent electric and magnetic current densities was obtained.

Also there was obtained integral relations, which allow to calculate surface, frequency and pulse responses of metal and dielectric objects of arbitrary shape and orientation, for the cases of various antenna system locations relative to object, and various sounding signal polarizations.

Further the results of numerical simulation of M15, MK7 anti-tank metal mines and DM11 anti-personnel plastic mine UWB responses are demonstrated and discussed. Also the results of UWB re-

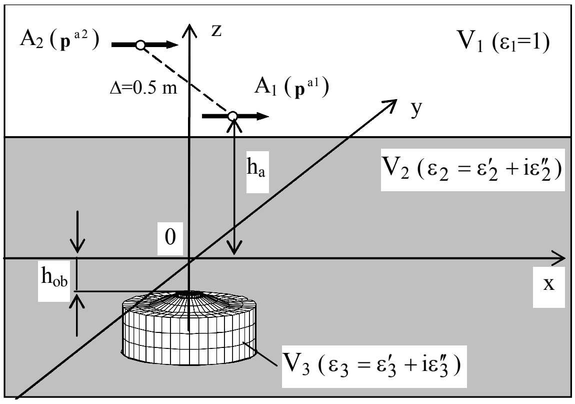

Fig. 1. *Mine buried in the ground*

sponse simulation for the case of thin air layer formed between the top of dielectric mine and ambient ground are demonstrated.

For the calculating it was accepted the model shown in Fig. 1. As the transmitting $A_1(x_{a1}, y_{a1})$ and the receiving $A_2(x_{a2}, y_{a2})$ elements of bistatic radar the antennas of small electric dimensions (magnetic dipoles with vector-moments $\mathbf{p}^{a1}$, $\mathbf{p}^{a2}$ correspondingly) were applied. They located in free half-space V_1 (permittivity $\varepsilon_1 = 1$). Vector-moments were oriented along Ox axis. The distance between antennas Δ in horizontal plane, and their height h_a above the ground interface accounted 0.5 m. At the same time the antenna system assumed completely isolated. In lower dielectric lossy dispersive half-space V_2 ($\varepsilon_2(f) = \varepsilon_2'(f) + i\varepsilon_2''(f)$), and adjoining on V_1 along the xOy plane the object V_3 was located. The object is filled with material having permittivity $\varepsilon_3(f) = \varepsilon_3'(f) + i\varepsilon_3''(f)$. Regions V_1, V_2, V_3 are uniform. Permeability $\mu = 1$ in all concerned regions.

Examined objects were illuminated by UWB signal with uniform spectrum from 100 to 1000 MHz. Interval between the spectral lines accounted 50 MHz. Magnetizing force amplitude of wave incident on the ground interface accounted 1 A/m. Module $H(f) = |H_x(f)|$ of scattered field at reception point was subject to calculation.

SO were located in two types of ground with various densities ρ, and humidity W: gray loam having $\rho = 1.2\ \frac{\text{g}}{\text{cm}^3}$, $W = 10\,\%$ (ground 1), and $\rho = 1.4\ \frac{\text{g}}{\text{cm}^3}$, $W = 20\,\%$ (ground 2); brown loam with parameters $\rho = 1.4\ \frac{\text{g}}{\text{cm}^3}$, $W = 10\,\%$ (ground 3). Frequency dependences of considered ground electrical parameters were taken from the paper [4]. Coordinates $x = y = 0$ corresponded to object center at all considered cases.

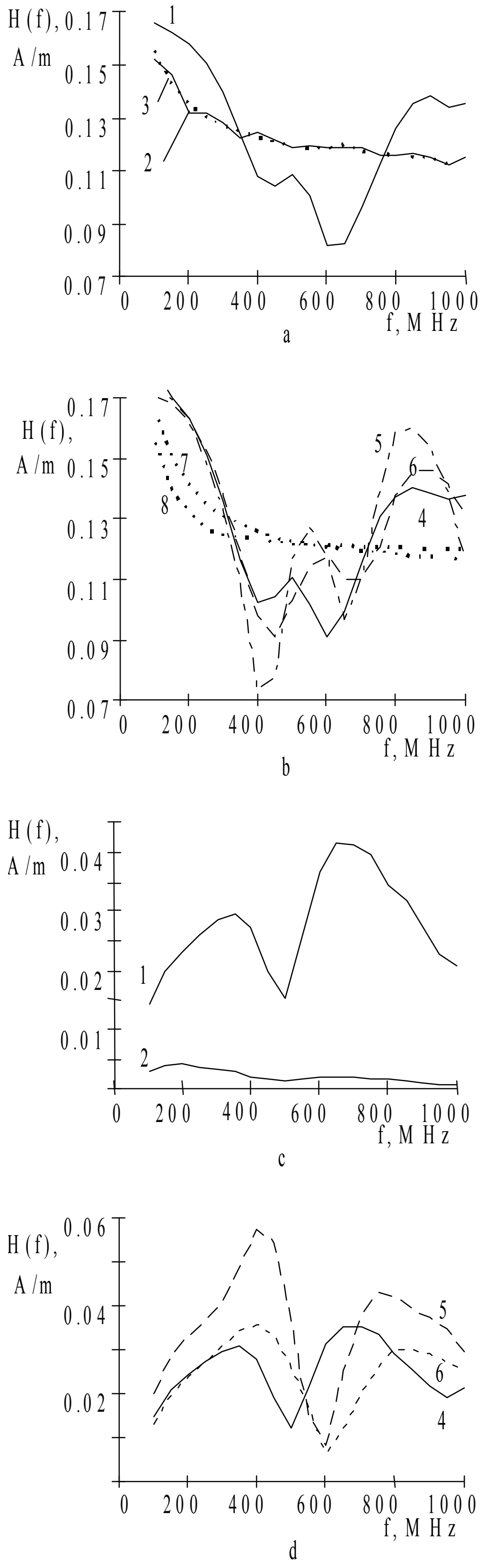

Fig. 2. *Frequency responses of metal, anti-tank mines M15 and MK7*

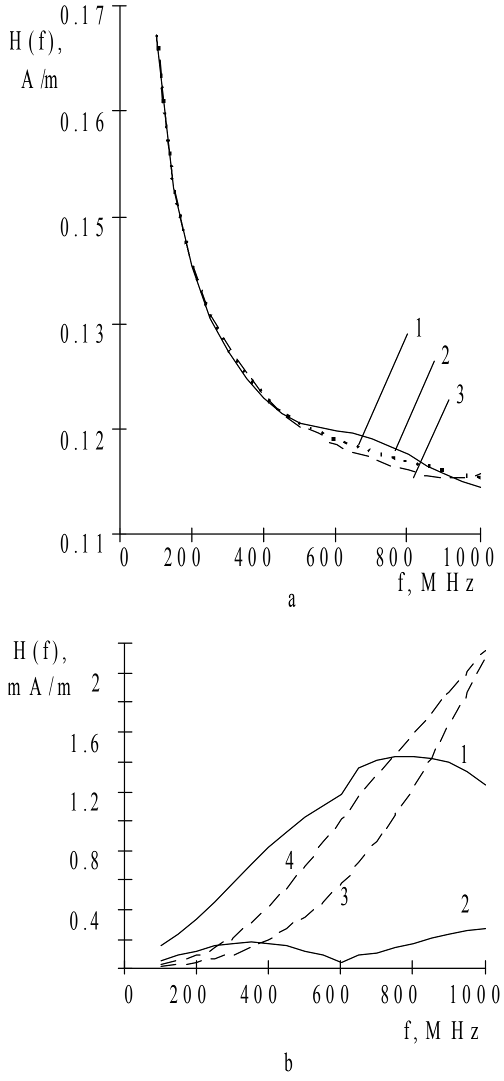

Fig. 3. *Frequency responses of plastic anti-personel mine DM11 and thin air layer*

In Fig. 2 are shown frequency responses of mines M15 и MK7 corresponding to following radar system coordinates: Fig. 2(a) and 2(c) – $x_{a1} = 20$ cm, $x_{a2} = -30$ cm, $y_{a1} = y_{a2} = 0$; Fig. 2(b) and 2(d) – $x_{a1} = 20$ cm, $y_{a1} = 0$, $x_{a2} = -15.36$ cm, $y_{a2} = 35.36$ cm. Fig. 2(a) and 2(c) show M15 mine responses for its location at different depth in ground 1 (line 1 – $h_{ob} = 6$ cm, 2 – $h_{ob} = 45$ cm, 3 – ground interface reflection). Fig. 2(b) and 2(d) illustrate frequency responses of M15 (line 4) and MK7 (5) at the same ground and in the ground 3 (6) at the depth of $h_{ob} = 6$ cm. Lines 7 and 8 illustrate the responses that correspond to reflection from ground 1 and 3 at the mine absence. In Fig. 2(c) and 2(d) ground interface reflection is left out of account.

Frequency responses of M15 and MK7 have the resonance character. Such these objects stably detected against a background of ground interface reflections. Demonstrated results show that the frequency response shape sufficiently depends on ground parameters, and also on depth of the object.

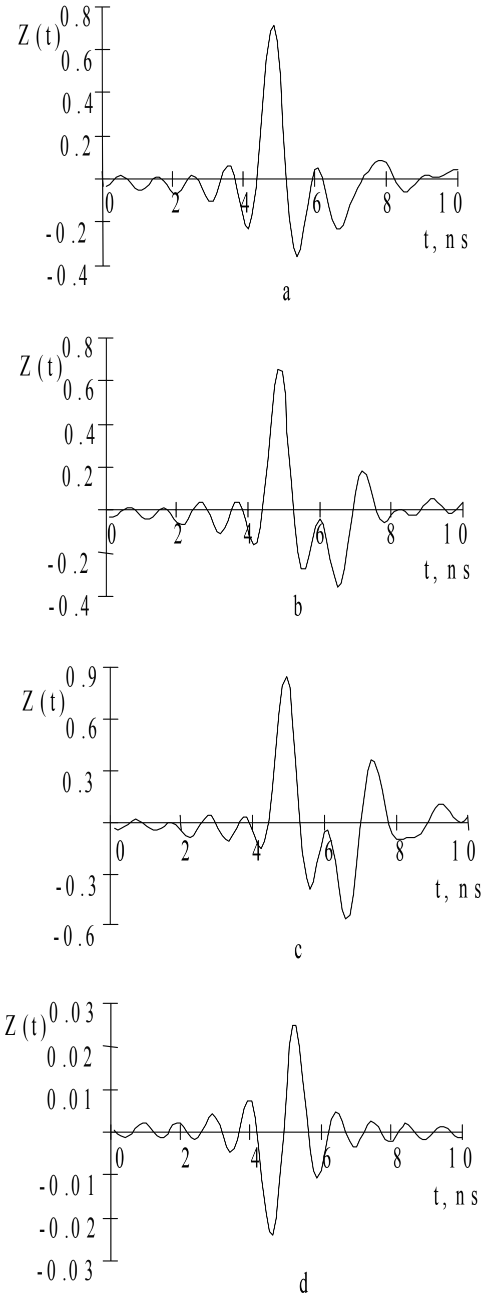

Fig. 4. *Pulse responses of mines*

Fig. 3a illustrates the frequency response of DM11 mine in ground 1 (line 2) corresponding the radar location considered in Fig. 2(b) and 2(d). On this figure also considered the response of the thin air layer of 3 mm thickness (line 3, ellipsoid with semi-axes: $a = b = 4$ cm, $c = 1.5$ mm). In Fig. 3(b) responses of mine DM11 and air layer in the same ground (line 1 – DM11, 3 – air layer) and in the ground 2 (line 2 – DM11, 4 – air layer) are shown. On graphs demonstrated in Fig. 3(b) ground interface reflection is left out of account. Considered objects were located at the depth of $h_{ob} = 6$ cm. The results show that in certain parameters of ground amplitude of thin air layer reflection can exceed the amplitude of plastic mine response. Amplitude of dielectric object responses depend on ground parameters, depth of location, and also on difference of SO permittivity and ambient ground one. Results demonstrated in Fig. 2 and 3 show that the plastic mine detection is sufficiently complicated relatively to metal mine detection. Further the pulse responses of considered SO are demonstrated.

In Fig. 4 are shown pulse responses of M15 (a), MK7 (b), DM11 (d), located in ground 1, and MK7 in ground 3 (c). Mines was buried at the depth of $h_{ob} = 6$ cm. Coordinates $x_{a1} = 20$ cm, $y_{a1} = 0$, $x_{a2} = -15.36$ cm, $y_{a2} = 35.36$ cm corresponded to radar locations.

Analysis of demonstrated responses shows that amplitude of metal and dielectric mine responses ratio accounts 30 at the same ground. The results of mathematical simulation show that for mine detection and identification it is necessary to know the ground parameters.

3. Mine Identification Algorithms

The obtained data could be used for developing algorithms of detection and identification of SO.

A mathematical model that allows for identifying objects those are supposed to be identified amongst others through detecting their nature resonance frequencies out of objects' UWB responses were developed.

As recognition criteria suggested algorithms for recognition of metal and dielectric objects use its natural resonance frequencies to which imaginary parts of natural complex resonances correspond.

As an example in Fig. 5 we took the distribution of complex resonances of mine-like object when the position of the antenna system changes within the same horizon (the same fixed height). Ovals outline resonances belonging to the same groups. The analysis showed that the average deviation of their imaginary parts makes about 4 %. Approximately the same values are obtained when one changes the distance between the transmitting and receiving antenna and the height the antenna system above the ground interface.

The research shows that nature resonance frequencies practically do not depend on probing conditions. It gives a possibility to reduce the required capacity of the memory part of the recognition device.

Operation of the recognition device that uses the algorithms requires performance of a limited number of simple arithmetic operations.

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МАТЕМАТИЧЕСКОЕ МОДЕЛИРОВАНИЕ СВЕРХШИРОКОПОЛОСНЫХ СИГНАЛОВ, РАССЕЯННЫХ МИНАМИ, НАХОДЯЩИМИСЯ В ЗЕМЛЕ. АЛГОРИТМЫ ВЫЯВЛЕНИЯ И ИДЕНТИФИКАЦИИ

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Описан метод математического моделирования сверхширокополосных сигналов, рассеянных металлической или диэлектрической миной и другими подповерхностными объектами, расположенными в земле или какой-либо другой среде. Метод позволяет получать электромагнитные сигналы, отраженные от подповерхностных объектов из произвольного материала, для произвольных формы, ориентации, параметров окружающей среды, при сканировании волнами произвольной поляризации. Обсуждаются результаты вычисления сверхширокополосного отклика металлической и пластиковой мин. Рассматривается также алгоритм обнаружения и идентификации мин, основанный на определении собственных комплексных резонансов объекта.

МАТЕМАТИЧНЕ МОДЕЛЮВАННЯ НАДШИРОКОСМУГОВИХ СИГНАЛІВ, ЯКІ РОЗСІЯНІ МІНАМИ, ЩО ЗНАХОДЯТЬСЯ У ЗЕМЛІ. АЛГОРИТМИ ВИЯВЛЕННЯ ТА ІДЕНТИФІКАЦІЇ

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Описано метод математичного моделювання надширокосмугових сигналів, які розсіяні металевою або діелектричною міною та іншими підповерхневими об'єктами розташованими у землі або якому-небудь іншому середовищі. Метод дозволяє отримувати електромагнітні сигнали, відбиті від підповерхневих об'єктів з довільного матеріалу, для довільних форми, орієнтації, параметрів оточуючого середовища та при скануванні хвилями довільної поляризації. Обговорено результати обчислення надширокосмугового відгуку металевої та пластикової мін. Розглянуто також алгоритм виявлення та ідентифікації мін, що ґрунтується на визначенні власних комплексних резонансів об'єкта.