https://doi.org/10.15407/ujpe66.6.528

A.V. PAVLYUCHENKO,[1] P.P. LOSHITSKY,[2] I.V. PONOMAREV[1]
[1] State Research Center of Superconductor Radioelectronics "Iceberg"
(2b, Lesya Kurbasa Ave., Kyiv 03148, Ukraine; e-mail: andy_pavluchenko@ukr.net)
[2] National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute",
Faculty of Engineering Electronics
(37, Prosp. Peremohy, Kyiv 03056, Ukraine)

RADIOMETRIC IDENTIFICATION OF GRANULAR MATERIALS

The paper shows a general possibility of remote identification of granular materials that are sealed in a dielectric package by the methods of close positioning with the use of a developed radiometric measurement setup at the 8-mm wavelength to obtain polarized thermal portraits. As a result of the interaction between the electromagnetic wave and granular materials, which are considered unstructured systems in this study, the possibility to determine and to show the useful information as a thermal portrait occurs at the molecular level. The presented polarized thermal portraits of granular materials with close characteristics are visually distinguishable. If the portraits appear to be similar, then the preliminary treatment of data is held, which allows the substance identification. It was experimentally proven that the radiometric methods can be used to determine the natural slope angle – a generalized parameter that characterizes all granular materials, regardless of properties and the particle size distribution. A connection between the natural slope angle and radiometric parameters of the granular materials is shown. The occurrence of coherent effects were registered during the passage of the electromagnetic wave through the unstructured systems. For a certain random combination of the size and the ratio of average electrical parameters, a sharp increase in received signal's amplitude can be observed.

Keywords: microwave range, radiometry, radio-brightness temperature, thermal profile, electromagnetic wave polarization, granular materials.

1. Introduction

The physics of condensed state declares the unstructured system as a system, which has a relatively firm framework that serves as a base for a realization of a quicker dynamics of degrees of freedom. The framework itself does not have to be firm; however, its rearrangement time has to be significantly higher than what is typical of the quicker processes. The unstructuredness of the system is related to a non-periodic random structure of the framework, which leads to the characteristic of an average spatial homogeneity and the absence of a correlation between the values of random parameter's unstructuredness for infinitely remote points for all of the systems of such type. One of the most important causalities which it causes if self-averaging of specific extensive physical values, meaning such values, while being random in a finite system, tend to become specific non-random values in macroscopic limit. The wave propagation in a medium with randomly distributed parameters is a good example of the agitation in the unstructured systems [1–5].

The interaction of the electromagnetic radiation with an unstructured material medium requires to find the correlation between medium's properties with the angular distribution of the diffused radiation and the absorption of the outer radiation by particles. The initial research was conducted in the optical wavelength range and then re-conducted in the radio wavelength range. Based on purely dimensional considerations, Rayleigh obtained an approximate solution for the radiation scattering by spherical particles in the case where particles' dimensions are small compared to the wavelength of the radiation falling on the particle [6]. A general theory of absorption and diffusion of the radiation by homogeneous particles, which have simple geometric form, was developed later by Mie. Mie's solution is useful to determine the absorption and diffusion coefficients for spherical particles suspended in a dielectric medium under the condition that the particles are far enough from one another. Currently, it is the only fundamental theory, regardless of it being developed for the ideal case [1, 2].

Under real conditions, unstructured material media are polydisperse systems, i.e. systems which consist of particles that have different sizes and complex geometric shapes and are located so close that the interference is possible between them. The physics of unstructured condensed systems addresses the theory of such media [2]. The sizes of particles and the presence of intrastate surfaces are of importance in different adsorption phenomena. Different physicochemical reactions that can take place at particles' surface are considered in the explanation of the properties of such systems. Granular materials (GMs) can be inherently amorphous or crystalline. In this article, GMs are considered as unstructured systems.

GM with different dispersities possesses several physical features: flowability, heat transfer [6–8], their thermal radiation differs from the thermal radiation of other unstructured systems such as liquid or solid media.

Flowability is the ability of solid media to move on inclined planes. All GMs including food (flour, cereal, sugar, *etc.*) and those, which consist of singular approximately spherical crystals/granules (grain, root vegetables, varieties of fruits), have good flowability. Flowability is characterized by two parameters: the friction angle and the natural slope angle (NSA). Friction angle is the minimum angle, which is required for the mass of the product to slide down on any surface. NSA or the slide angle is the angle between base's diameter and the cone generatrix, which is created by the fall of product's mass on a horizontal surface. Flowability is affected by the form, size, characteristics, and state of the surface of the singular specimen (granules), humidity, and impurities [7].

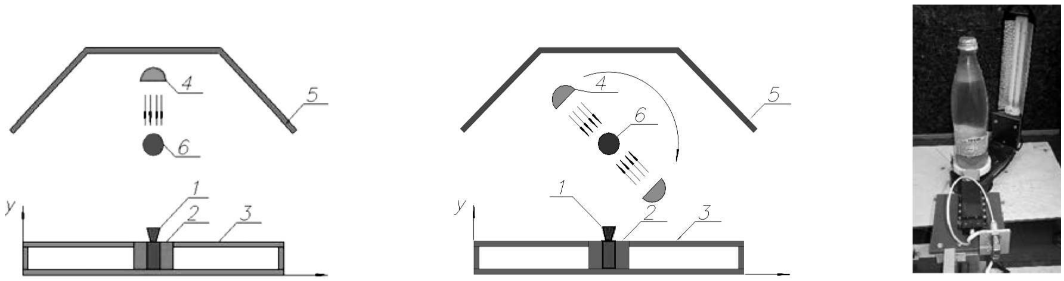
Heat transfer in GM is determined by a complex of thermal processes: radiative, convective, and inner heat transfer [4, 7, 8], each of which differs from equivalent processes for crystalline and amorphous materials.

Works [9, 10] showed a general possibility of remote identification of different liquids based on their thermal profiles (TPs), including explosives, sealed in dielectric containers (packaging), by the methods of close location [11–18]. This article examines samples of GMs as a particular case of unstructured (disordered) systems. The clarification of the general possibility of a distant identification of different GMs, for example, food, using the same methods, has relevance. The task is relevant to monitoring the state and quality of different GMs, which are, for example, kept in the storage or warehouses.

This research aims to explore the possibility of obtaining TPs of different GMs by the methods of linear (LS) and angular (AS) radiometric scanning in the 8-mm-wavelength range; the results of the preliminary TP analysis are used to research the possibility of remote identification of GMs with relatively close physicochemical properties sealed in dielectric packages.

2. Methodology of the Experimental Research

The research of GMs was carried out with a measurement setup by methods described in [9, 10]. The schemes of the measurement setup for LS and AS are shown at Fig. 1, *a* and Fig. 1, *b*, respectively. The setup consists of a radiometric receiver 1 (in the 8-mm-wavelength range) with an antenna and a radiometric illumination noise source (RINS) 4. The setup is set to receive and to process the radio-brightness illumination in the corresponding (8 mm) operating frequency range. All of the units and modules of the experimental setup are developed and created by the authors. The used frequency range, which has a relatively large wavelength, contributes to minimizing the number of errors during experiments, which are related to positions of the research objects and backlash of scanner's mechanical parts. The receiver is situated on a platform 2, which moves on rails 3 in two



a *b* *c*

Fig. 1. Radiometric measurement setup: scheme for the LS mode (*a*); scheme for the AS mode (*b*); photo (*c*). Markings: receiver *1*; platform *2*; rails *3*; RINS *4*; absorbing material *5*; tested object *6*

perpendicular directions. The platform 2 is capable to rotate 90° about the receiver's axis, which allows us to change the polarization plane of the received signal and to make the polarization measurements. The liquid's package axis is located vertically, which was set perpendicular to the spread front of RINS's electromagnetic wave (EMW). The photo of the experimental setup is shown in Fig. 1, *c*.

Radiometric measurements were conducted in a shielded box, which has its walls covered by an absorbing material 5. The absorption coefficient of the material was measured by a network analyzer and was no less than 35 dB in the operating frequency range. The distance between the panels with absorbing material and the receiver's antenna $L = 300$ mm.

The research was carried out indoors. Therefore, the RINS was used as a source of the radio-brightness contrast, as there were no natural sources of radiation. An energy-saving fluorescent desk lamp with a metal reflector was used as a RINS. In [10], it was shown that such RINS provides the spectral power density of noise (ENR means theenergy-to-noise ratio) at the level of 15–20 dB/kT at the frequency range of 28–37 GHz. Lamp's tanks were situated vertically during the experiments. The radiation's polarization strongly depends on the presence of a reflector, which changes polarization's plane of the generated radiation [8, 18].

The receiver was calibrated against the thermal background, which was the radio-brightness temperature of the absorbing material. To exclude the possible different destabilizing factors affecting the result, the calibrations were carried out at the start, in the end, and during the measurements. In the LS mode (Fig. 1, *a*) RINS and the tested object were situated along the same axis, while the platform with the receiver was moving from one aftmost position to another one along the X-axis, making 250 steps in the process. The step is 1.75 mm. The measurements were carried out at the ambient temperature of +(15–27) °C and the indoors humidity no more than 60%.

The scheme for a radiometric measurement setup in the AS mode is shown in Fig. 1, *b*. In the AS mode, RINS is able to rotate about the longitudinal axis of the tested object, while the receiver and the tested object are situated coaxially and are in fixed positions [10]. RINS is rotated step-by-step, irradiating the tested object at predefined angles. RINS's rotation angle is set in the GUI window. Maximum rotation angle is 180 degrees with a step of 1 degree. The accuracy of the tested object's position and the backlash of scanner's carriage were no more than 0.5 mm and 0.5 degree, respectively.

The measurement setup is fully automated. Three measurements of the received signals are carried out in each spot of the scanning area, and then those measurements are averaged and are written in an output data file, and are shown as a point at the graphical user interface (GUI) in quasi-real-time. TP in the LS mode is formed on 750 measurements, while TP in the AS mode is formed on 540 measurements. The full scanning time with receiving the experimental output data was 42 s for the LS mode, while it was 14 s for the AS mode.

The researched GM was sealed in hermetically sealed mass-produced packages (bottles) with a volume of 0.33 dm^3. The packages were made of plastic or green glass. The wall thickness of plastic packages was 0.3–0.5 mm, while the wall thickness of glass packages was 1.5–3 mm. The outer diameter of the packages was within 50–52 mm, and the height was 200 mm. Dielectric permittivity for glass pack-

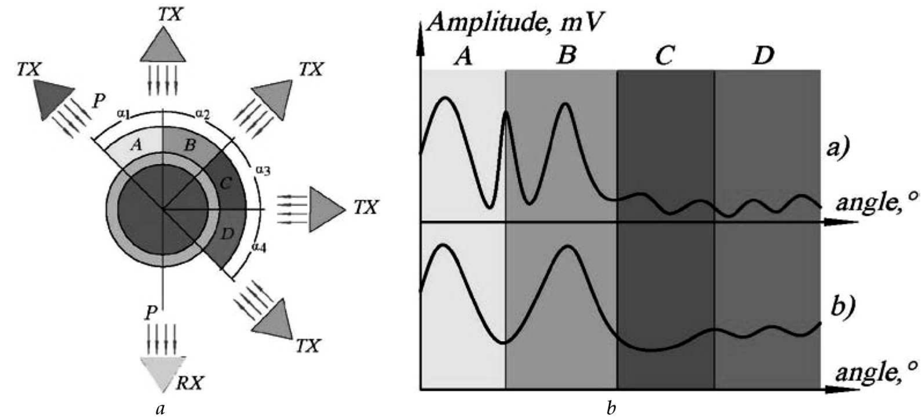


Fig. 2. AS scheme: mutual positions of RINS (TX), receiver (RX), and the researched object (*a*); defining areas on TP (*b*)

ages is in the interval $\varepsilon \cong$ 12–16. Dielectric permittivity for plastic packages is in the interval $\varepsilon \cong$ 2.4–3 [8–10]. Dielectric permittivity spread is based on different additives which are used in the glassmaking.

3. Methodology of Obtaining the Thermal Profiles

During LS [9], the radiometric receiver measures the amount of the EMW energy which passed through the tested object and diffused around it in the half-plane in which the receiver is situated. The cylindric dielectric package is used in GM researches. Only the cylindric part of the package, which was 70% of its height from the bottom, was used in the scanning. From the optic point of view, the package with a liquid should be viewed as a two-layer dielectric lens [8, 9, 18], which gives a mirror image of the object, while its vertical dimensions remain intact. Incident rays which went through and reflected rays satisfy the laws of geometric optics involving the dielectric permeabilities of researched materials and packages.

Work [10] shows the AS usage feasibility to identify liquids with close physiochemical properties. Therefore, an improved method of experiments is used to research GMs, i.e., to obtain distinctive TPs. The improvement of the method allows the step-by-step change of RINS' position 4 (in Fig. 2, *a* – TX) relatively to the optical axis of the setup and receiver's antenna 1 (ln Fig. 2, *b* – RX), i.e., carrying out AS. During AS, the EMW emitted by RINS falls onto the researched object under a set angle, while the receiver is set in a fixed immovable position. The 2D scanner ensures that the receiver and the researched object are situated coaxially. The researched GM, which is situated in the package, is shown as a blue circle, while its dielectric package is shown as a green ring. The starting position of RINS relatively to the axis of the measurement setup is α_1 degree. The step-by-step change of RINS' position (from area A to area D) as shown in Fig. 2, *a* ensures a redistribution of the energy levels of rays, which went through, were reflected, or were absorbed. The EMW energy, which enters the receiver's input, determines its output signal's amplitude, which depends on GM properties, packages type, and steering angle of RINS. Figure 2, *b* shows, provided the defining TPs, the dependences of changes in the amplitudes of output signals on the EMW angle of descent for GM. Each of the defining areas of mutual positions of RINS and the receiver, and the corresponding areas of the output amplitudes on TP is marked as A–D. The absence or presence of a central maximum on TP is related to the coefficients of EMW absorption and reflection. This feature of the AS method allows identifying the substances with close physicochemical properties, as shown below.

4. Results of Experimental Research

The samples of edible GMs which had visually distinctive average particle size were used in the research: edible table salt, edible iodized salt, granulated sugar, and baking soda. Salts of different grindings were used, which means that the salts had different average particle sizes: first grinding degree and "extra" vacuum pan salt.

Kitchen salt (NaCl) is made under DSTU 3583 : 2015. The granulometric composition of first

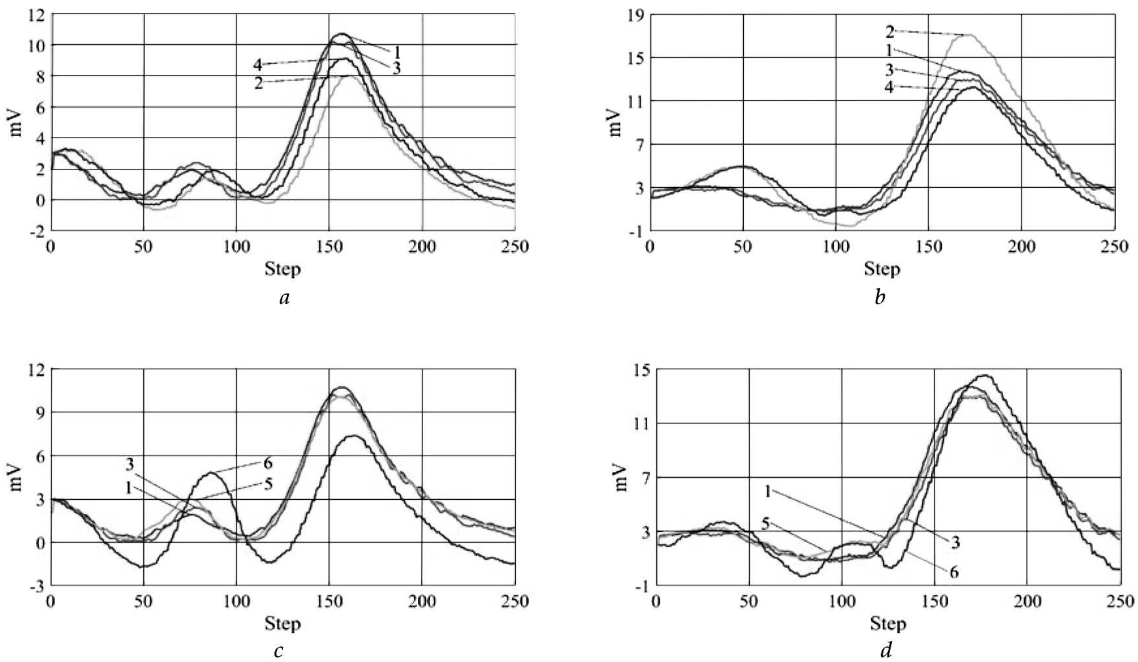


Fig. 3. TP of salts during LS in the green glass package: VP (a, c); HP (b, d). Markings: *1* – rock kitchen salt, first grade of grinding; *2* – rock kitchen salt, "extra" grade of grinding; *3* – iodized kitchen salt, first grade of grinding; *4* – iodized kitchen salt, "extra" grade of grinding; *5* — granular sugar; *6* – baking soda

grinding degree kitchen salt is: under 1.2 mm inclusively – no less than 85%, more than 2.5 mm – no more than 3%. "Extra" kitchen salt was made under DSTU 3583-97 (GOST13830-97) and had an anticaking agent E-536 (potassium hexacyanoferrate), whose mass fraction was not more than 0.001%. The granulometric composition of "extra" vacuum pan salt is: under 0.5 mm inclusively – no less than 95%, more than 0.5 mm and less than 1.2 mm – no more than 5%. Kitchen salt is mixed with potassium iodide to create iodized salt (25 g for each 1 tonne of salt). "Extra" iodized salt is made under TS U14.4-30215858-002-2002. "Extra" iodized salt consisted of "extra" vacuum pan salt and KIO3 (potassium iodate) with a mass fraction of $(40 + 15) \times 10^{-4}$%. Baking soda was made under GOST2156-76. The particle size of baking soda was 0.1 mm. Granular crystalline white sugar of the 3rd category was made under DSTU 4623-2006(GOST31361-2008). Crystalls of granular sugar had a size of 1 mm on average.

The measurements of the coefficient of losses for all of the mentioned GM samples in packages by a standard network analyzer in the 8-mm-wavelength range resulted in the approximately same result: the attenuation losses of the signal (not less than 33–38 dB). The difficulties of the GM identification remain during the transition from scalar to phase measurements using this method. The first question, which arises during a remote radiometric research of GM, which introduce a noticeable weakening, is the general possibility of obtaining distinctive TPs.

Figure 3, a, b shows TPs for the vertical (VP) and horizontal (HP) polarizations of the received signals, which were obtained during LS for rock kitchen salt and iodized kitchen salt of two different grindings, being first grade and "extra" grade in a package made of green glass. The TP comparison shows that there are matching maxima in graphs for VP for rock kitchen salt samples and iodized kitchen salt samples. Graph's maximum for iodized kitchen salt of "extra" sort is noticeably higher than the maximum of kitchen salt of the same sort.

The position of rock kitchen salt maximum in TP is much higher not only than the maximum of iodized kitchen salt, but also the first- grade kitchen salts and all other high-grinding salts. It was mentioned above that GM in the packages used can be seen as a multilayer dielectric lens which has the prop-

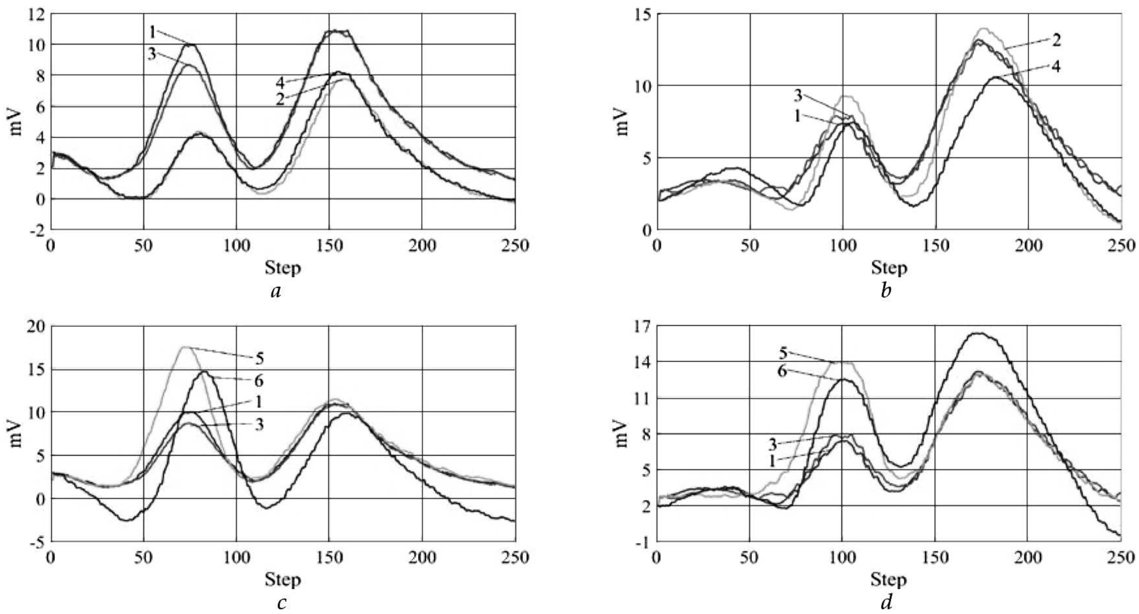


Fig. 4. TP of kitchen salts during LS in plastic packages: VP (a, c); HP *(b, d)*. Markings: *1* – rock kitchen salt, first grade of grinding; *2* – rock kitchen salt, "extra" grade of grinding; *3* – iodized kitchen salt, first grade of grinding; *4* – iodized kitchen salt, "extra" grade of grinding; *5* – granular sugar; *6* – baking soda

erty of focalizing. According to [8, 9], the package made from green glass has a permittivity of ($\varepsilon \cong 16$) and brings losses. Therefore, it has the most impact on the TP formation. Both types of salts have the same crystal lattice and close physicochemical properties. As the provided TPs show, regardless of the polarization type of the received signal and the granulometric composition, it is hard to determine GMs (salts) during LS by their TPs. As for the salts in the green glass package, in our opinion, a coherent effect of EMW passing through unstructured systems can be observed [1], that is, the correlation of dielectric properties of the package and GM and their geometric sizes are aligned in such manner that the received signal is amplified as a result of the focalizing.

Main maxima of the received signal during VP for samples of first grinding rock and iodized kitchen salt and granular sugar are practically identical (Fig. 3, c, d). The amplitude of the received signal's maximum for baking soda in VP is lower than amplitudes of maxima of materials with larger particles (crystals). Small particles of baking soda create a higher and more pronounced left maximum in TP. The amplitude of the main (central) maximum in TP for HP of the received signals for all GMs regardless of their granulometric composition has the same magnitude. TP of the baking soda is defined by having three pronounced areas of maxima while other GMs, which consist of larger particles, have only two maxima. Major differences in GMs' nature result in qualitative changes in their TP's graphs during polarization changes of the received signal and the scanning methods.

Figure 4, a, b shows packages' influence on formed TP during LS and different polarizations with samples are sealed in plastic packages. GM in a plastic package shows two maxima of the received signals with practically identical amplitudes in TP during VP. Right maxima for first grade grinding rock and iodized kitchen salts coincide in TP, while left maxima of the received signal are lower for iodized kitchen salts than the corresponding maxima of rock kitchen salt. The amplitudes of left maxima in TP coincide fully for salts of finer grindings. The amplitudes of right maxima in TP are close, however, the samplitude maximum of the signal for iodized kitchen salt is higher than the same maximum of rock kitchen salt. The amplitude of signals in TP is 1.4–2.5 times lower for kitchen salts of finer grinding than the same amplitude for salts with bigger particle sizes. The amplitudes maxima of received signals for kitchen salts of the first grade of grinding practically coincide during

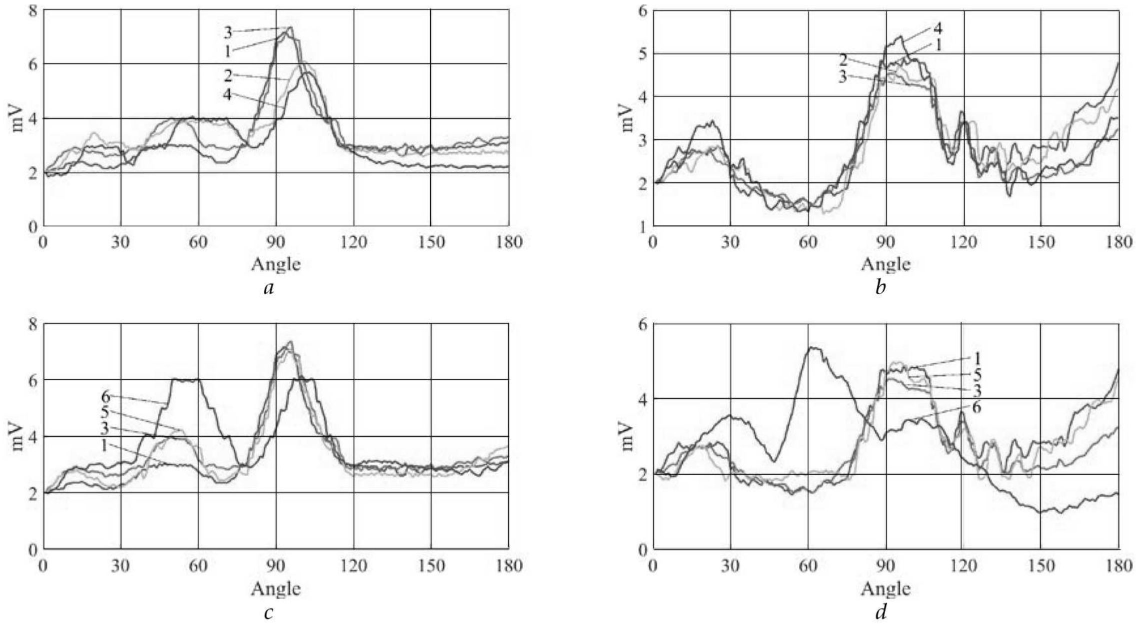


Fig. 5. TP of salts during AS in a green glass package: VP (*a, c*); HP (*b, d*). Markings: *1* – rock kitchen salt, first grade of grinding; *2* – rock kitchen salt, "extra" grade of grinding; *3* – iodized kitchen salt, first grade of grinding; *4* – iodized kitchen salt, "extra" grade of grinding; *5* – granular sugar; *6* – baking soda

HP, while maxima of the received signals are times higher for the finely ground kitchen salts compared to iodized kitchen salt. The reduced thickness of the package and its dielectric permeability lower EMW losses and allows us to get a better, but not perfect, distinguishing of samples of kitchen salts compared to LS.

TPs of GMs which are shown in Fig. 4, *c, d* illustrate that LS with GMs such as kitchen salt of the first degree of grinding and granular sugar, i.e. substances which consist of larger particles in plastic packages, have lesser amplitudes of right maxima, which coincide. They are 1.2 times less than those of baking soda. The amplitudes of left maxima have large differences. It is worth noting that the maximum of the amplitude of the received signal for granular sugar is higher than other maxima in TP. Those maxima move to the left related to the optical axis of the measurement setup. Maximum's position for granular sugar corresponds to an angle of ≈70°, while its position for salts corresponds to a ≈75° angle, and the same angle for baking soda is ≅80°. The symmetry in the positions of the left and right maxima, or TP symmetry, is typical of HP of GM in a plastic package. The occurrence of maxima and minima in TP is related mainly to the focusing of the received signal. However, it is hard to distinguish GMs based on TP.

The following series of experiments shows the results of examining the same GM in the same package, while using AS. Figure 5, *a, b* shows TP during HP and VP of the received signals for kitchen salts with differrent grades of grinding sealed in green glass packages. During AS of GM samples in green glass package using VP, main maxima in TPs for the salts of the first level of grinding have angles of ≈90° and approximately equal amplitudes. The appearance of the main maxima in TPs for salts with approximately 90° angles is related to the EMW focusing and a coherent signal increase. Side maxima and minima appear as a result of the EMW skimming on package's surface, i.e. a redistribution of the energy between its partial absorption and reflection. The difference in amplitudes and angular positions of maxima and minima are connected mainly to a combination of packages' and GM properties. The differences in the chemical composition of salts result in different TPs and, therefore, allow one to distinguish the salts.

Two maxima which coincide with each other in the area of the main maximum $\alpha \approx (95–105)^\circ$ and the second maximum $\alpha \approx (40–50)^\circ$ can be observed during AS of GM with VP of the amplitude of the re-

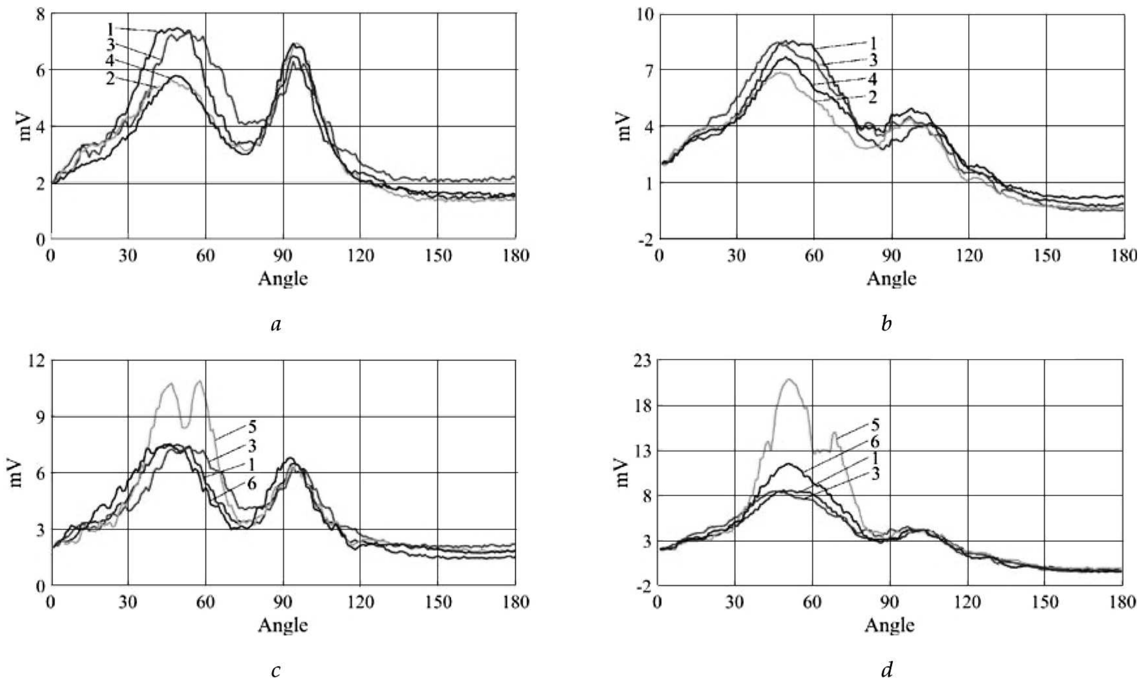
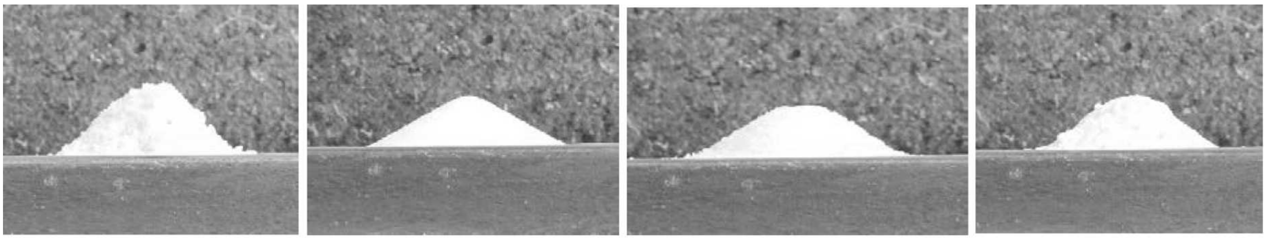


Fig. 6. TP of salts during AS in plastic package: VP (a, c); HP (b, d). Markings: *1* – rock kitchen salt, first grade of grinding; *2* – rock kitchen salt, "extra" grade of grinding; *3* – iodized kitchen salt, first grade of grinding; *4* – iodized kitchen salt, "extra" grade of grinding; *5* – granular sugar; *6* – baking soda

ceived signal in green glass package in Fig. 5, c, d. Baking soda has the shifted angular positions of maxima of the received signals during HP: the main maximum corresponds to $\alpha \approx 30°$ angle and the second maximum corresponds to $\alpha \approx 63°$. Amplitudes of those maxima are 1.2 times higher than signal amplitudes of the same maxima of other GMs. The high value of the dielectric constant of the package leads to the identity of TPs and complicates the identification of GMs with close parameters of particle sizes without any additional processing of the received data. TPs of GMs with a significant difference of particle sizes (baking soda, for example) are easily distinguished from TPs of other materials. While liquids have constant chaotic movements of molecules related to their temperature, a crystal GM is characterized by vibrations of the crystal lattice based on substance's temperature. Particles (crystals) of GM inside the package are situated chaotically. A decrease in the particle (crystal) size leads to an increase in the GM density. On the other hand, the larger crystal sizes correlate with fewer defects in their crystal lattices such as tears, therefore, having less non-compensated charges on their facets and, consequently, to an increase in the amplitude of EMW which went through. The interaction of EMW and non-compromised charges of GM lead to differences in TPs in areas of the second maximum and minimum of the received signal. TPs, which were obtained during VP, are characterized by a significant difference in the second maximum's amplitudes for GM. TPs for all of GMs with HP being used have the most differences in areas of the EMW skimming on packages' surface.

During AS regardless of the EMW polarization type, let the salts be in plastic package. Then two maxima of amplitudes of the received signal can be observed for different particle sizes, as shown in Fig. 6, a, b. Based on optics, those maxima can be explained by the EMW diffraction. The main maximum is smaller in amplitude and narrower in angular longevity. The main maximum of amplitudes has an angular position of $\alpha \approx 90°$, while the left maximum has an angular position of $\alpha \approx (40–60)°$ for VP of the received signal. Rock and iodized kitchen salts of the first grade of grinding have identical amplitudes of the main maxima. The amplitudes of the right maxima of the received signals for finer salts are 1.2 times bigger compared to the amplitude of maxima of the salts of



a *b* *c* *d*

Fig. 7. Flowability test: Kitchen pan salt, first grade of grinding (*a*); Kitchen pan salt, "extra" grade of grinding (*b*); Granular sugar (*c*); Baking soda (*d*)

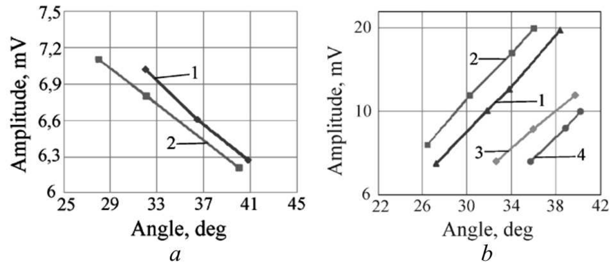


Fig. 8. Dependence of amplitude maxima of the received signals for GM in a plastic package and the slope angle (NSA) during VP: (*a*) AS; (*b*) LS

the first grade of grinding. The left maxima are identical in pairs as well, but for salts of the first grade of grinding (the ones with larger crystals) are characterized by high amplitudes. During HP of the received signals, the angular positioning is vaguer: the main maximum coincides with $\alpha \approx (85–105)^\circ$ angle, while the left maximum coincides with $\alpha \approx (40–60)^\circ$ angle. Salts in packages with lower dielectric permittivity and smaller crystal sizes regardless of the polarization type are characterized by in-pair proximities of TPs. The most differences can be observed in the left area of TP's maximum.

Two maxima which coincide with each other in the area of the main maximum $\alpha \approx (90–95)^\circ$ and the second maximum $\alpha \approx 50^\circ$ can be observed during AS of GM with VP of the amplitude of the received signal in a plastic package in Fig. 6. *c, d*. The amplitudes of the main maxima of the received signals for all materials except for baking soda are identical in TP. A plastic package with granular sugar presents a multilayer cylindric lens, which, from unstructured systems' point, creates a coherent effect and enhances the signal, when it passes through. For HP of the received signal, a coherent effect can also be observed, while the main maximum is heavily blurred. The dependences of the left amplitude maxima have resonance nature, because the coherent: materials with smaller particles reemit a less energy compared to granular sugar which has interim particle size.

Figure 7 shows photos of the researched samples before measurements to determine their natural slope angles (NSA). The procedure was held according to the method described in GOST-28251-2014. The angle between the slope of the cone and the horizontal plane is the natural slope angle (slope angle) $\alpha \pm 2^\circ$. Based on this method, the experimentally determined natural slope angles are the following: kitchen pan salt, first grade of grinding – 40°; kitchen pan salt, "extra" grade of grinding – 28°; granular sugar – 34°; baking soda – 32°. As the provided photos show, the determination of NSA based on this method is the easiest and the least affected by the measurements errors for GMs with minimal particle sizes (≅0.1 mm).

The results received allow determining a relation between angular displacements of the amplitude maxima and the corresponding slope angle for each of the researched GMs. Figure 8, *a* shows the averaged dependences of the right maximum amplitude (red curve) and the left maximum amplitude (blue curve) in TP obtained by the radiometric method during AS in a plastic package and VP to a slope angles magnitude. The dispersion of experimental data for the left and right maxima is not more than 2°. The graph shows a negative incline of the dependence between the value of the received signal amplitude and the slope angle magnitude, i.e. with an increase by $\Delta\alpha = 8^\circ$ in the slope angle magnitude, the received signal amplitude is reduced by 0.6 mV. An increase in the precision of the proposed method of determining the NSA can be obtained by the amassing and averaging of data.

Figure 8, *b* shows the averaged dependences of the amplitudes of right and left maxima in TP for the same GM in a plastic package during VP of the received signal and the natural slope angle during a linear scanning. The graph shows a positive incline of the dependence between the amplitude and slope angle magnitudes. With an increase by $\Delta\alpha = 10^\circ$, in the slope angle, the received signal amplitude is increased by 14 mV. AS distorts the received signal compared to LS. The larger the starting angle α_1, the greater the distortion is. Therefore, the dependence between the amplitude of the signal and slope angle changes.

5. Conclusions

1. A general possibility of the remote identification of granular materials, which are sealed in a dielectric package by the methods of close location, is shown. A measurement setup in the 8-mm-wavelength range is designed and produced, and a method which uses the linear and angular radiometric scannings to obtain the polarization thermal profiles (thermal portraits) of the analyzed materials in their packages is developed.

2. Properties of unstructured systems are applied to granular materials during a radiometric research. A general possibility of determining NSA by the remote radiometric method is shown, and its potential accuracy is higher than the standard method's accuracy. The experimental dependences of the received signal amplitudes of granular materials and the slope angle magnitude are determined for both linear and angular scannings. The research has shown that the dependences of maximum amplitudes for the left and right maxima of thermal portraits and slope angles have not only different magnitudes, but also different inclinations for both linear and angular scannings.

3. The influence of a package on the results of the research is shown, as well as a possibility of determining TPs (thermal portraits) to identify granular materials regardless of high similarities in parameters of the researched substances, which leads to the necessity of using the polarization measurements. Depending on the physicochemical properties of granular materials and packages, the polarization thermal profiles which were obtained and the differences in them, even at the preliminary processing stage, are enough to identify substances with similar characteristics (edible salts).

4. The occurrence of coherent effects was registered during the passage of the electromagnetic wave through the unstructured (disordered) granular materials. The phases and amplitudes of waves should be random. However, at a certain random combination of the size and dielectric properties of substance and the average electrical parameters, the wave interference (pattern) can be observed, which manifests itself in a sharp increase in the received signal's amplitude.

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Received 21.12.19

А.В. Павлюченко, П.П. Лошицький, І.В. Пономарьов

РАДІОМЕТРИЧНА ІДЕНТИФІКАЦІЯ ГРАНУЛЬОВАНИХ РЕЧОВИН

В роботі показана принципова можливість дистанційної ідентифікації гранульованих речовин, що знаходяться в закритій діелектричній тарі, методами ближньої локації з використанням радіометричної вимірювальної установки у 8-ми міліметровому діапазоні довжин хвиль з метою отримання поляризаційних теплових портретів. Гранульовані речовини розглядаються як невпорядковані системи. В результаті взаємодії електромагнітної хвилі з гранульованими речовинами, на молекулярному рівні з'являється можливість виділити та відобразити характерну інформацію у вигляді теплового портрета. Поляризаційні теплові портрети гранульованих речовин з близькими характеристиками візуально відмінні, для подібних портретів виконувалася попередня обробка даних, що забезпечило ідентифікацію речовин. Експериментально показана можливість використання радіометричних методів для визначення узагальненого параметра гранульованих речовин – кута природного скосу, незалежно від їх властивостей та гранулометричного складу. Наведено зв'язок кута природного скосу та радіометричних параметрів гранульованих речовин. Під час проходження електромагнітної хвилі через невпорядковані системи при окреслених довільних поєднаннях співвідношень розмірів та усереднених електричних параметрів спостерігається різке збільшення амплітуди сигналу, що приймається, тобто когерентні ефекти.

Ключові слова: мікрохвильова область, радіометрія, температура радіо-яскравості, температурний профіль, електромагнітна хвильова поляризація, гранульовані матеріали.