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Investigation of Diffraction of Electromagnetic Microwaves on Explosive Materials

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Abstract. A mathematical model of diffraction of electromagnetic microwaves on explosive materials with different physical and electromagnetic parameters has been developed. The model was constructed by solving Maxwell's equation for two surfaces separating three dielectric materials, in particular air, explosive material, and the substrate on which the explosive material is located. Different types of soil and wood are considered as the substrate material, which meets the conditions for demining large areas of the locality. The results of the numerical calculation showed that 67 % to 92 % of the energy of electromagnetic radiation is concentrated in the explosive material. In this case, trinitrotoluene, which is placed on dry sand, has the highest absorption rates, while wet wood, due to its high coefficient of dielectric permittivity, successfully transmits electromagnetic microwaves through its surface. The obtained models and numerical results are considered as theoretical basis for predicting the effectiveness of remote methods of detection and disposal of explosive materials using electromagnetic microwaves. The obtained results showed that this method will be least effective for explosive materials placed on wet wood. In this case, the lowest reflection coefficient is observed that complicates the search for explosive material and the lowest absorption coefficient that complicates the artificial detonation of explosive material due to its heating under the influence of electromagnetic microwaves.

1 Introduction

Over the past 10 years active hostilities in the territory of Ukraine have led to the contamination of a large area of the country with explosive objects containing explosive materials (EM). At the same time, various explosive items were used, including home-made and those that have no sheath. The de-occupation of territories poses a serious danger to the population and personnel returning back home after evacuation. Therefore, the primary task of today in Ukraine is to clear the area of explosive objects. To solve this problem, various methods are used for their detection and deactivation [1]. However, in order to clean the territory of Ukraine from EMs using the existing methods and technical devices, tens of years of search works are needed. An increase in the intensity of work may result in an increased risk of uncontrolled explosion of EM and incomplete cleaning of the territory. All this requires intensifying the work relating to finding and developing new methods of detecting and deactivating explosive objects. Such methods should be based on new operating principles to ensure conditions for rapid scanning of a large-size area and remote deactivation of EMs.

2 Problem Formulation

Practical expert subdivisions involved into humanitarian demining use magnetic field analysis devices that are simple in their design and are cheap, but work efficiently only at short distances of searching for EMs with metal shells [2]. Lately, the EMs with no metal elements are widely used on the battlefield, and as a matter of fact it results in an uncontrolled detonation of EMs leading to the death and injury of people. Uncontrolled explosions of explosives are conditioned by the availability of a wide range of explosive objects, in particular, with a minimum content of metal components. Therefore, the existing methods of detecting and deactivating explosive objects have proved their insufficient effectiveness.

So, there is a problem of detection and disposal of explosive objects that contain no metal structural elements.

3 Analysis of Publications

The year 2023 demonstrated to the whole world a significant increase in dangers of a various nature. Unfortunately, this trend will only grow in 2024. In recent years, the number of natural, man-made, social, and military emergencies has significantly increased [3, 4]. Despite the fact that the developed countries of the world are intensifying the development of safety-related technologies and appropriate organizational approaches to the problem, the risks to human life and health are increasing [5, 6]. Ensuring the overall security situation in a separate region has several stages and avenues. First of all, it includes an assessment of the level of risk [7, 8]. It requires in its turn the availability of complete and reliable information that can be collected during quality monitoring [9, 10]. Secondly, it requires the development of modern methods and means of prevention and liquidation of emergency situations of a various nature [11, 12].

A large number of active military conflicts are accompanied by new, large-scale threats [13]. However, mine hazards and the risk of using weapons of mass destruction pose the main threat. If there is a potential risk of a large-scale contamination of the territory and water ecosystems [14] with dangerous chemical and radioactive materials as a result of the use of weapons of mass destruction [15], then the threat posed to the civilian population due to the use of explosive objects is already a real reality [16]. For example, in Ukraine, more than 15 % of the territory is potentially contaminated with explosive objects. Technologies and methods of finding and disposing of explosive materials have recently advanced significantly [17, 18]. The main techniques include magnetic and ultrasonic methods. However, the main drawback of these methods is a short detection range [19]. This leads to two negative consequences. First, in order to detect an explosive device, rescuers must get dangerously close to it and it sometimes leads to injury and/or death as a result of uncontrolled detonation. Secondly, the short detection range results in low territory surveying rates, which is ineffective in the case of survey areas covering several hundred square kilometers [20]. Recently, a visualization method using artificial intelligence tools has been actively developed, which allows for automatic recognition of objects on the surface of the earth [21]. This method allows us to quickly survey a significant area of the territory, but certain flaws of artificial intelligence technology result in network errors. Additional obstacles of this method are the location of EMs in a dense vegetation area and under a layer of soil, which makes searching by visualization method impossible.

An additional negative factor that reduces the effectiveness of existing methods of detection and disposal of explosives is the widespread use of explosive objects with significantly different design features that require a specific approach [22]. So, for example, sheathless EMs and EMs having no metal structural materials have been widely used at the moment. This almost completely prevents the use of the most common and proven magnetic method of detecting EMs [23].

In paper [24], the authors propose to use electromagnetic microwaves to search for EMs of any composition and design. The advantage of electromagnetic microwaves is the possibility of transmitting a signal over a long distance with negligible energy losses and the selective interaction of EMs with electromagnetic microwaves. The latter property enables a precise location of the places with anomalies by receiving the reflected signal. The construction of a model based on the theory of long lines (a theory according to which the longitudinal length of the transmission line exceeds the wave length of the wave propagating in it, and the transverse length of the transmission line is much shorter than the wave length) can be considered as a drawback of the research done in [24].

Proceeding from the fact that the main and most dangerous part of any explosive object is the EM itself, a study of the physicochemical properties of the most common EMs was carried out in [25]. As is known, the physical and chemical properties of materials define their electromagnetic properties and also heat and radiation resistances [26, 27, 28]. In order to develop new effective methods of searching for explosive objects, it is necessary to focus attention precisely on the study of the patterns of interaction of EMs with electromagnetic microwaves.

4 Aim of Paper

The purpose of this scientific paper is investigation of diffraction of electromagnetic waves in the microwave range on explosive material depending from the parameters of the material and the surface on which it is located.

5 Main Part

Let's assume that the electromagnetic wave of a microwave range is coming from the air perpendicular to the plane of the sheathless EM lying on the substrate (Fig. 1).

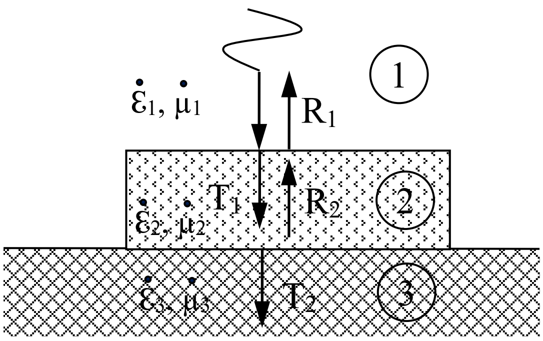

Fig. 1. The coming of an electromagnetic microwave on the EM lying on the substrate

Let's calculate what amount of the power of the coming electromagnetic microwave can be localized inside the EM. When making calculations, we rely on basic sources [29] and [30]

The air is considered to be an ideal dielectric, which is characterized by absolute complex dielectric permittivity and magnetic permeability, respectively:

$$\dot{\varepsilon}_1 = \varepsilon_1 \cdot [1 - i \cdot tg\delta_{\varepsilon_1}] = 1 \cdot [1 - i \cdot 0], \; \dot{\mu}_1 = \mu_1 \cdot [1 - i \cdot tg\delta_{\mu_1}] = 1 \cdot [1 - i \cdot 0], \tag{1}$$

where (here and hereinafter $j = 1, 2, 3$)

ε_j – is the absolute dielectric permittivity of the medium (material),

$tg\delta_{\varepsilon_j}$ – is the tangent of the dielectric loss angle of the medium (material),

μ_j – is the absolute magnetic permeability of the medium (material),

$tg\delta_{\mu_j}$ – is the tangent of the magnetic loss angle of the medium (material).

EM is to be a dielectric with losses, which is characterized by absolute complex dielectric permittivity and magnetic permeability, respectively:

$$\dot{\varepsilon}_2 = \varepsilon_2 \cdot [1 - i \cdot tg\delta_{\varepsilon_2}], \; \dot{\mu}_2 = \mu_2 \cdot [1 - i \cdot tg\delta_{\mu_2}] = 1 \cdot [1 - i \cdot 0]. \tag{2}$$

The substrate is considered to be a dielectric with losses that is characterized by the absolute complex dielectric permittivity and magnetic permeability, respectively:

$$\dot{\varepsilon}_3 = \varepsilon_3 \cdot [1 - i \cdot \mathrm{tg}\delta_{\varepsilon_3}],\ \dot{\mu}_3 = \mu_3 \cdot [1 - i \cdot \mathrm{tg}\delta_{\mu_3}] = 1 \cdot [1 - i \cdot 0]. \quad (3)$$

In fact, the electromagnetic microwave successively propagates through the two interfaces of materials 1-2 and 2-3. For the first boundary, we denote the power reflection coefficient as R_1 and the power transmission coefficient as T_1 for an electromagnetic microwave. For the second boundary, we denote the power reflection coefficient as R_2 and the power transmission coefficient as T_2 for the electromagnetic microwave. The amount of the power of the electromagnetic microwave that will be localized in the EM can be derived from the formula $(T_1 + T_1 \cdot R_2)$.

Let's analyze case when electromagnetic microwave is coming from a homogeneous medium with parameters of $\dot{\varepsilon}_1 = \varepsilon_1 \cdot [1 - i \cdot \mathrm{tg}\delta_{\varepsilon_1}]$, $\dot{\mu}_1 = \mu_1 \cdot [1 - i \cdot \mathrm{tg}\delta_{\mu_1}] = 1 \cdot [1 - i \cdot 0]$ into a homogeneous medium with parameters of $\dot{\varepsilon}_2 = \varepsilon_2 \cdot [1 - i \cdot \mathrm{tg}\delta_{\varepsilon_2}]$, $\dot{\mu}_2 = \mu_2 \cdot [1 - i \cdot \mathrm{tg}\delta_{\mu_2}] = 1 \cdot [1 - i \cdot 0]$ (Fig. 2). We assume that the length of the electromagnetic microwave is shorter compared to the dimensions of the EM on which this electromagnetic microwave is coming (the electromagnetic wave is flat).

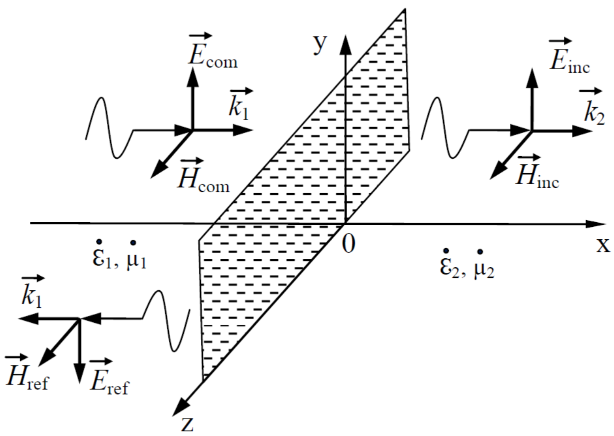

Fig. 2. The coming of an electromagnetic microwave on the interface of two materials ($\vec{k}_1$, $\vec{k}_2$, $\vec{k}_3$ are wave vectors)

We assume the electromagnetic microwave that coming in the positive direction of the 0x axis. Suppose that the polarization of the coming electromagnetic microwave is such that the electric field strength vector is directed along the 0y axis, and, accordingly, the magnetic field strength vector is directed along the 0z axis. Let's write down the expressions for the complex amplitudes of the electric and magnetic field strengths, respectively (assume that the initial phase is equal to zero):

$$\dot{E}_{com} = \dot{E}^{a}_{com} \cdot e^{i \cdot k_1 \cdot x}$$
$$\dot{H}_{com} = \frac{\dot{E}^{a}_{com}}{\dot{Z}_1} \cdot e^{i \cdot k_1 \cdot x}, \quad (4)$$

where $\dot{E}^{a}_{com}$ – is amplitude of the coming microwave,

$k_1 = |\dot{k}_1| = \left| \frac{2 \cdot \pi}{\lambda} \cdot \sqrt{\dot{\varepsilon}_1 \cdot \dot{\mu}_1} \right|$ – is the wave number of the coming microwave,

$\dot{Z}_1 = \sqrt{\dfrac{\dot{\mu}_1}{\dot{\varepsilon}_1}}$ – is the wave resistance of the first medium.

An electromagnetic microwave is reflected from the interface between the materials. In the first material, the reflected microwave has electric and magnetic components:

$$\dot{E}_{\text{ref}} = \dot{E}^{\text{a}}_{\text{ref}} \cdot \text{e}^{-\text{i}\cdot k_1 \cdot \text{x}}$$
$$\dot{H}_{\text{ref}} = \frac{\dot{E}^{\text{a}}_{\text{ref}}}{\dot{Z}_1} \cdot \text{e}^{-\text{i}\cdot k_1 \cdot \text{x}}, \tag{5}$$

where $\dot{E}^{\text{a}}_{\text{ref}}$ – is a amplitude of the reflected microwave.

Then the electric and magnetic components of the total electromagnetic microwave in the first medium have the form:

$$\dot{E}_1 = \dot{E}_{\text{com}} + \dot{E}_{\text{ref}} = \dot{E}^{\text{a}}_{\text{com}} \cdot \text{e}^{\text{i}\cdot k_1 \cdot \text{x}} + \dot{E}^{\text{a}}_{\text{ref}} \cdot \text{e}^{-\text{i}\cdot k_1 \cdot \text{x}}$$
$$\dot{H}_1 = \dot{H}_{\text{com}} - \dot{H}_{\text{ref}} = \frac{\dot{E}^{\text{a}}_{\text{com}}}{\dot{Z}_1} \cdot \text{e}^{\text{i}\cdot k_1 \cdot \text{x}} - \frac{\dot{E}^{\text{a}}_{\text{ref}}}{\dot{Z}_1} \cdot \text{e}^{-\text{i}\cdot k_1 \cdot \text{x}}, \tag{6}$$

The electric and magnetic components of the electromagnetic microwave that incoming into the second medium have the form:

$$\dot{E}_2 = \dot{E}^{\text{a}}_{\text{inc}} \cdot \text{e}^{\text{i}\cdot k_2 \cdot \text{x}}$$
$$\dot{H}_2 = \frac{\dot{E}^{\text{a}}_{\text{inc}}}{\dot{Z}_2} \cdot \text{e}^{\text{i}\cdot k_2 \cdot \text{x}}, \tag{7}$$

where $\dot{E}^{\text{a}}_{\text{inc}}$ – is the amplitude of the microwave that coming into the second medium,

$k_2 = \left|\dot{k}_2\right| = \left|\dfrac{2\cdot\pi}{\lambda} \cdot \sqrt{\dot{\varepsilon}_2 \cdot \dot{\mu}_2}\right|$ – is the wave number of the microwave that coming into the second medium,

$\dot{Z}_2 = \sqrt{\dfrac{\dot{\mu}_2}{\dot{\varepsilon}_2}}$ – is the wave resistance of the second medium.

Let's determine the amplitude reflection coefficient $\dot{\rho} = \dfrac{\dot{E}^{\text{a}}_{\text{ref}}}{\dot{E}^{\text{a}}_{\text{com}}}$ and the amplitude transmission coefficient $\dot{\tau} = \dfrac{\dot{E}^{\text{a}}_{\text{inc}}}{\dot{\text{E}}^{\text{a}}_{\text{com}}}$. For this purpose, we shall use the continuity conditions of the tangential components of the electric and magnetic fields at the interface of the materials:

$$\begin{cases} \dot{E}_1 = \dot{E}_2 \,|_{\text{x}=0} \\ \dot{H}_1 = \dot{H}_2 \,|_{\text{x}=0} \end{cases}. \tag{8}$$

$$\begin{cases} \dot{E}^{\mathrm{a}}_{\mathrm{com}} \cdot \mathrm{e}^{\mathrm{i}\cdot k_1 \cdot 0} + \dot{E}^{\mathrm{a}}_{\mathrm{ref}} \cdot \mathrm{e}^{-\mathrm{i}\cdot k_1 \cdot 0} = \dot{E}^{\mathrm{a}}_{\mathrm{inc}} \cdot \mathrm{e}^{\mathrm{i}\cdot k_2 \cdot 0} \\ \dfrac{\dot{E}^{\mathrm{a}}_{\mathrm{com}}}{\dot{Z}_1} \cdot \mathrm{e}^{\mathrm{i}\cdot k_1 \cdot 0} - \dfrac{\dot{E}^{\mathrm{a}}_{\mathrm{ref}}}{\dot{Z}_1} \cdot \mathrm{e}^{-\mathrm{i}\cdot k_1 \cdot 0} = \dfrac{\dot{E}^{\mathrm{a}}_{\mathrm{inc}}}{\dot{Z}_2} \cdot \mathrm{e}^{\mathrm{i}\cdot \mathrm{k}_2 \cdot 0} \end{cases}, \tag{9}$$

$$\begin{cases} \dot{E}^{\mathrm{a}}_{\mathrm{com}} + \dot{E}^{\mathrm{a}}_{\mathrm{ref}} = \dot{E}^{\mathrm{a}}_{\mathrm{inc}} \\ \dfrac{\dot{E}^{\mathrm{a}}_{\mathrm{пcom}}}{\dot{Z}_1} - \dfrac{\dot{E}^{\mathrm{a}}_{\mathrm{ref}}}{\dot{Z}_1} = \dfrac{\dot{E}^{\mathrm{a}}_{\mathrm{inc}}}{\dot{Z}_2} \end{cases}. \tag{10}$$

We divide the left and right parts of the equations of system (10) by the amplitude of the coming microwave and obtain

$$\begin{cases} 1 + \dot{\rho} = \dot{\tau} \\ \dfrac{1}{\dot{Z}_1} - \dfrac{\dot{\rho}}{\dot{Z}_1} = \dfrac{\dot{\tau}}{\dot{Z}_2} \end{cases}. \tag{11}$$

Finally, the amplitude reflection and transmission coefficients have the form:

$$\dot{\rho} = \frac{\dot{Z}_2 - \dot{Z}_1}{\dot{Z}_2 + \dot{Z}_1}, \tag{12}$$

$$\dot{\tau} = \frac{2 \cdot \dot{Z}_2}{\dot{Z}_2 + \dot{Z}_1}. \tag{13}$$

Let's define the power reflection coefficient R and the power transmission coefficient T:

$$\mathrm{R} = \frac{\left|\dot{S}_{\mathrm{ref}}\right|^2}{\left|\dot{S}_{\mathrm{com}}\right|^2}, \tag{14}$$

$$\mathrm{T} = \frac{\left|\dot{S}_{\mathrm{inc}}\right|^2}{\left|\dot{S}_{\mathrm{com}}\right|^2}, \tag{15}$$

where $\dot{S}_{\mathrm{com}} = \dfrac{1}{2} \cdot \dfrac{\left|\dot{E}^{\mathrm{a}}_{\mathrm{com}}\right|^2}{\dot{Z}_1}$, $\dot{S}_{\mathrm{ref}} = \dfrac{1}{2} \cdot \dfrac{\dot{E}^{\mathrm{a}\,2}_{\mathrm{com}} \cdot |\dot{\rho}|^2}{\dot{Z}_1}$, $\dot{S}_{\mathrm{inc}} = \dfrac{1}{2} \cdot \dfrac{\left|\dot{E}^{\mathrm{a}}_{\mathrm{com}}\right|^2 \cdot |\dot{\tau}|^2}{\dot{Z}_2}$ are average power flows (Poynting vectors (in the general case $\dot{S} = \dfrac{1}{2}[\dot{E} \cdot \dot{H}]$)) carried by coming-, reflected-, and incoming electromagnetic microwaves, respectively. According to the energy conservation law $\dot{S}_{\mathrm{com}} = \dot{S}_{\mathrm{ref}} + \dot{S}_{\mathrm{inc}}$ and $\mathrm{R} + \mathrm{T} = 1$.

After the substitution we get:

$$R = \left|\dot{\rho}\right|^2, \tag{16}$$

$$T = \left|\dot{\tau}\right|^2 \cdot \left|\frac{\dot{Z}_1}{\dot{Z}_2}\right|. \tag{17}$$

Finally, based on previously made assumptions, we get:

$$R = \left|\frac{\sqrt{\frac{\dot{\mu}_2}{\dot{\varepsilon}_2}} - \sqrt{\frac{\dot{\mu}_1}{\dot{\varepsilon}_1}}}{\sqrt{\frac{\dot{\mu}_2}{\dot{\varepsilon}_2}} + \sqrt{\frac{\dot{\mu}_1}{\dot{\varepsilon}_1}}}\right|^2 = \left|\frac{1 - \sqrt{\dot{\varepsilon}_2 / \dot{\varepsilon}_1}}{1 + \sqrt{\dot{\varepsilon}_2 / \dot{\varepsilon}_1}}\right|^2, \tag{18}$$

$$T = 1 - R. \tag{19}$$

Then:

$$R_1 = \left|\frac{1 - \sqrt{\dot{\varepsilon}_2 / \dot{\varepsilon}_1}}{1 + \sqrt{\dot{\varepsilon}_2 / \dot{\varepsilon}_1}}\right|^2, \ T_1 = 1 - R_1, \ R_2 = \left|\frac{1 - \sqrt{\dot{\varepsilon}_3 / \dot{\varepsilon}_2}}{1 + \sqrt{\dot{\varepsilon}_3 / \dot{\varepsilon}_2}}\right|^2. \tag{20}$$

Fig. 3 shows the dependence of the amount of the power $(T_1 + T_1 \cdot R_2)$ of the electromagnetic microwave that will be localized in the EM, calculated using formulas (20), on the change in the absolute dielectric permittivity ε_2 and the decimal logarithm of the tangent of the dielectric loss angle $\lg(\mathrm{tg}\delta_{\varepsilon_2})$ of the EM in the range of $\varepsilon_2 = 2 \div 20$ and $\lg(\mathrm{tg}\delta_{\varepsilon_2}) = 10^{-4} \div 10^{-1}$ for the EM lying on the surface of dry sand, wet wood and alumina (absolute complex dielectric permittivity is $\dot{\varepsilon}_3 = 5{,}0 \cdot [1 - i \cdot 0{,}01]$, $\dot{\varepsilon}_3 = 30{,}0 \cdot [1 - i \cdot 0{,}01]$ and $\dot{\varepsilon}_3 = 10{,}0 \cdot [1 - i \cdot 0{,}001]$ respectively).

Fig. 3 shows that an extremum of the amount of power $(T_1 + T_1 \cdot R_2)$ of the electromagnetic microwave localized in the EM located on the surface of wet wood and alumina is observed with an increase in the value of the absolute dielectric permittivity ε_2 at a fixed value of $\lg$ of the tangent of the dielectric loss angle $\lg(\mathrm{tg}\delta_{\varepsilon_2})$ of the EM in the range of $\varepsilon_2 = 2 \div 5$, with a further gradual decrease to a value close to 0.5 at $\varepsilon_2 = 20$. From a physical point of view, we can draw a conclusion that the resonance $(T_1 + T_1 \cdot R_2)$ is available at low ε_2. For the EM located on the surface of dry sand, there is no resonance in the entire range of ε_2 changes. When the absolute permittivity ε_2 is decreased, the resonance shifts in the direction of lower ε_2. It can also be seen that the lower the value of ε_2, the higher the value of $(T_1 + T_1 \cdot R_2)$ in the range of $\varepsilon_2 \approx 2 \div 10$, which is indicative of a significant reflection of the electromagnetic microwave from the surface on which the EM is located. The dependence of $(T_1 + T_1 \cdot R_2)$ on $\lg(\mathrm{tg}\delta_{\varepsilon_2})$ is linear and it is changed insignificantly over the entire range of the investigation of a change in ε_2 (from 2 to 20).

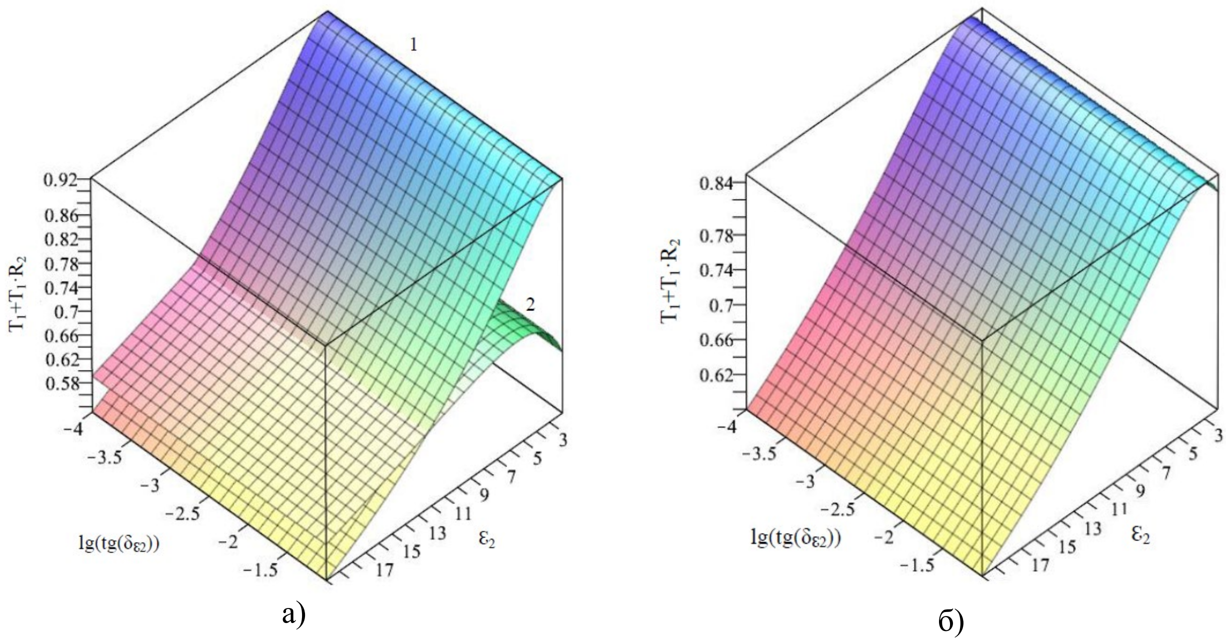

Fig. 3. Dependence of the amount of the power $(T_1 + T_1 \cdot R_2)$ of the electromagnetic microwave that will be localized into the EM on the value of ε_2 and $\lg(tg\delta_{\varepsilon_2})$ for the EM lying on the surface of dry sand (Fig. 3a, dependence 1), wet wood (Fig. 3a, dependence 2) and alumina (Fig. 3, b)

Fig. 4 shows the dependence of the amount of power $(T_1 + T_1 \cdot R_2)$ of the electromagnetic microwave that will be localized into the EM, calculated using formulas (20), on the change in the absolute dielectric permittivity ε_3 and the decimal logarithm of the tangent of the dielectric loss angle $\lg(tg\delta_{\varepsilon_3})$ in the range of $\varepsilon_3 = 1 \div 12$ and $\lg(tg\delta_{\varepsilon_3}) = 10^{-4} \div 0,5$ of the substrate with the EM on it, in particular TNT, PET and ammonium nitrate (absolute complex permittivity $\dot{\varepsilon}_2 = 2,7 \cdot [1 - i \cdot 0,01]$, $\dot{\varepsilon}_2 = 3,0 \cdot [1 - i \cdot 0,001]$ and $\dot{\varepsilon}_2 = 30,0 \cdot [1 - i \cdot 0,01]$ respectively).

Fig. 4 shows that an extremum of the amount of power $(T_1 + T_1 \cdot R_2)$ of the electromagnetic microwave localized inside the EM, in particular TNT and PET, is observed in the range of $\varepsilon_3 = 2 \div 4$ with an increase in the value of the absolute dielectric permittivity ε_3 at a fixed value of $\lg$ of the dielectric loss tangent $\lg(tg\delta_{\varepsilon_3})$ of the surface on which the EM is located. From a physical point of view, it can be concluded that the resonance $(T_1 + T_1 \cdot R_2)$ is available in the range of low ε_3 values. No resonance is observed for the EM presented by ammonium nitrate. When the absolute permittivity ε_3 is decreased, the resonance shifts in the direction of lower ε_3 values. It can also be seen that the lower the value of ε_3, the higher the value of $(T_1 + T_1 \cdot R_2)$ in the range of $\varepsilon_2 \approx 2 \div 10$, which is indicative of the localization of the electromagnetic microwave inside the EM. The dependence of $(T_1 + T_1 \cdot R_2)$ on $\lg(tg\delta_{\varepsilon_3})$ is linear and it is changed insignificantly over the entire range of the investigation in the change of ε_3 (from 2 to 20).

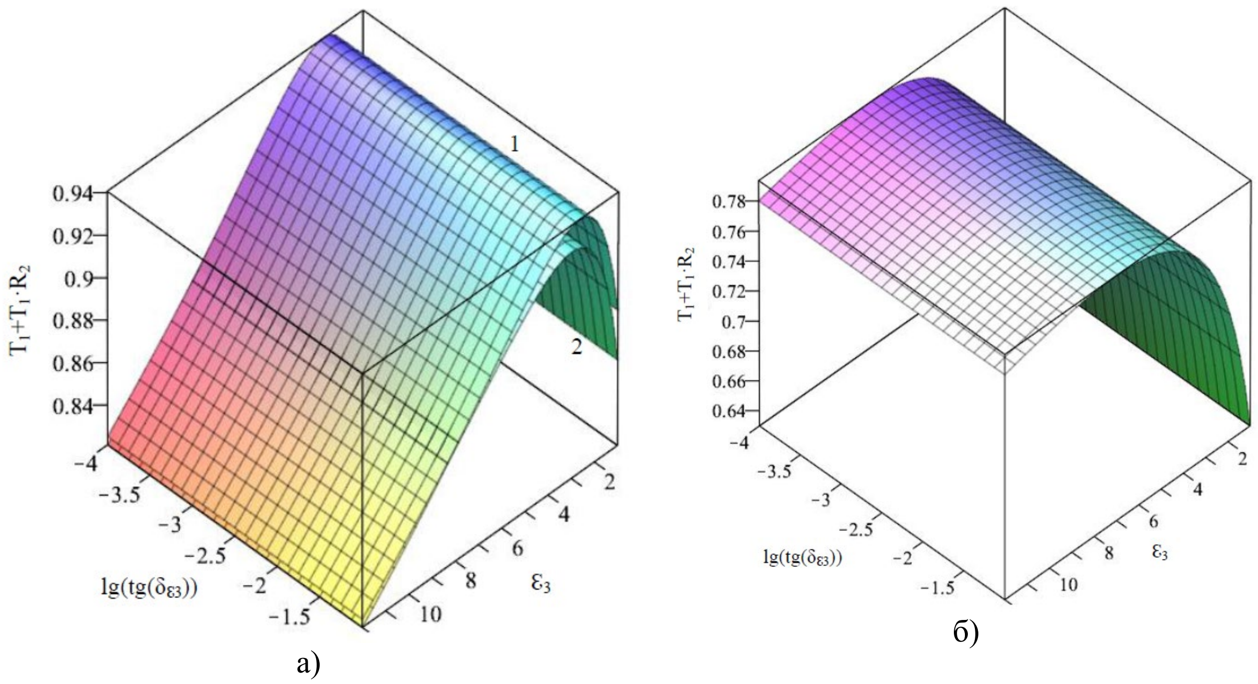

Fig. 4. Dependence of the amount of power $(T_1 + T_1 \cdot R_2)$ of the electromagnetic microwave localized into the EM on the value of ε_3 and $\lg(tg\delta_{\varepsilon_3})$ of the substrate on which the EM of a TNT brand lies (Fig. 4a, dependence 1), PET (Fig. 4a, dependence 2) and ammonium nitrate (Fig. 4,b)

The amount of power $(T_1 + T_1 \cdot R_2)$ of the electromagnetic microwave that will be localized inside the specified brands of EMs (TNT, PET, and ammonium nitrate) located on the specified surfaces (dry sand, alumina, and wet wood) was numerically calculated. The calculation data ranked towards a decreasing value of the indicator $(T_1 + T_1 \cdot R_2)$ are given below:

$(T_1 + T_1 \cdot R_2) \approx 0{,}919$ for the EM of a TNT brand located on the dry sand surface,

$(T_1 + T_1 \cdot R_2) \approx 0{,}913$ for the EM of a PET brand located on the dry sand surface,

$(T_1 + T_1 \cdot R_2) \approx 0{,}849$ for the EM of a PET brand located on the alumina surface,

$(T_1 + T_1 \cdot R_2) \approx 0{,}847$ for the EM of a TNT brand located on the alumina surface,

$(T_1 + T_1 \cdot R_2) \approx 0{,}788$ for the EM of an ammonium nitrate brand located on the dry sand surface,

$(T_1 + T_1 \cdot R_2) \approx 0{,}788$ for the EM of an ammonium nitrate brand located on the alumina surface,

$(T_1 + T_1 \cdot R_2) \approx 0{,}699$ for the EM of an ammonium nitrate brand located on the wet wood surface,

$(T_1 + T_1 \cdot R_2) \approx 0{,}678$ for the EM of a PET brand located on the wet wood surface,

$(T_1 + T_1 \cdot R_2) \approx 0{,}668$ for the EM of a PET brand located on the wet wood surface.

The highest degree of the absorption of the electromagnetic microwave energy inside the EM is observed for TNT and PET located on the surface of dry sand and the lowest degree of absorption is observed for TNT and PET located on the wet wood surface. For ammonium nitrate, the value of the indicator $(T_1 + T_1 \cdot R_2)$ does not depend significantly on the material of the substrate, on which this EM is located. It is indicative of a significant effect of the material of the substrate on the localization of electromagnetic energy inside EMs with lower ε_2 values (TNT and PET in the case under study).

When $(T_1 + T_1 \cdot R_2)$ values are known, it is possible to determine the type of the EM and the substrate surface with a certain probability.

6 Conclusion

A mathematical model of diffraction of electromagnetic microwaves at the air-EM and EM-substrate interfaces has been developed. Mathematical expressions were derived for determining the amount of power of an electromagnetic microwave that is localized in the material of an EM depending on the electromagnetic properties of the EM and the substrate on which it is located. The amount of energy localized into the most common EM, i.e. TNT, PET and ammonium nitrate located on the surface of such EM as sand, alumina and wood was determined by calculation. The results of numerical simulations showed that the largest amount of electromagnetic radiation energy is localized in TNT located on the sand surface ~ 92 %, while the lowest amount is localized in the same TNT EM located on the wet wood surface ~ 67 %. It was established that the absorption index $(T_1 + T_1 \cdot R_2)$ for TNT and PET has an explicit optimum in the range of $\varepsilon_3 = 2 \div 4$, corresponding thus to the main dry soils. The obtained results make it possible to predict the effectiveness of the remote methods of detection and disposal of explosives under the influence of powerful pulses of electromagnetic waves in the microwave range.

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