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Georadiolocation physical modeling for disk-shaped voids

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Abstract

Georadiolocation\5,6,9,10,11\, one of modern and rapidly developing branches of Geophysics, according to its activity spheres, requires maximally increased resolution of textures of certain objects located near the surface. For discovering and verification of the textures of such targets the field of Georadiolocation uses the direct and inverse tasks \7,8.\, widely used in electrodynamics, by means of mathematical modeling. In electrodynamics for mathematical tasks some initial and boundary conditions are introduced. For them Maxwell's electrodynamics equations are solved, according to the solution results the correspondence of the model to its physical reality is determined and the physical essence of the phenomenon is revealed.

Introduction

The theoretical basis of physical modeling \4,5,6,7,11\ of electro dynamical processes is the similarity theory based on the isomorphism of the reality and equations. The prerequisite for the study of a phenomenon by means of modeling equipments is geometrical similarity of the real structure and its model and also fulfillment of the similarity law of varying electromagnetic fields /1,2/. Hereby, we introduce similarity criteria for similarity numerical coefficients /1,8/ by the similarity principles of georadiolocation frequency fields, which may be used in physical modeling:

$$\phi_\nu^2 \cdot \varepsilon_\nu \cdot \lambda_\nu^2 = \phi_\mu^2 \cdot \varepsilon_\mu \cdot \lambda_\mu^2 \qquad \textbf{(1)},$$

where ϕ_ν is the central frequency of georadar impulse electromagnetic waves used in the field, λ_ν - geometric size of the real, i.e. georadiolocation object-for-study placed in the field, ε_ν- relative dielectric conductivity of the georadiolocation layer measured in the field, ϕ_μ- modeling frequency, i.e., the central frequency of georadar impulse electromagnetic waves used for the modeling equipment, λ_μ- modeling geometric size, i.e., the geometric size of the georadiolocation object-for-study placed in the modeling equipment, ε_μ- correlative dielectric conductivity of the georadiolocation layer measured in the modeling equipment.

Let us admit that $\varepsilon_\mu = \varepsilon_\nu$, which is quite acceptable in the most cases of modeling and geological mediums. For (1) we receive the simplification:

$$\phi_\nu^2 \cdot \lambda_\nu^2 = \phi_\mu^2 \cdot \lambda_\mu^2 \qquad (2),$$

or $\phi_\nu \lambda_\nu = \phi_\mu \lambda_\mu$ (3) ,

In this case for similarity coefficients we will receive:

$$K_\phi = \frac{\phi_\mu}{\phi_\nu} \qquad \frac{1}{K_\lambda} = \frac{\lambda_\nu}{\lambda_\mu} \qquad (4).$$

Thus, in Georadiolocation it is possible to use the GEORADAR Zond-12 2 GHz and sometimes 500 MHz \3\.(according to the equipment modeling space measure in regard to the given physical modeling task) screened antennas for laboratory modeling for real (natural, field) phenomena. Low MHz frequency antennas (38 MHz, 75 MHz, 150 MHz, 300 MHz) are also used in natural, i.e. field conditions. Besides, interpretation results for frequency diapasons taking into account the measures, geometry of the object and correlative dielectric conductivity, will be preserved.

On the basis of the similarity theory let us introduce the georadiolocation comparison principle, according to which we determine frequency similarity coefficients for central frequencies and the characteristic length, in which the sizes of the laboratory model for the real object are measured and which is considered as 1m model measurement unit for the length measurement of the real, i.e. natural object.

Let us see, for example, determination of frequency-length coefficients for the sizes of modeling and natural discs.

$\phi_\mu = 2$ GHz for the central frequency, to which in natural situation we conform $\phi_\nu = 38$ MHz the central frequency of the antenna, for which we receive frequency similarity coefficient $K_\nu = 52,63$, which is equal to $\frac{1}{K_\lambda}$, for the length similarity modeling 1 m we receive $\lambda_\nu = \lambda_\mu \cdot \frac{1}{K_\lambda}$ = 1m $\cdot$ 52,63 = 52,63m, i.e., 0.37m size model expresses $0.37 \cdot 52.63 = 19.47$ m natural size object.

Thus, for transformation of the modeling characteristic length into natural characteristic length it is necessary to multiply the frequency similarity coefficient, which is equal to the inverse length similarity coefficient, by the characteristic natural length similarity coefficient. The natural sizes for the given disk model will be counted in the same way by 2 GHz modeling frequency for the rest natural central frequencies (500, 300, 150, 75, 38 MHz) of the georadiolocation antenna.

In the case of the different dielectric conductivity the similarity correlation written in $K_\varepsilon = \frac{\varepsilon_\mu}{\varepsilon_\nu}$ similarity coefficients receives the following form:

$$K_\phi^2 \cdot K_\lambda^2 \cdot K_\varepsilon = 1, \qquad (5).$$

For characteristic natural size we will receive:

$$\lambda_\nu = \frac{1}{K_\lambda} \cdot \lambda_\mu = K_\phi \cdot \sqrt{K_\varepsilon} \cdot \lambda_\mu \qquad (6).$$

The peculiarities in the direct task model, which appear on the radiogram (the first inverse task) must also appear and correspondingly be interpreted on the field (the second inverse task) radiogram, which will make it easy to identify the object with the corresponding natural peculiarities.

An article in Georadiolocation on the solution of direct and inverse tasks, including modeling and numerical scaling, was published in 2013 in Geophysical Journal V.35, №4, 2013 (Odilavadze, Chelidze, ...).

Experimental setup

Experimental setup consisted of a tank of dimensions 1.2x1.2x2.4 cub.m filled up with quartz ("Sachkhere") sand at room humidity. For a modeling equipment georadiolocation set Zond-12 with its 2 MHz component antennas, ultrahigh frequency and 500 MHz screened antennas was used.

As a georadiolocation target-object, an air-containing thin (2-3 mm thick) organic glass disc was chosen with its measures and given placement coordinates (direct task). For determining the form of the disk (the first inverse task) we used georadiolocation physical modeling equipment.

For the equipment we selected a modeling space maximally free from external field influence.

In order to receive radiograms we passed the 2 GHz GEORADAR antenna over the profiles of the target-object (disc) diameter and chords located at different depths.

We had to determine the minimal reflection area by passing over the disc by means of georadiolocation physical modeling, i.e., Fresnel area value for modeling and natural sizes.

For calculation of the Fresnel reflection area we used /6./ formula:

$r = \frac{l}{4} + \frac{H}{\sqrt{\varepsilon - 1}}$, where r is an approximate radius of the reflection area, l –central frequency wave length, H –reflection area depth, ε -average correlative dielectric conductivity according to H depth.

By this formula we calculated the reflection areas with minimal resolution at correspondent depths - when $l = c/v$. $v = 2$ GHz, $H =$ 0.05 m, $\varepsilon = 5$ than $r = 0.06$ m and the reflection area $S = 0.01$ sq. m=100 sq. m.

The areas for the rest of the depths are calculated in the same way.

For example, the modeling frequency 500 MHz reflection area for 0.5 m depth is: $S = 0.5$ sq. m = 500 sq. m.

Results and discussion

We constructed parallel profiles for investigation of the modeling background tank (without the disc model) image. We will consider just one among them, namely the radiogram received at central profile 4. As seen from the image the modeling space is rather homogeneous that enables sharply distinguishing of the modeling object (disc).

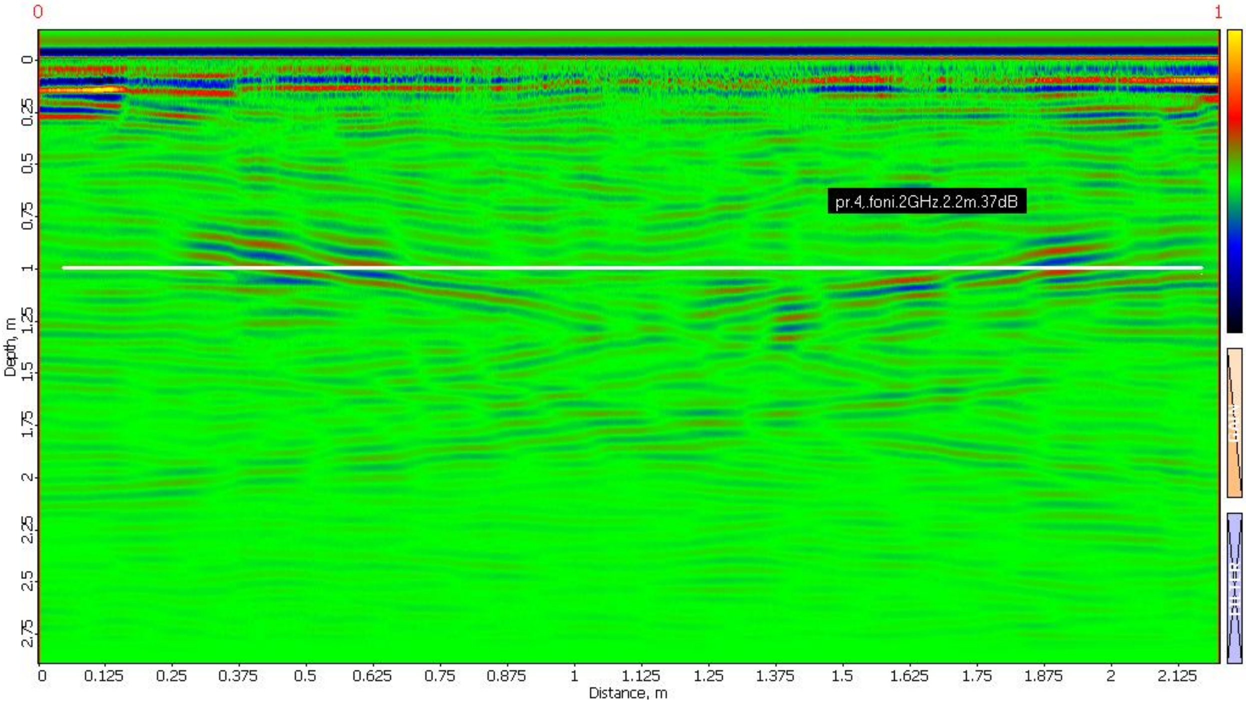

Figure 1. The background value of the field corresponding to the central profile (profile 4) of the modeling space surface without void disk. Profile length 2.2 m. 2 GHz antenna.

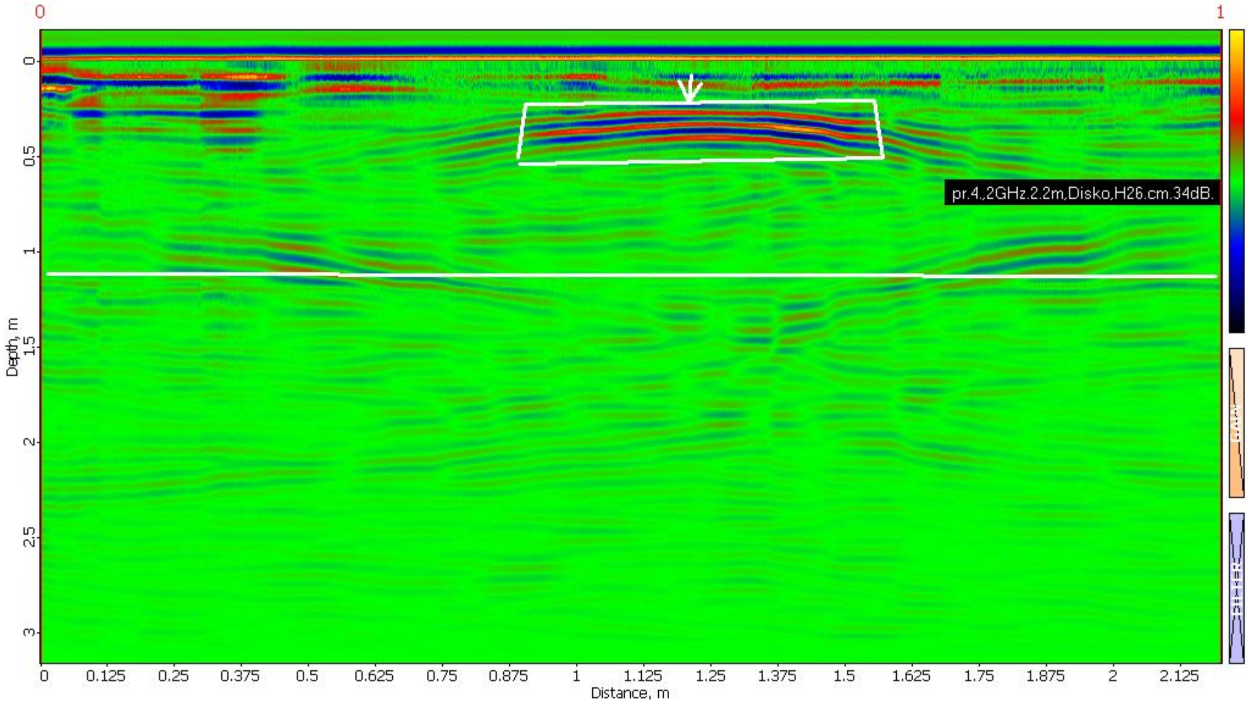

Figure 2. The model profile with void disc is given on the radiogram with wave amplitude density image. The maximum, minimum and zero values of which correspond to the colours in the scale. The depth of the model placement is H =25 cm. Central profile 4 passing over the disc diameter. 2 GHz central frequency GEORADAR antenna is used.

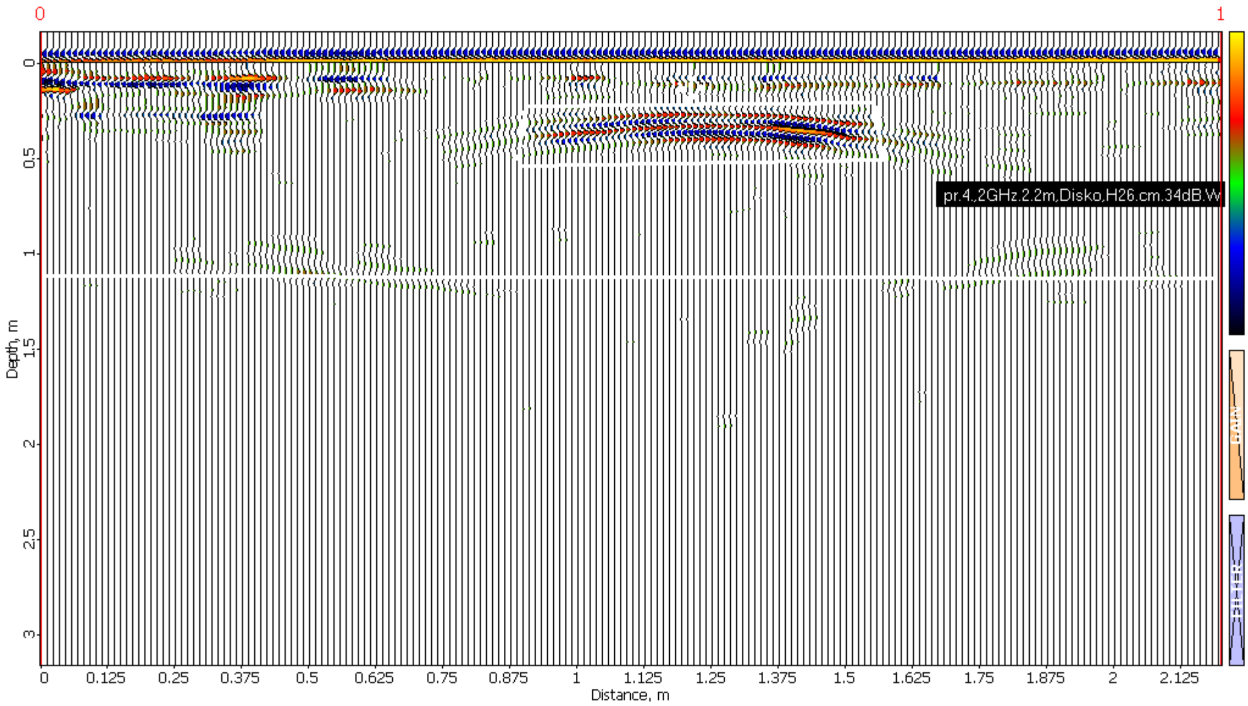

Figure 3. Central diameter profile 4 with a disc model, H = 25 cm.. This radiogram shows the wave image of the profile. The maximum, minimum and zero of the amplitude correspond to the scale colours.

Figures 2 and 3 show the existence of the void (air) of the disc (reverberation). They also show less sharp forms of the parabola of the electromagnetic wave phase synchronism axes created by the influence of the external surface of the disc. The superposition of the forms makes the texture of the object. The interpretation of the disc texture revealed the distance between the sharply expressed upper and lower electromagnetic wave phase synchronism axes is 0.08 m, which coincides with the real thickness of the disc. In the void filled with air, due to multiple internal dispersions of the electromagnetic waves a sharply expressed interference image has been created.

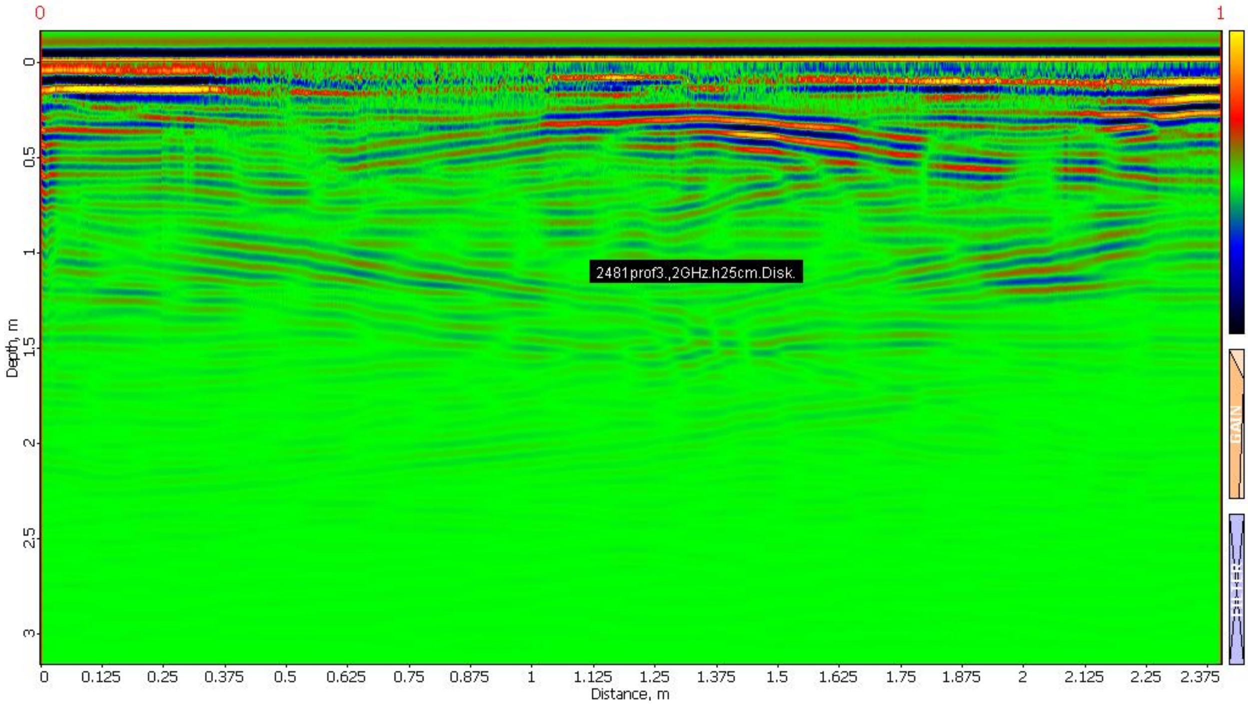

Figure 4. The disc model. The depth of the model placement surface H = 25 cm. Profile 3 passing over the disc diameter, parallel to profile 4. The distance between the parallel profiles is 0.13 cm. Profile 3 crosses the minimized part of the disc surface. 2 GHz central frequency GEORADAR antenna is used for modeling.

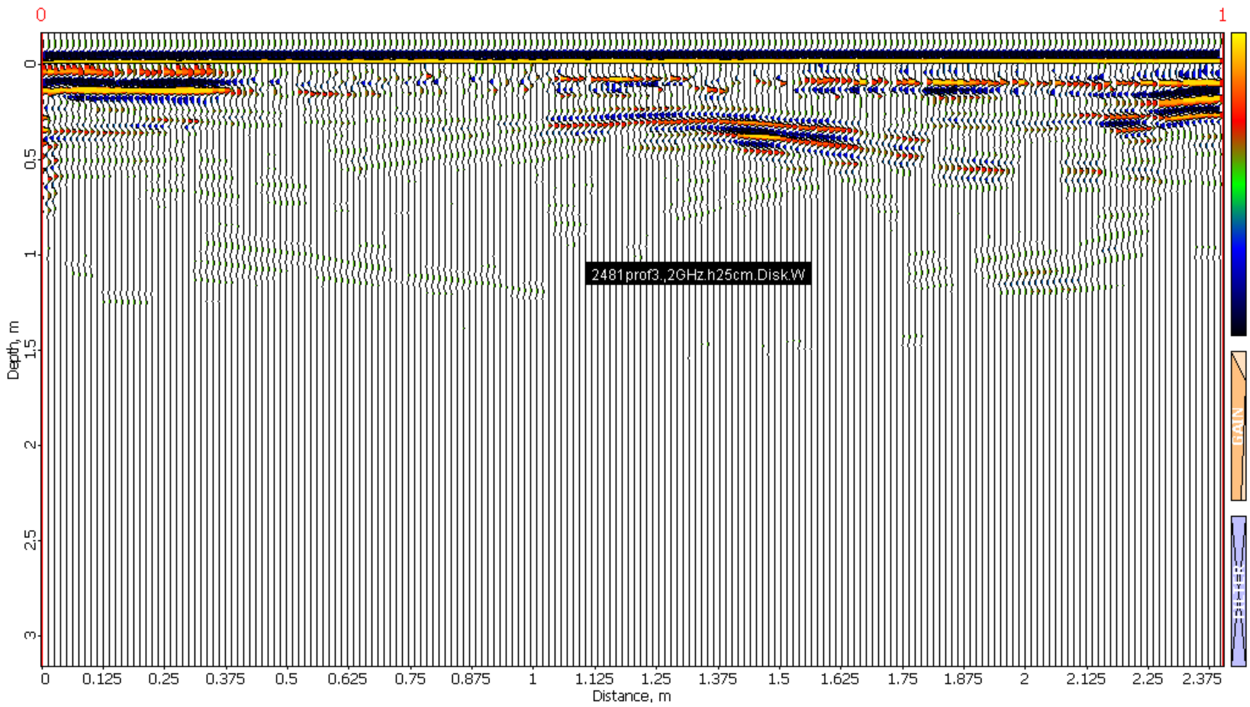

Figure 5. The disc model, H = 25 cm. The wave image of the parallel profile (№3).

Figures 4 and *3* show the existence of the void (air) of the disc. The upper parabola (the upper facet of the disc) corresponds to the air dielectric conductivity 1, the lower one (the lower facet of the disc) corresponds to the medium (sand) conductivity 5. The distance between the sharply expressed upper and lower electromagnetic wave phase synchronism axes is 0.08 m, which coincides with the real thickness of the disc. Besides, the profile cuts a part of the reflection surface of the disc, due to which the texture has changed its measures as reverberation image is recorded not for the whole void, but for its part, which is more clearly seen on the given profile wave image.

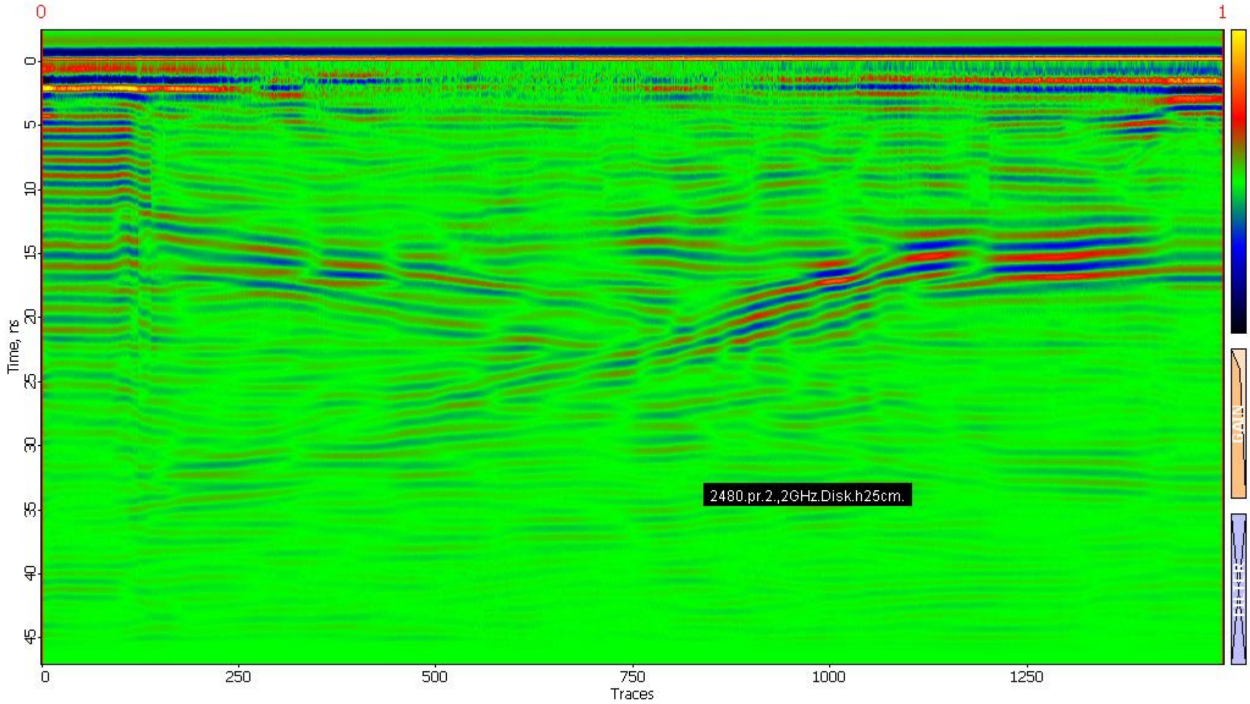

Figure 6. The disc model. The depth of the model placement surface is H = 25 cm. Profile 2 passing over the disc diameter, parallel to profile 4. The distance between the parallel profiles is 0.28 cm. Profile 2 crosses a minor part of the disc surface. 2 GHz central frequency GEORADAR antenna is used for modeling.

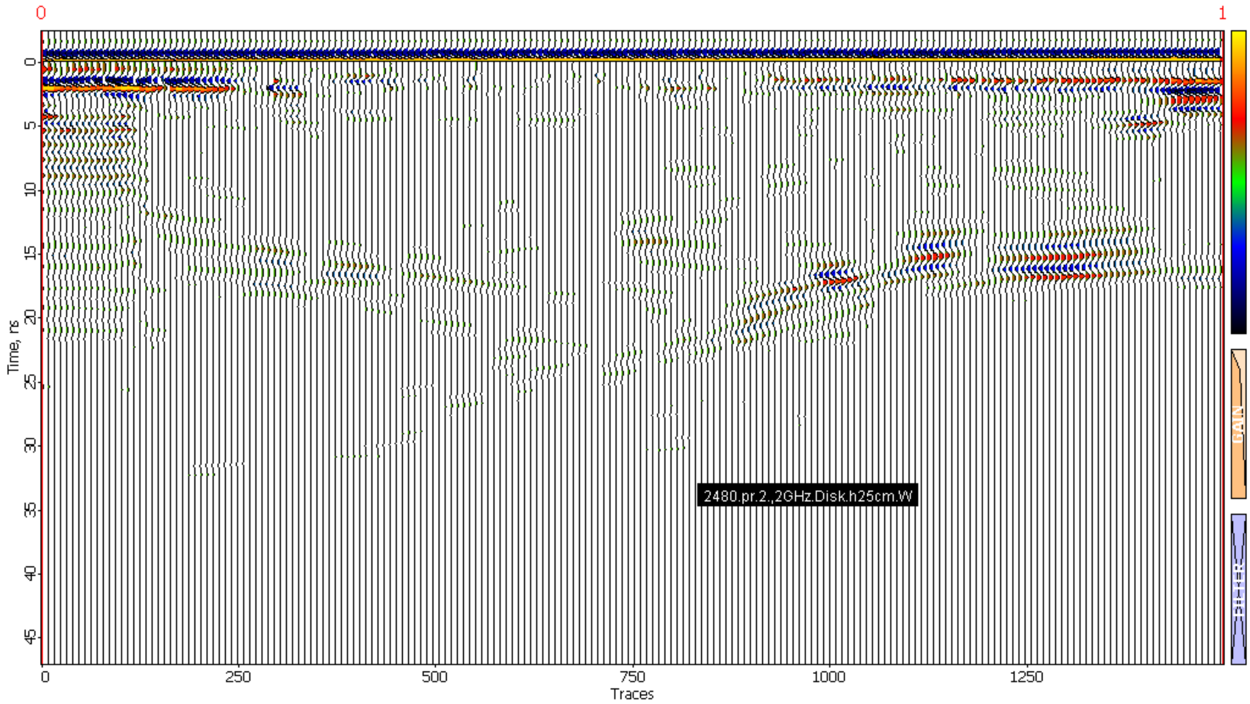

Figure 7. The disc model on the radiogram, H = 25 cm. Profile 2, parallel to profile 4, is presented. A wave image.

There is no existence of disc texture on the radiograms shown in *Figures 6 and 7*. That is caused by the decrease of the Fresnel zone area. The phase synchronism axes of these reflected electromagnetic waves do not appear in the profile, which is located from the disc center at the distance almost equal to the radius. Thus, the size of the disc containing air and located in the 0.25 m depth is now outlined according to depth, length, width and thickness. The increased sharpness of the phase synchronism axes existed at the edge must be caused not by horizontal placement of the disc but by the edge surface effect.

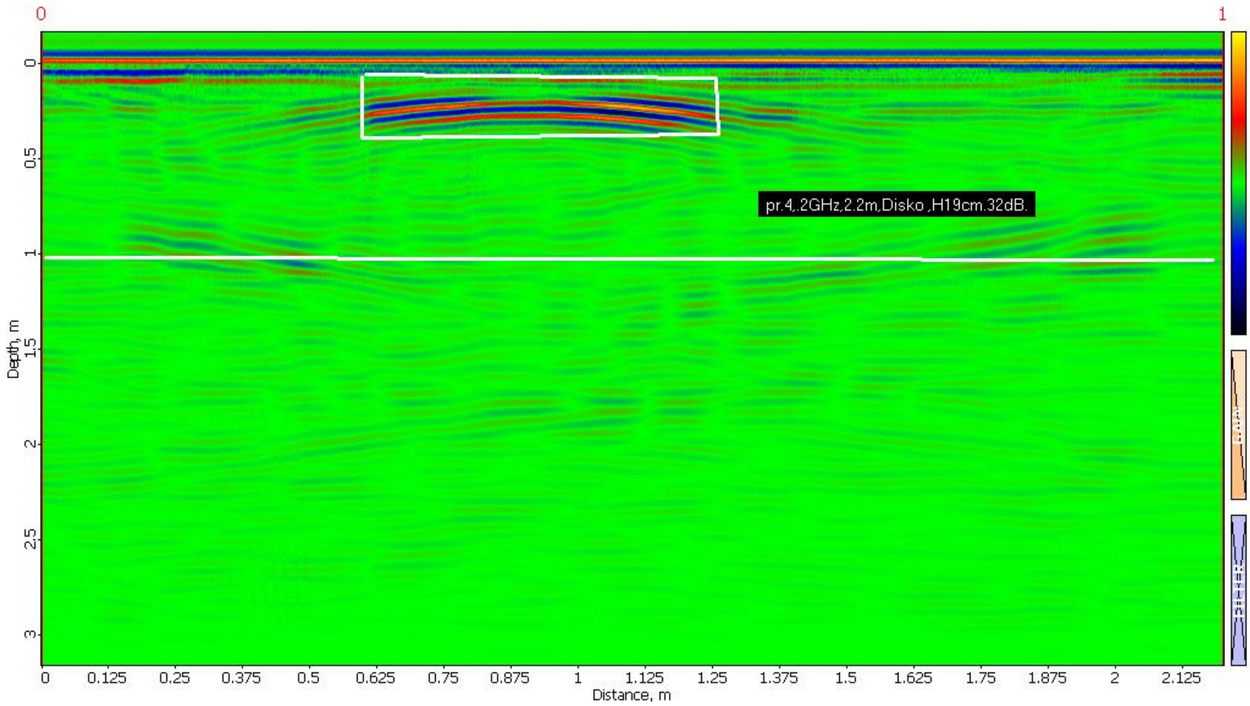

Figure 8. The disc model, H = 19 cm. The central frequency - 2 GHz. Profile 4 passing over the diameter.

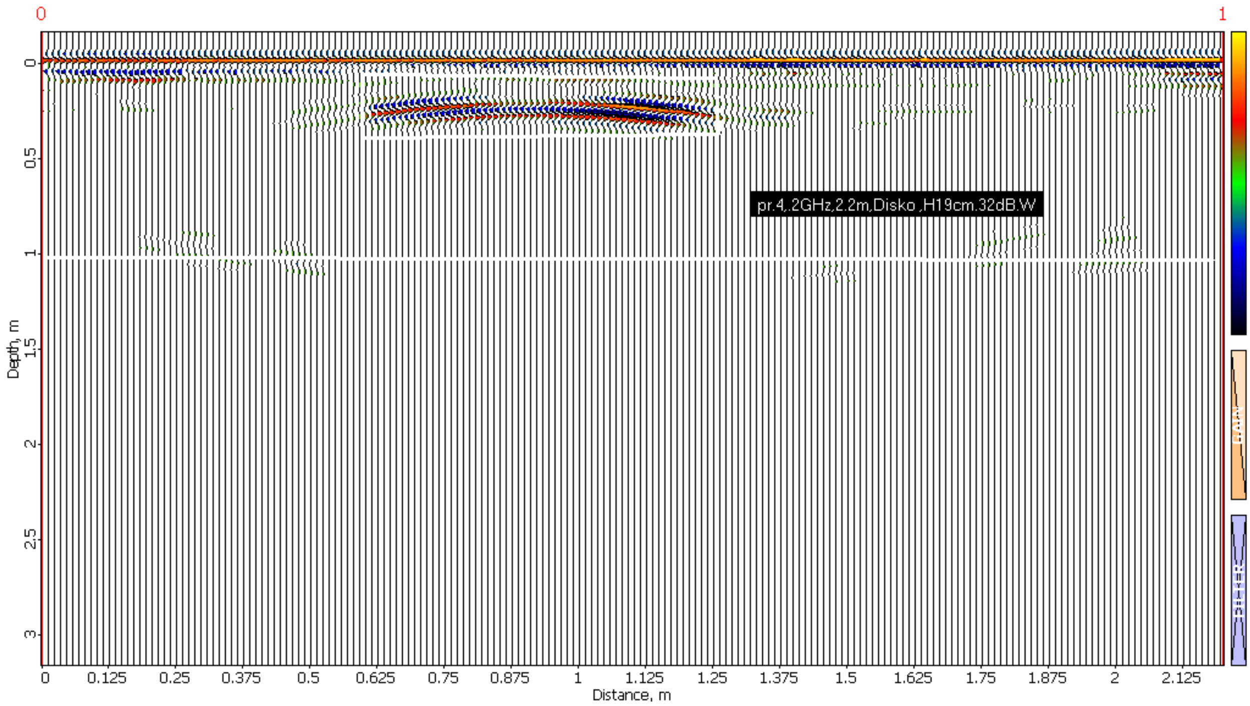

Figure 9. The disc model, H = 19 cm. The central frequency - 2 GHz. The diameter profile 4 (the profile is presented in a wave form on the radiogram).

Figures 8 and *9* clearly show the texture of the air containing disc, which definitely outlines the length measures and placement depth of the disc. Besides, the texture is changed, namely, the fixation of the upper part of the maximum of the phase synchronism axes is changed, the upper parabola has lost its sharpness, i.e., there are no radio-waves reflected from the surface. This must be caused by the effect of the electromagnetic wave dispersing by surface inhomogeneity (the received signal becomes immeasurable) when the antenna is moved off. On the radiogram the surface inhomogeneity of the cavity (diameter – 0.13 m, depth – 2 cm) in the disc form corresponds to the 0.13 m diameter phase synchronism axes cut at the upper part. Thus, now the measures of the disc have been outlined and the inhomogeneity of its surface and its sizes in length and depths has been defined.

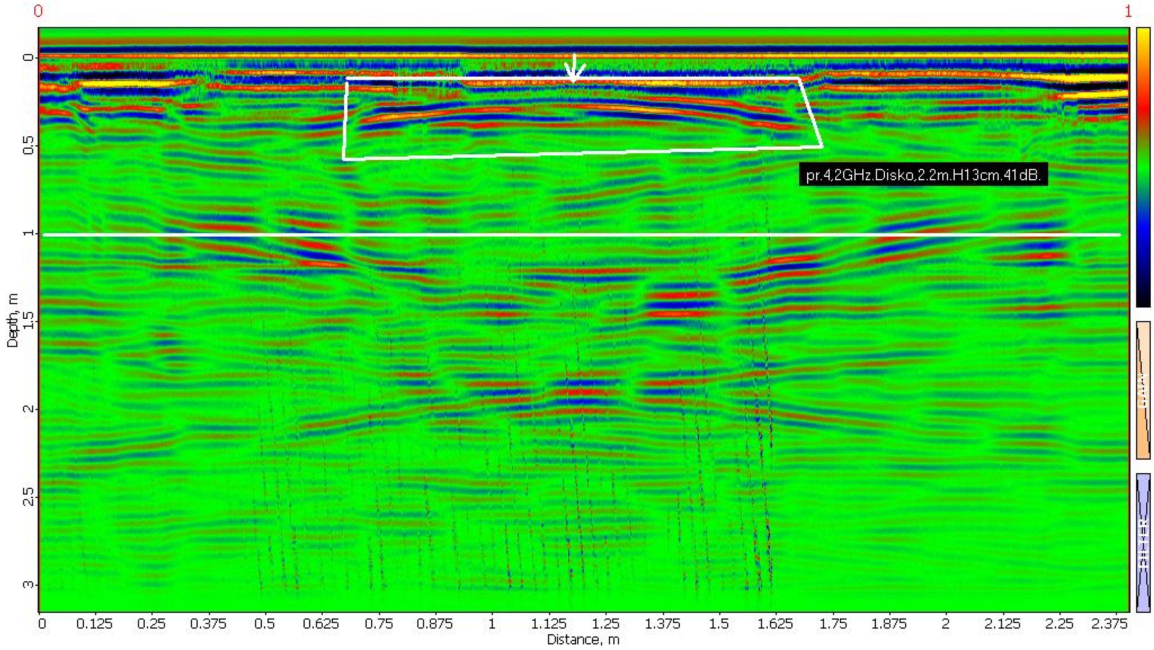

Figure 10. The disc model on the radiogram, H = 13 cm. The central diameter profile was constructed according to a density image.

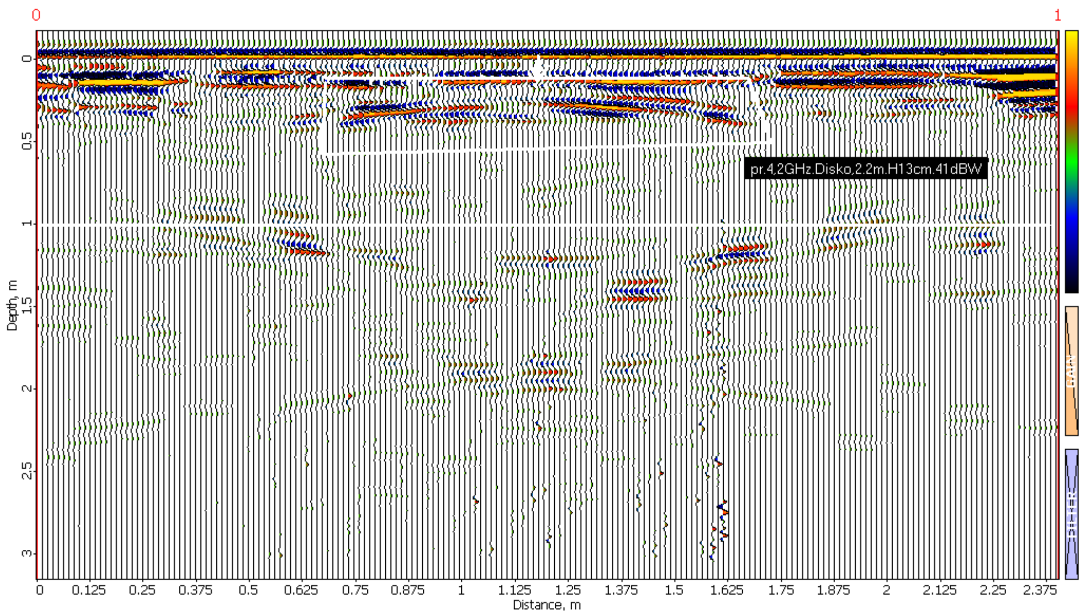

Figure 11. The disc model on the radiogram, H = 13 cm. The central diameter profile was constructed according to a wave image.

Figures 10 and *11*clearly show the texture of the air containing disc, which outlines the length measures and placement depth of the disc. Besides, the texture is changed, namely, the fixation of the upper part of the maximum of the phase synchronism axes is changed, the upper parabola is less sharp than at the 0.19 m depth, i.e., there are no radio-waves reflected from the surface. This must be caused by the effect of the electromagnetic wave dispersing by surface inhomogeneity (0.13 m diameter and 2 cm depth cavity in the disc form) when the antenna is moved off and approaching of the disc surface cavity to the mean wave zone of the antenna (which causes entering into the "shade zone" of the antenna). On the radiogram the disc corresponds to the increased incompatible peculiarity of the diameter at the parabola vertex. Thus, when approaching to the mean zone the disc measures were outlined and the inhomogeneity of its surface was determined. Approaching of the target-object to the mean zone of the antenna appeared to be a factor preventing from determining the disc surface inhomogeneity.

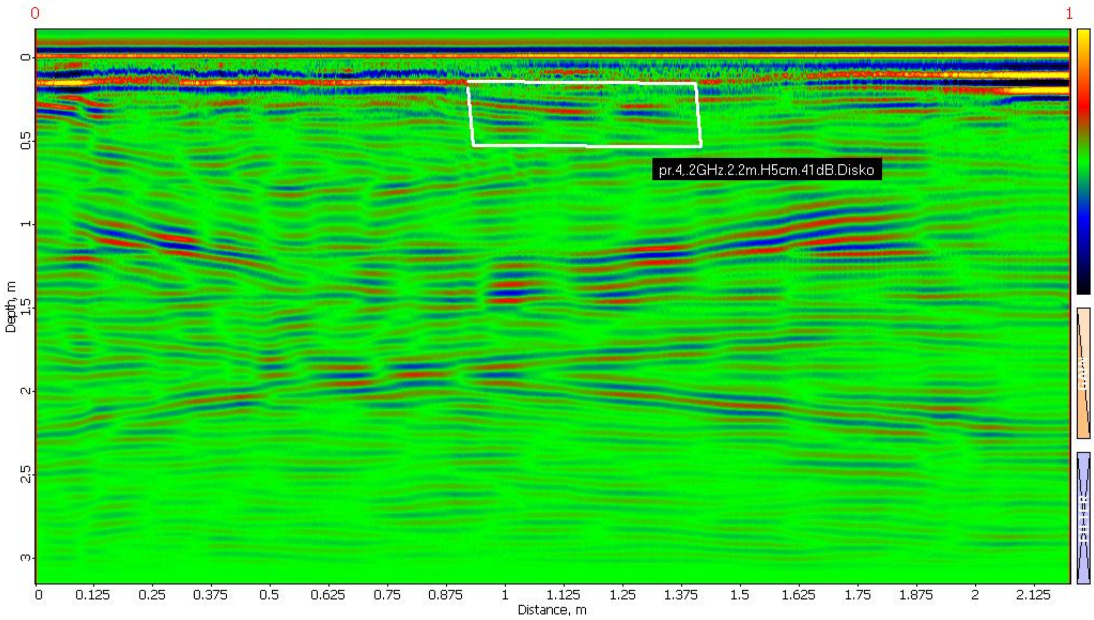

Figure 12. The disc model, H = 5 cm. The central diameter profile.

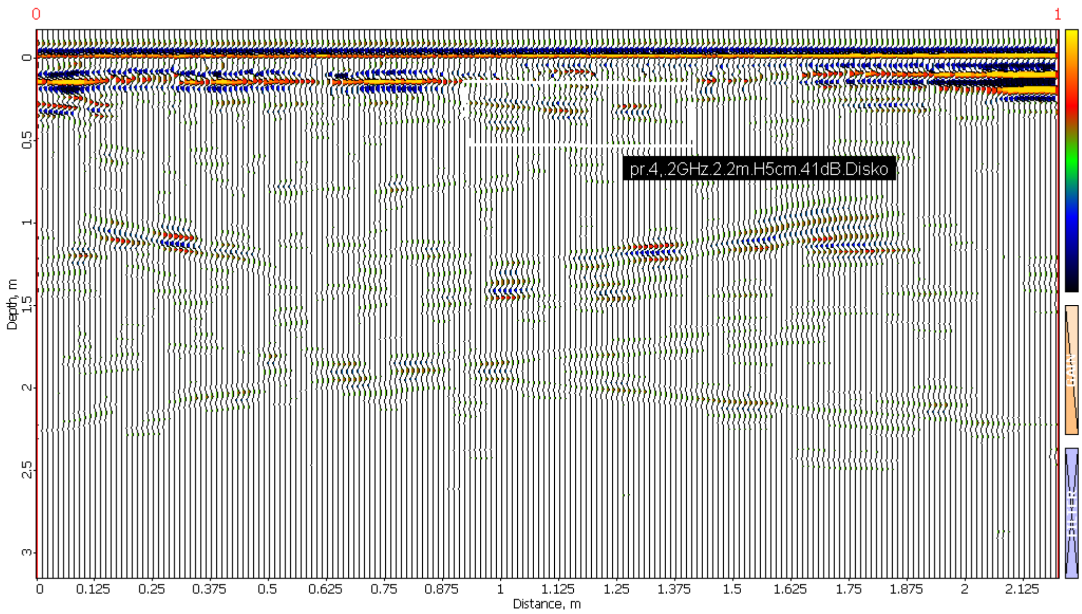

Figure 13. The disc model on the radiogram, H =5 cm. It was constructed by placing at the depth, according to a wave image of the central diameter profile.

Figures 12 and *13* indistinctly show the texture of the air containing disc, which indefinitely outlines the length measures and placement depth of the disc. The texture is changed, namely, the fixation of the phase synchronism axes is changed, it has lost its sharpness at depth up to 0.05 m, i.e., there are no radio-waves reflected from the surface. This must be caused by approaching to the antenna zone. However, the existence of air cavity is partially proved by its light reverberation image. Approaching of the target-object to the mean zone of the antenna appeared to be a factor preventing from determining the disc surface inhomogeneity.

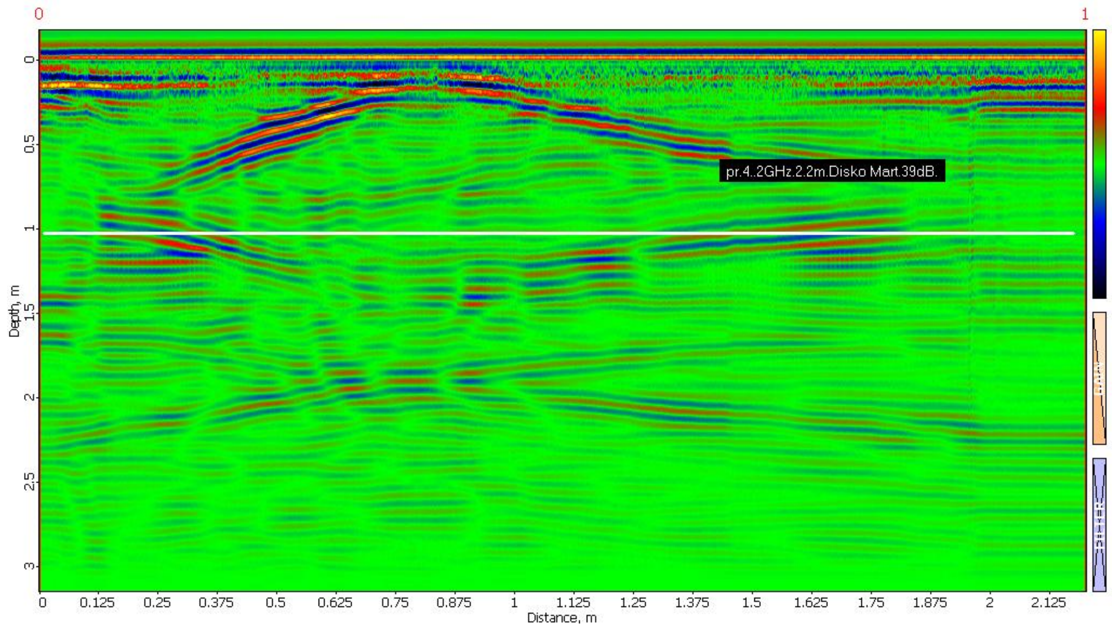

Figure 14. The disc model placed vertically, H = 7 cm. The central frequency – 2 GHz. Central profile 4.

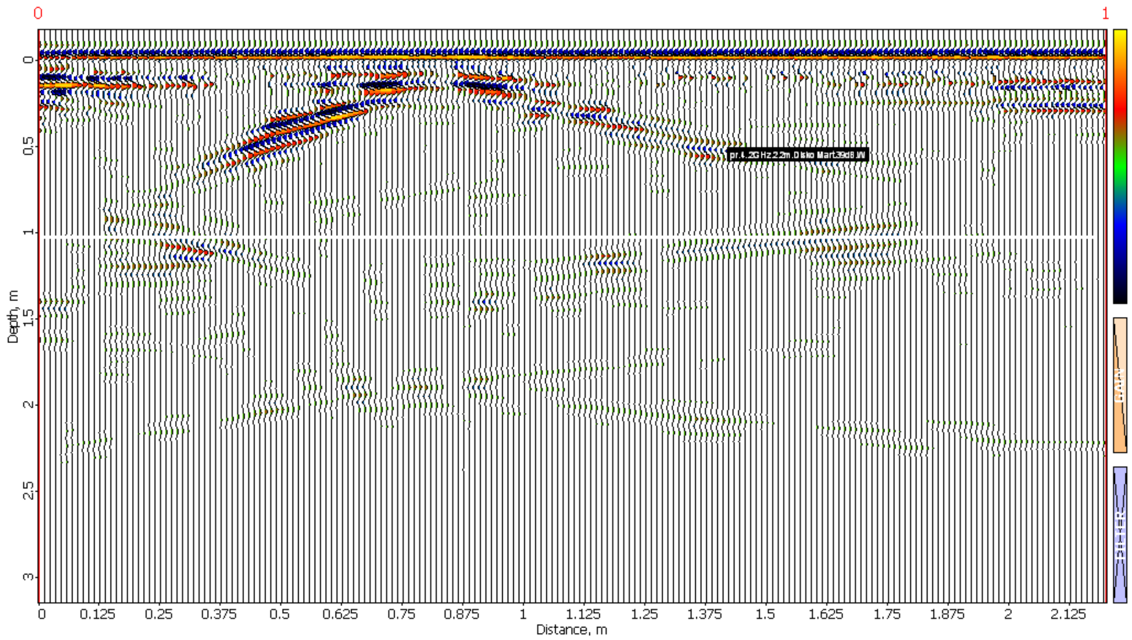

Figure 15. The disc model placed vertically, H = 7 cm. The central frequency – 2 GHz. (A radiogram according to the electromagnetic wave amplitude image).

Figures 14 and *15* indistinctly show radiograms for the same object (disc) placed in 0.07 m depth; namely, the disc is placed vertically in the perpendicular plane of the central profile, the texture of the object in the profile 4 clearly show the length measures and placement depth of the object. However, the texture of the vertical disc at the used frequencies does not appear. The air object is seen as a separate texture of an object with two parabolic symmetric phase synchronism axes. This must be caused by partially entering of the upper part of the object to the middle zone of the antenna and dispersing of wave by the side surface (0.08 m width) of the disc.

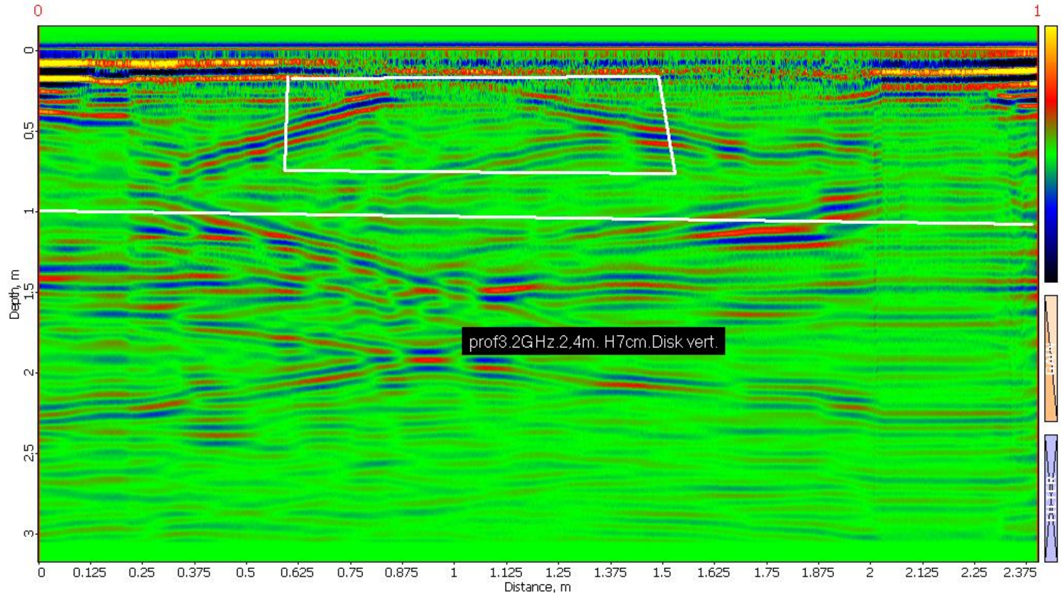

Figure 16. The disc model, H =11 cm. Profile 3 parallel to the central diameter profile.

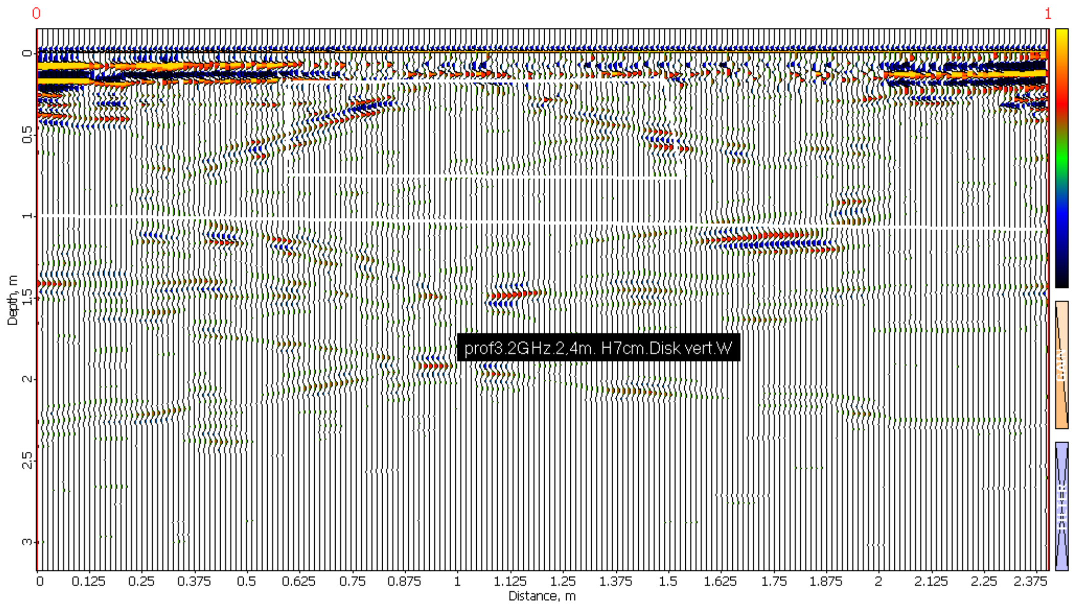

Figure 17. The disc model, H =11 cm. Profile 3 parallel to the central diameter profile (according to the wave image).

Figures 16 and *17* show a radiogram of the same object ("vertical" disc) placed at 0.11 m depth. The texture of the "vertical" disc in profile 3 proves the existence of the vertical plane of the object. However, the reverberation effect is not seen in the air containing space at the used frequencies. The object appears as two planes reflecting vertical placement. This is caused by placement of the upper part of the object in the middle zone of the antenna and dispersion of the side reflected waves from the uneven surface, which are not received by the antenna.

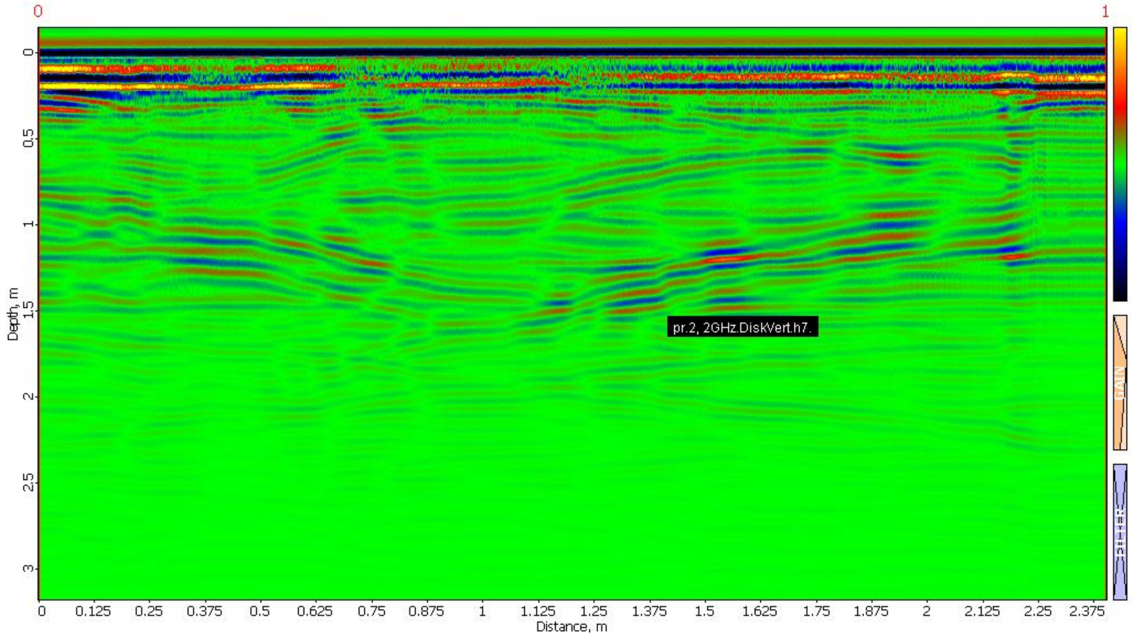

Figure 18. The disc model. Profile 2 parallel to the central diameter profile.

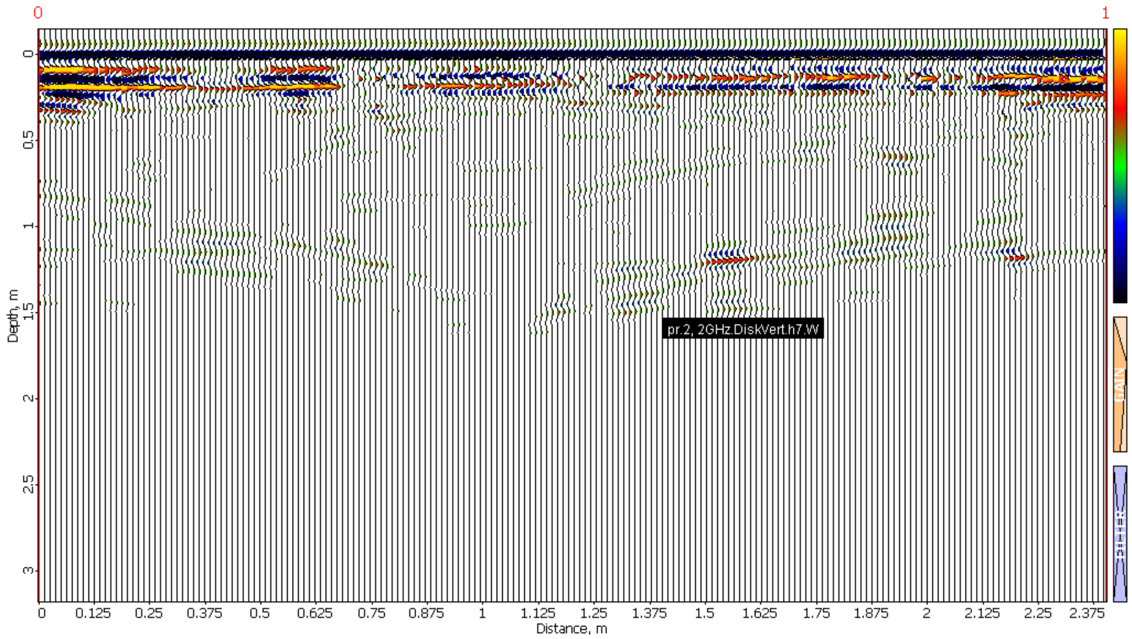

Figure 19. The disc model. Profile 2 parallel to the central diameter profile (wave image).

According to the analysis of *Figures 19* and *20* we can say that the object texture does not at all appear in profile 2 located at a distance equal to the disc radius as a result of dispersion of the reflected waves due to the significantly decreased received signal (impact).

Conclusion:

1. On the basis of physical modeling of electrodynamic processes, according to the comparison principles of the given georadiolocation frequencies, georadiolocation physical modeling was conducted for an empty object in a disc form by means of a physical modeling equipment.

2. The texture of the target-object (empty disc) was discovered and studied for different placement depths and orientation (placement of the disc axis in parallel and perpendicular directions to the day surface) of the object.

3. The electro dynamical effects influencing on the variation of the disc-shape object texture in the profiles at the disc center and far from it have been revealed.

4. For determining a texture of an object in field conditions a georadar frequency comparison method is suggested, according to which physical modeling, taking into account similarity coefficients, is used as an additional means of interpretation of radiolocation results.

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გეორადიოლოკაციური ფიზიკური მოდელირება დისკოსებური ფორმის სიღრუვისათვის

დ. ოდილავაძე, თ. ჭელიძე, გ. ცხვედიაშვილი

რეზიუმე

1. ელექტროდინამიკური პროცესების ფიზიკური მოდელირების საფუძველზე შემოტანილი გეორადიოლოკაციური სიხშირეების შედარებითობის პრინციპის თანახმად მყარ გარემოში ფიზიკური მოდელირების დანადგარზე ჩატარდა გეორადიოლკაციური ფიზიკური მოდელირება დისკოსებრი ცარიელი ობიექტისათვის.

2. დაფიქსირებულ და გამოკვლეულ იქნა სამიზნე –ობიექტის (ცარიელი დისკო) რადიოსახე ობიექტის განთავსების სხვადასხვა სიღრმეებისა და ორიენტაციისათვის (დისკოს განთავსება დღიური ზედაპირის პარალელურად და მართობულად).
3. გამორკვეულ იქნა ელექტროდინამიკური ეფექტები რომლებიც გავლენას ახდენენ დისკოსებრი ობიექტის რადიოსახის ცვლილებაზე.
4. საველე პირობებში დაფიქსირებული ობიექტის რადიოსახის გარკვევისათვის, შემოთავაზებულია გეორადარული სიხშირული შედარებითობის პრინციპი რომლის თანახმად გამოიყენება ფიზიკური მოდელირება მსგავსობის კოეფიციენტების გათვალისწინებით, როგორც რადიოლოკაციური შედეგების ინტერპრეტაციის დამატებითი საშუალება (ხერხი) .