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ABSTRACT

of the dissertation for the degree of Doctor of Science

MICROWAVE NON-REFLECTIVE COATINGS AND DEVELOPMENT OF METHODS OF THEIR DIELECTRIC AND MAGNETIC PARAMETERS

Specialty: 3337.01 - Information-measuring and control systems (by industry)

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GENERAL DESCRIPTION OF WORK

Relevance of the topic. Currently, the task of developing microwave non-reflective coatings in various fields of science and technology is becoming increasingly relevant. The need for its solution arises when creating antireflection coatings for indicating non-reflective flying objects, protective antiradar non-reflective coatings that provide defense for objects from light detection, control the speed of a moving object, suppress the harmful effects of microwave radiation on biological tissues, enhance solar energy storage systems, enlightenment thermal receivers of electromagnetic radiation, creating accurate methods for measuring the dielectric and magnetic properties of substances, methods of distance measuring control of environmental parameters, as well as optics for a clear presentation of images by optical devices.

Non-reflective absorbers of electromagnetic radiation used in microwave technology are formed, as a rule, on the basis of layered absorbing dielectrics or a layer of matrix non-absorbing material (ceramic, polymer) with the introduction of highly dispersed metallic or ferromagnetic substances into it. In this case, the complete absorption of the incident radiation in a wide frequency range is ensured by the selection of the thickness and properties of the coating substances, as well as a certain distribution of the filler concentration over the thickness of the absorber layer. For technological and structural reasons, such non-reflective absorbers are usually made on a metal substrate, which is not always acceptable, for example, in the case of possible optical detection of a hidden object or when solving an important environmental problem to protect the population from the harmful effects of penetrating microwave radiation on biological tissues. The resulting coatings turn out to be mechanically unstable, heavy, have insufficiently high heat resistance and require sophisticated technology for their manufacture.

In addition, previous studies were limited mainly to the analysis of the occurrence of conditions for the complete absorption of a wave during its normal incidence on layered systems, as well as on systems that do not contain absorbing magnetic materials. At the same time, non-reflective microwave coatings can be made with help of available technology using layered dielectrics and magnets. In this regard, layered absorbent coatings applied on non-absorbent substrates are preferred. The possibility of using an absorbing dielectric coating was already considered by us in previous works. It would be desirable, by comparison, to use magnetic materials applied on a dielectric substrate as a coating substance.

In this regard, work related to the study of the phenomenon of complete absorption of a wave during its normal or angular passing through layered environment containing, among other things, absorbing magnetic materials, as well as the application of this phenomenon to: increase the sensitivity and accuracy of microwave, infrared, and optical wavelength receivers; creating accurate microwave methods for measuring the dielectric and magnetic properties of liquid and solid substances; methods for isolating the polarizing components of the incident radiation when developing polaroids; creation of protective anti-radar non-reflective coatings that provide the defense for objects from their light detection; radar monitoring of the linear speed of a weakly reflecting body and the indication of non-reflecting flying objects in technology is relevant. The dissertation was carried out in accordance with the thematic plans of the Institute of Physics of National Academy of Sciences of Azerbaijan in 2002-2009 and Azerbaijan Technical University in 2009-2021.

The objective of the work was to develop scientific principles and practical recommendations for creating layered absorbers containing absorbing magnetic materials and not reflecting electromagnetic radiation which incident on them normally or at an angle and using this phenomenon to increase the sensitivity of thermal sensors in the microwave, infrared and optical wavelengths, amplification accumulation of solar energy, accuracy of measurements of the dielectric and magnetic properties of substances in the microwave and infrared wave ranges.

To achieve this goal it was necessary to solve the following tasks:

- explore the conditions for the occurrence of complete absorption of electromagnetic radiation in a layer of absorbing magnetic substance, applied on a metal and non-absorbing dielectric substrate;
- to investigate the conditions for the occurrence of complete absorption of electromagnetic radiation when it falls at an angle on the translucenced absorbing substrate and the absorbing layers of a dielectric and a magnet applied on a metal and non-absorbing dielectric substrate;
- to study the conditions of the translucense of the absorbing substrate when incident on it at the angle of a parallel-polarized wave and a transversely polarized wave;
- to study the conditions of the translucence of the absorbing substrate when it falls on it at an angle of a transversely-polarized wave;
- to develop microwave methods for measuring the dielectric and magnetic properties of highly absorbing liquids using a resistance transformer with an adjustable transformation ratio.
- to assess the modulation frequency when sensing a flying low-reflecting object.
- study of the possibility of expanding the range of applicability of the microwave method for measuring moisture content in petroleum products.

The scientific novelty of the work is:

- For the first time, software was developed for microwave methods for measuring the dielectric and magnetic properties of liquid and solid substances based on computer programs MathCad 15, MATLAB 9.1, Mathematica 11.1, Microsoft Excel 2016.
- For the first time, algorithms and software modules have been developed for calculating the dielectric and magnetic parameters of highly absorbing substances using a quarterwave plate, matching liquid, a constant or variable resistance transformer in the measurement circuit.
- Algorithms and software modules were developed for the first time to find the conditions for the complete passing of an

electromagnetic wave through a layered structure consisting of periodically alternating absorbing layers of a dielectric and a magnet and non-absorbing layers of a dielectric, which make it possible to almost completely extinguish the radiation, while creating antiradar non-reflective coatings that ensure that objects are protected from light detection .

- For the first time, calculation equations were obtained for deciphering signals received during remote location probing of observed objects.
- For the first time, systems of equations were obtained that determine the optical parameters of the substances of the layered system and the thickness of the layers of antireflection coatings under which the conditions for the complete absorption of a wave of a given frequency are satisfied.
- For the first time, systems of equations are written that describe the conditions for the complete absorption of a wave in an absorbing substrate with a thickness-adjustable layer of a non-absorbing coating and quarter-wave non-absorbing layers;
- For the first time, systems of equations have been compiled that describe the conditions for the complete absorption of waves when they are incident at an angle onto an antireflected absorbing substrate and absorbing layers of a dielectric and a magnet applied on a metal and non-absorbing dielectric substrate;
- For the first time, mathematical and algorithmic methods have been developed to ensure the dielectric and magnetic properties of liquid materials based on an analysis of the information parameters of radiation reflected from a substance.
- For the first time, a method for controlling the linear velocity of a weakly reflecting body was developed, and the modulation frequency was estimated when probing a flying weakly reflecting body with location signals of known frequency.

The main provisions to be defended:

- Conditions for the complete passing of electromagnetic radiation through systems containing periodically alternating layers of absorbing dielectric or magnetic materials and non-absorbing dielectric layers. The optimal number of double layers (bilayers) providing complete damping of radiation passing through such a system.

- The phenomenon of complete absorption of electromagnetic radiation during its normal or angular passing of layered media, including layers of absorbing magnetic materials, to increase the sensitivity and accuracy of the receivers of the microwave, infrared and optical wavelength ranges, to enhance the accumulation of solar energy, polarization emission methods of components of incident radiation.
- Dependences of the wave reflection coefficient on the layer thickness of a liquid absorbing dielectric and magnet in free space and in a waveguide. Establishment of functional relationships between the position and magnitude of the extrema of these dependences and the values of the dielectric and magnetic properties of the studied substances.
- Software for microwave methods for measuring the dielectric and magnetic properties of substances using the effect of complete absorption of electromagnetic radiation in a layer of a substance. Development of mathematical and algorithmic methods for measuring the dielectric and magnetic properties of liquid and solid substances, based on the analysis of information parameters of radiation reflected from a substance.
- Systems of equations that determine the optical parameters of the substances of the layered system and the thickness of the layers of antireflection coatings under which the conditions of complete absorption of a wave of a given frequency are satisfied.
- A method for radar monitoring the linear velocity of a weakly reflecting body and determining the modulation frequency when probing a flying low-reflecting body with location signals of known frequency.
- The conditions of the frequency band of the translucence of thermal detectors of the microwave and infrared wavelengths using two non-absorbing antireflective coatings sequentially

applied on a substrate: a base layer with an adjustable thickness and a quarter-wave additional coating.

- Analysis of the characteristics of the reflection of an electromagnetic wave from a flat layer of an absorbing magnet applied on an ideal metal substrate. The establishment of the existence of normal and anomalous regions in these dependencies. Conditions for the complete absorption of electromagnetic radiation in a flat magnetic-metal system.
- Characteristics of the reflection of an electromagnetic wave from a flat layer of an absorbing magnet applied on a non-absorbing semi-infinite dielectric layer. Conditions and frequency band of the total absorption of electromagnetic radiation in a planar absorbing magnetic-dielectric system. Conditions for highlighting the desired polarization component of the incident radiation.
- Microwave methods for measuring the dielectric properties of liquid and solid substances using a constant or variable resistance transformer in the measurement circuit.
- Analytical equations that describe the conditions for the complete passing of electromagnetic waves through a layered structure consisting of periodically alternating absorbing layers of a dielectric or magnet and non-absorbing layers of a dielectric.
- Calculation equations for the conditions and the translucence band of both absorbing and non-absorbing substrates, an analysis of their behavior depending on the thickness and properties of the coating and substrate.

Object of study. The objects of study were layered absorbing coatings consisting of periodically alternating absorbing layers of a dielectric and a magnet, non-absorbing layers of a dielectric to increase the sensitivity of thermal receivers of the microwave, infrared and optical wavelengths. A substance with n_1=1.5 was used as antireflection coating materials: acetone, cyclohexanone, chlorobenzol, phenol, methanol, propanol, ethanol, butanol, cyclohexanone, ethyl pyridine.

As a double antireflecting of the absorbing substrate, we consider the problem of translucence a photodetector with a silicon substrate, and with a coating - silicon dioxide and titanium oxide, with a refractive index of silicon dioxide equal to 1.46.

Practical significance. The possibility of practical application of the found phenomenon in ecology is considered, in the accumulation of solar energy by creating non-reflective and antireflective coatings, as well as to increase the sensitivity of microwave, infrared, optical radiation receivers and in the development of various microwave methods for the quantitative and qualitative analysis of the properties of substances, including methods for its analysis by remote sensing. The use of layered systems containing periodically alternating layers of absorbing and non-absorbing materials makes it possible to create antiradar non-reflective coatings that provide defense for objects from their light detection. The proposed method for measuring the linear velocity of a moving body can be used for radar speed control of weakly reflecting objects. The conducted studies allow us to conclude that it is possible to use the full effect wave absorption in the development of simple polaroids to highlight the desired polarization component of the incident waves. The developed methods for measuring the dielectric properties of substances can be used in studies of the molecular structure of weakly absorbing solutions and liquids to create a simple method for controlling the low content of polar substances in a non-polar solvent, which may be in demand in the petrochemical industry in solving the important problem of quickly finding the moisture content in oils and in petroleum products.

Approbation of work. The main results of the thesis were reported and discussed at:

- X международном научно-практическом семинаре "Практика и перспективы партнерства в сфере высшей школы" (Донецк, Украина. 4-7 мая 2009 года);
- International Conference on Communications, Control and Information Technology. World Academy Of Science, Engineering And Technology (Paris, France. August 24-26. 2011);

- International Conference on “Computer, Electrical, and Systems Sciences, and Engineering” World Academy Of Science, Engineering And Technology (Venice, Italy, november 28-30, 2011);
- International Congress And Exhibition “Natural Cataclysms And Global Problems Of The Modern Civilization” (Istanbul, Turkey, september 19-21, 2011);
- XIX Менделеевском съезде по общей и прикладной химии (Волгоград, Россия. 25-30 сентября 2011 года);
- İnternational Scientific And Technical Conference “Prospects Of Development Of Modern Information And Communication Technologies” (Baku, Azerbaijan, september 22-24, 2011);
- International Academic Conference on Engineering, Internet and Technology (Prague, Czech Republic, december 12-13, 2014).

Publications The total number of published scientific papers is 69, of which 58 articles(*Thomson Reuters*, *Web of Science*, *Scopus, Impact Factor, İEE, JCR, RSCI*, *Springer*, *JCR*, *RSCI*, *CAS, INSPEC,ADS*, *EBSCO*, *SJR*, *CSA*, *OCLC*), 1 Eurasian patent, 1 monograph, based on the materials of the doctoral dissertation.

The content of the work. The dissertation consists of an introduction, 6 chapters, main results and conclusions, a list of cited literature. It is set out on 286 typescript pages and contains 52 figures, 8 tables and a bibliography of 206 items.

BASIC CONTENT OF THE DISSERTATION

The introduction justifies the relevance of the work, formulates the goal and objectives of the research, and also sets out the main results that have scientific novelty and practical significance.

I**n the first chapter.** The conditions for the appearance of complete absorption[1] of electromagnetic radiation in a flat layered system are considered, which consists of the main layer of the absorbing substance and a number of layers of non-absorbing

[1]Yuping Duan. Microwave Absorbing Materials. USA. 2016, 402 pp.

substances applied on it, matching the input resistance of the main layer with the wave impedance of the free space, in which the incident radiation will pass through the reflecting layers and completely absorbed in the material of the absorbent substrate.

The problem of reflection of a plane-polarized wave incident normally on an absorbing substrate with the main and additional antireflection coatings applied on it with the corresponding refractive indices n_1, n_2 and layer thicknesses l_1, l_2 is considered. In this case, we will assume that the substrate substance has refractive indices n and absorption χ, and its layer thickness is chosen infinite in magnitude.

Figure 1 shows the dependences between the selective values of the optical parameters of the substrate n, χ and the additional coating n_2 and deviation Δ from a multiple of 0.5 wavelength in the material of the main coating. The substance with n_1= 1.5 was chosen as the substance of the main antireflection layer.

To determine the translucence band, we use the equation:

$$\Delta\lambda = \frac{4\rho_г}{\sqrt{(E')_0^2 + (F')_0^2}} \quad ; \qquad (1)$$

where: $\rho_г$ is the selected value of the modulus of the reflection coefficient of the wave of the considered system at the edges of the translucence band near $\rho = 0$,

E'_0, F'_0 - derivatives of the real and imaginary components of the input resistance of the system at $\rho = 0$

$$E'_0 = 0 \;;\; F'_0 = \frac{\left(n_2^4 - n_1^2\right)\left(2\pi + 4\pi\Delta\right) + \pi n_1 n_2\left(n_2^2 - 1\right)}{2\lambda_0 n_1 n_2^2} \quad ; \qquad (2)$$

$$\frac{\Delta\lambda}{\rho_г \lambda_0} = \frac{8 n_1 n_2^2}{\pi\left[\left(n_2^4 - n_1^2\right)\left(2 + 4\Delta\right) + n_1 n_2\left(n_2^2 - 1\right)\right]} \quad . \qquad (3)$$

As an example of the use of double anti-reflection of an absorbing substrate, the problem of photodetector translucence is considered, in which silicon is the substrate and silicon dioxide is the coating. In the optical wavelength range, the refractive index of silicon dioxide is 1.46, and the dependence χ on n is determined by the curve shown in Fig. 1 in the coordinate plane $[n, \chi]$. With such a ratio of the optical parameters of the substrate and the coating, it is impossible to provide conditions for the complete extinction of optical radiation by changing the thickness of the coating layer. However, translucence is achievable if, along with the main coating (silicon dioxide), a second, additional and quarter-wave antireflection coating is used, the substance of which would have a refractive index in magnitude that lies between the refractive indices of the substrate and the main coating. As such an additional coating, a quarter-wave titanium oxide coating could be used.

In the second chapter, the conditions for the complete absorption of a wave when it is incident at an angle on an translucened absorbing substrate are considered.

With this type of polarization of the incident wave, the complex expression of the wave reflection coefficient $\hat{\rho}$ for the considered two-layer planar system is equal to:

$$\hat{\rho} = \frac{Z_d \cos\alpha_0 - Z_0 \cos\alpha_1}{Z_d \cos\alpha_0 + Z_0 \cos\alpha_1}\ ; \tag{4}$$

$$Z_d = Z_1 \frac{Z \cos\alpha_1 + Z_1 \cos\alpha_2 th(\gamma l \cos\alpha_1)}{Z_1 \cos\alpha_2 + Z \cos\alpha_1 th(\gamma l \cos\alpha_1)} \tag{5}$$

where: Z_1, Z - wave impedances, respectively, of the coating materials and the substrate; $\cos\alpha_2 = \sqrt{1 - p/\varepsilon}$; $\gamma = i2\pi\sqrt{\varepsilon_1}/\lambda$ - constant wave propagation in the coating material; α_2 is the angle of refraction of the wave in the substrate material; ε_1 и l are the dielectric constant

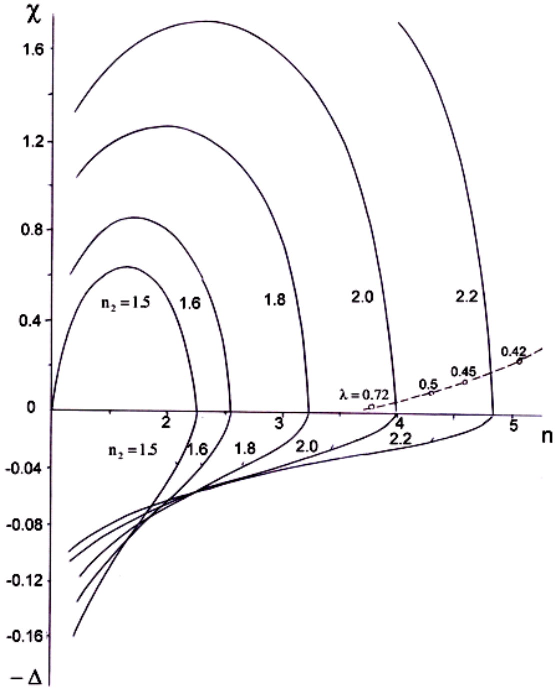


Fig. 1. Dependences between the selective values of the refractive indices *n* and the absorption χ of the wave of the absorbing substrate and the deviations Δ from the magnitude of a multiple of 0.5 wavelength for the main antireflection coating. The refractive indices of the wave, respectively, of the main n_1 = 1.5 and the additional antireflection coating n_2. The wavelength λ of the incident radiation, microns. The dashed curve is the dependence of χ on *n* silicon in the region of its dispersion.

and the thickness of the coating layer; λ is the wavelength of the incident radiation.

$$\bar{\chi} = \sqrt{(\bar{n}-1)(\bar{n}_1^2 - \bar{n})} \;; \tag{6}$$

$$tg\,4\pi x = \frac{2\bar{\chi}\bar{n}_1}{\bar{n}_1^2 - \bar{n}^2 - \bar{\chi}^2} \;. \tag{7}$$

$$x = \frac{2N_o - 1}{4} + \Delta \;; \tag{8}$$

$$\Delta = \frac{1}{4\pi} arctg \frac{2\bar{\chi}\bar{n}_1}{\bar{n}_1^2 - \bar{n}^2 - \bar{\chi}^2} \;. \tag{9}$$

$$\frac{l_0}{\lambda} = \frac{1}{\bar{n}_1\sqrt{1-p}}\left[\frac{(2N_0-1)}{4} + \frac{1}{4\pi} arctg \frac{2\bar{\chi}\bar{n}_1}{\bar{n}_1^2 - \bar{n}^2 - \bar{\chi}^2}\right] \tag{10}$$

Figures 2 and 3 show families of dependences of χ and Δ on n at n_1= 1.5 and various values of the angle of incidence of the wave.

It is characteristic that the deviation Δ of the thickness of the antireflective layer from $\bar{\lambda}_{1d}/4$, is negative in the entire interval of variation of n and α_0. At $\chi = 0$, it is equal to zero, with decreasing n it increases in absolute value and reaches its limiting value of 0.25 (see Fig. 2).

Table 1 shows the results of calculating the selective values of λ_0, l_0 for N_0 = 1, 2, and 3 two-layer systems in which a number of polar liquids with known values of ε_0, ε_∞ and τ are used as the substrate material. As a substance of an antireflection coating, a substance with a value of n_1 = 1.5 was used.

The possibility of the appearing of this effect when a plane transversely-polarized wave was transmitted through a layer of

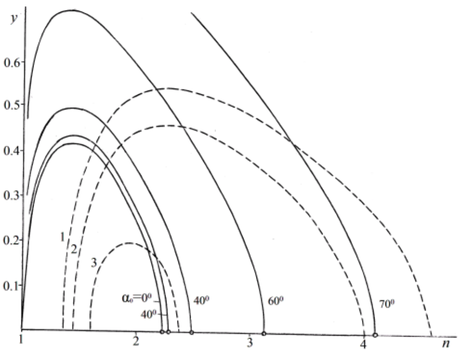


Fig. 2. Dependences between the refractive index *n* and the dielectric loss factor *y* of an absorbing substrate material of infinite thickness: A) when the transverse-polarized wave incident on it at an angle α_0 is completely absorbed if the substrate has a coated coating layer with a refractive index n_1 = 1.5 ; C) for the Debye type of wave dispersion in acetone (1), cyclohexanone (2) and chloro-benzol (3) (dashed lines).

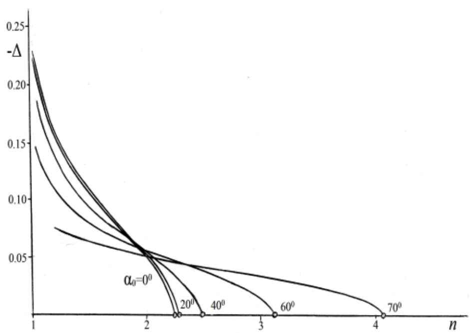


Fig. 3. The deviation Δ of the thickness of the coating layer from multiples of a quarter of the wavelength in the coating material, depending on the refractive index *n* of the substrate and the angle of incidence of the wave α_0 when the conditions for the complete absorption of radiation in a two-layer coating-substrate system are satisfied

Table 1.

Selective values of the thickness l_0 of the antireflection coating layer and the wavelength λ_0 of the incident radiation of a number of Debye-type polar fluids at different angles of incidence of the wave; ε_0, ε_∞, τ respectively, the static and high-frequency permittivities and the relaxation time of the liquid. N_0 is the number of the zero minimum of the reflected signal.

№	Liquid	α_0, degr	λ_0, sm	$-\Delta$	l_0, sm		
					$N_0 = 1$	N_0=2	N_0=3
1	Acetone	0	0.058	0.099	0.007	0.025	0.046
	$\varepsilon_0 = 21.2$;	20	0.062	0.095	0.007	0.028	0.049
	ε_∞ =1.90 ;	40	0.077	0.082	0.010	0.038	0.067
	$\tau = 3.01.10^{-12}$c	60	0.155	0.051	0.025	0.088	0.151
		70	0.468	0.046	0.091	0.291	0.492
2	Cyclohexanone	0	0.304	0.085	0.034	0.135	0.236
	$\varepsilon_0 = 16.0$;	20	0.322	0.082	0.037	0.148	0.258
	$\varepsilon_\infty = 2.18$;	40	0.407	0.070	0.054	0.204	0.355
	$\tau = 10.3.10^{-12}$c	60	0.869	0.042	0.148	0.502	0.857
3	Chlorobenzol	0	1.538	0.034	0.221	0.734	1.247
	ε0=5.74; ε_∞ =2.55; τ =7.0.10^{-12}c	20	1.949	0.028	0.297	0.964	1.631
4	Phenol	0	0.414	0.053	0.055	0.193	0.330
	$\varepsilon_0 = 11.7$;	20	0.447	0.051	0.061	0.214	0.367
	$\varepsilon_\infty = 3.19$;	40	0.597	0.045	0.090	0.310	0.530
	$\tau = 87.10^{-12}$c	60	1.692	0.023	0.314	1.005	1.696

non-absorbing substance into an absorbing substrate of infinite thickness was considered.

According to the studies, the conditions for the complete passing of the wave through a similar two-layer system can occur at the minimum point of dependence of the modulus of the wave reflection coefficient ρ on the thickness l of the antireflective coating layer and if the condition $\rho = 0$ is satisfied at this point .

The obtained results are suggesting the possibility of experimental observation of the full absorption of electromagnetic radiation, incident at an angle on an absorbing substrate with an antireflective coating applied on it.

Table 2 shows the results of calculating the selective values of the radiation wavelength λ_0 and the first three thicknesses l_0 of the coating layer of the absorbing substrate, under which the conditions for the complete absorption of the incident radiation in a two-layer system are fulfilled.

A number of polar liquids with the known values of ε_0, ε_∞ and τ are used as the substrate material, and a substance with the value $n_1 = 1.5$ is used as the substance of the antireflection coating.

As follows from the data in Table 2, in a liquid with a certain selection of the coating layer thickness, complete absorption of a parallel-polarized wave is possible when it is incident both at the clearing angles and at the Brewster angles. The revealed conditions for the existence of a complete transmission of a parallel-polarized wave at an angle to the coated antireflective substrate make it possible to carry out a targeted search for materials when designing non-reflecting elements, in particular, thermal radiation detectors.

The conditions were found for the complete transmission of a parallel-polarized wave at an angle to a two-layer planar system consisting of an absorbing substrate with a non-absorbing coating applied on it. The conditions for the complete passing of the parallel-polarized wave through the two-layer system arise at the minimum point of the dependence of the modulus of the reflection coefficient of the wave ρ on the thickness l of the antireflection coating layer and when the condition $\rho = 0$ is fulfilled at this point.

The relationship between the selective values of the pre-refraction coefficient n and the absorption χ of the substrate, the wavelength of the incident radiation λ_0, the layer thickness l_0 and the refractive index n_1 of the antireflection coating are described by the following equations:

$$Y = \frac{1}{N}\sqrt{\left(\bar{n}_1 N / n_1^2 - 1\right)\left(1 - n_1^2 N / \bar{n}_1\right)} \qquad (11)$$

Table 2

Selective values of the thickness l_0 of the antireflection coating layer and the wavelength λ_0 of the incident radiation of a number of polar Debye-type liquids at various angles of incidence of the wave; $\alpha_{пр}$, $\alpha_{бр}$ - respectively the angles of illumination and Brewster; ε_0, ε_∞, τ – are the static and high-frequency dielectric permittivities and the relaxation time of the liquid at a temperature of 20° C, respectively; N_0 is the number of the zero minimum of the reflected wave; Δ is the deviation l_0 from values that are multiples of a quarter of the wavelength in the coating material.

№	Liquid	$\alpha_{пр}$, degr	$\alpha_{бр}$, degr	λ_0, sm	– Δ	l_0, sm		
						$N_0 = 1$	$N_0 = 2$	$N_0 = 3$
1	Acetone	0		0.059	0.099	0.006	0.025	0.045
	$\varepsilon_0 = 21.2$;	20		0.055	0.104	0.006	0.024	0.043
	$\varepsilon_\infty = 1.90$;	40		0.039	0.126	0.004	0.018	0.033
	$\tau = 3.01.10^{-12}$s	50		0.020	0.161	0.001	0.009	0.017
			60	0.018	0.166	0.005	0.012	0.020
			65	0.053	0.139	0.016	0.038	0.061
			70	0.116	0.098	0.040	0.089	0.139
2	4–Ethylpyridine	0		1.133	0.068	0.138	0.516	0.893
	$\varepsilon_0 = 11.0$;	20		1.057	0.071	0.130	0.492	0.853
	$\varepsilon_\infty = 2.52$;	40		0.731	0.082	0.090	0.360	0.630
	$\tau = 22.10^{-12}$s	50		0.367	0.087	0.046	0.189	0.331
			60	0.325	0.090	0.109	0.241	0.374
			65	0.998	0.091	0.341	0.759	1.176
			70	2.554	0.058	0.965	2.057	3.149
3	Chlorobenzol	0		1.538	0.034	0.221	0.734	1.247
	ε_0=5.74;	20		1.281	0.040	0.184	0.623	1.061
	ε_∞ =2.55;	40		0.683	0.061	0.095	0.347	0.599
	$\tau = 7.0.10^{-12}$s	50		0.299	0.074	0.041	0.157	0.273
			60	0.261	0.078	0.090	0.197	0.304
			65	1.085	0.056	0.403	0.857	1.311

$$x = \frac{l_0}{\bar{\lambda}_{1d}} = \frac{2N_o - 1}{4} + \Delta \quad ; \quad \text{at angles of translucence} \qquad (12)$$

$$x = \frac{l_0}{\bar{\lambda}_{1d}} = \frac{N_o}{2} + \Delta \quad ; \quad \text{at Brewster angles} \qquad (13)$$

As an example, Fig. 4 shows the dependences of ε''on ε' calculated from these equations for $\varepsilon_1 = 2.25$ and $N_0 = 1$, respectively, for the antireflection angles of incidence of the wave (solid lines) and for the Brewster angles (dashed lines).

$$\varepsilon'_{np} = \frac{1 + \sqrt{1 - 4ap}}{2a} \quad ; \qquad (14)$$

Table 3 shows the selective values of the angles of incidence of the wave and the thicknesses of the coating layer calculated on the basis of equations (11) - (14), in which conditions are created in the two-layer system under consideration for the complete absorption of the electromagnetic radiation incident on it. Dielectric with a value of $\varepsilon_1 = 2.25$ was used as a coating material in the system, and various polar liquids having dispersion in the microwave range were used as a substrate material. For the values of ε'_0, ε''_0 of liquids measured in the microwave range indicated in Table 3, the total absorption of waves in these liquids can be expected in the range of α_0 and l_0, respectively, 30–70^0 and 0.4–4 cm.

The dependences of the reflection coefficient modulus of the wave ρ of such systems on the angle of incidence of the wave α_0 were determined in the interval (0.90^0) and for coating layer thicknesses close to or equal to selective values determined respectively by equations (12) and (13). To find these dependences, a complex expression was used for the reflection coefficient of a parallel-polarized wave $\hat{\rho}$ of the considered two-layer system (15).

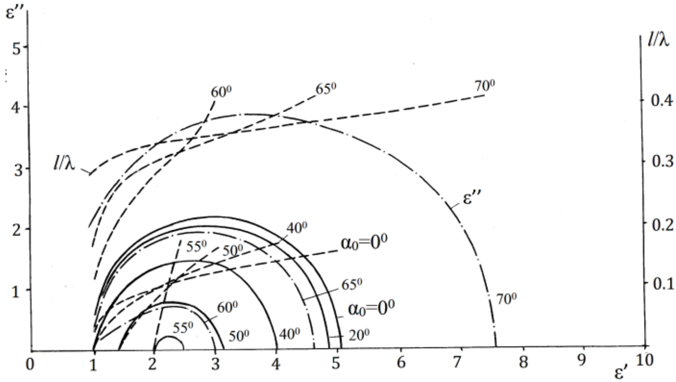


Fig. 4. Dependences between the thickness l_0 of the coating layer, the dielectric constant ε′ and the dielectric loss ε″ of the substance of the absorbing substrate of infinite thickness upon complete absorption of a parallel-polarized wave incident at an angle α_0 on the coating-substrate system.

Figure 5 shows the dependences calculated according to equation (15) on the angle of incidence α_0, the model of the wave reflection coefficient ρ of a two-layer system consisting of a coating with $\varepsilon_1 = 2.25$ and ethyl alcohol as a substrate substance.

$$\hat{\rho} = \frac{Z_0 \cos\alpha_0 - Z_d \cos\alpha_1}{Z_0 \cos\alpha_0 + Z_d \cos\alpha_1}; \qquad (15)$$

We used the data of measurements of the dielectric coefficients of ethyl alcohol obtained at a wavelength of λ= 3.2 cm. Calculations were performed at values of the coating layer thickness equal to or close to the first ($N_0 = 1$) its chosen value found previously from the condition of complete absorption in the substrate of the incident radiation.

Table 3

B The calculated values of the angle of incidence of the wave α_0 and the thickness l_0 of the coating layer of the clarified absorbing substrate, under which conditions arise for the complete absorption of the incident radiation in it; ε'_0 и ε''_0 – are the experimental values of the dielectric constant and dielectric loss of liquids at a temperature of 20^0C.

№	Liquid	λ_0,sm	ε'_0	ε''_0	For antireflection angles α_a				for Brewster corner α_{br}			
					α_0, gr.	Layer thickness l_0, sm			α_0, gr.	Layer thickness l_0, sm		
						N_0=1	N_0=2	N_0=3		N_0=1	N_0=2	N_0=3
1	Methanol	0.818	5.35	3.20	–	–	–	–	69.7	0.316	0.665	1.015
2	Ethanol	3.20	3.85	1.05	36.3	0.497	1,658	2.819	64.0	1.221	2.554	3.886
3	Propanol	3.22	3.53	1.16	38.8	0.480	1.661	2.843	63.6	1.197	2.532	3.873
4	Butanol	3.22	3.14	0.75	46.7	0.492	1.720	2.947	61.8	1.188	2.514	3.841
5	2- ethylpyridine	3.22	5.73	2.65	–	–	–	–	69.2	1.266	2.638	4.010
6	4- ethylpyridine	3.22	5.76	3.95	–	–	–	–	70.7	1.250	2.631	4.012

The results of these calculations indicate that the complete absorption of a wave in a given liquid is expected when a parallel-polarized wave is incident, not only at an illuminating angle of 36.3^0 and at the first possible thickness of the coating layer corresponding to it equal to 0.50 cm, but also at a Brewster angle of 64.0^0 and corresponding to the first possible thickness of the coating layer equal to 1.22 cm. A similar result was obtained in the case of using propyl alcohol as a substrate substance (see Fig. 6).

At λ= 3.22 cm and N_0 = 1, in such a two-layer system two dependences ρ on α_0 are fixed, which have zero minima respectively at l_0 = 0.48 cm (antireflection angle α_0= 38.8^0) and l_0 = 1.20 cm (Brewster angle $\alpha_0 = 63.6^0$). However, when using 2-ethylpyridine as the substrate material for the same values of λ and N_0, a similar dependence of ρ on α_0 is observed only at the Brewster angle $\alpha_0 = 69.2^0$ and the coating layer thickness l_0= 1.26 cm.

Thus, the conducted studies of the nature of the reflection of electromagnetic radiation from an absorbing endless layer of substance with a layer of non-absorbing dielectric applied to it indicate the possibility of the existence of conditions and experimental observation of the phenomenon of complete absorption of radiation of a given frequency at strictly determined thicknesses of the coating layer for the materials used and the angles of incidence of a wave of a certain polarization.

It has been established that, in contrast to the incidence of a parallel-polarized wave onto such a system, the complete absorption of a transverse-polarized wave is possible not only at an antireflection angle, but also at corner, analogue of the Brewster angle for transparent media. The conditions are found for the selection of the desired polarization component of the incident radiation.

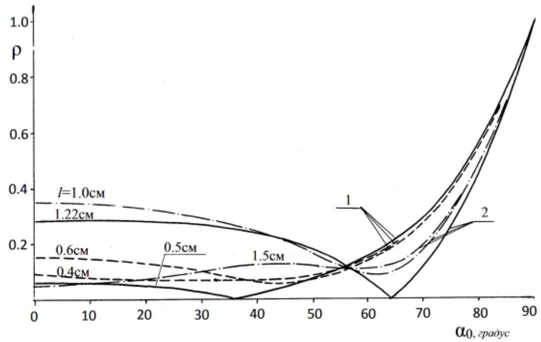


Fig. 5. Dependences of the modulus of the wave reflection coefficient ρ on the angle of incidence α_0 for an absorbing liquid with an antireflective coating of a substance with a dielectric constant ε_1 = 2.25 and with selective thicknesses of the layer : A. Corresponding angles of translucence (1) and Brewster (2) (solid lines); C. Close to the electoral magnitude, corresponding to the angle of illumination (dashed lines) and Brewster (dashed-dotted lines). The absorbing liquid is ethanol; radiation wavelength λ = 3.2 cm.

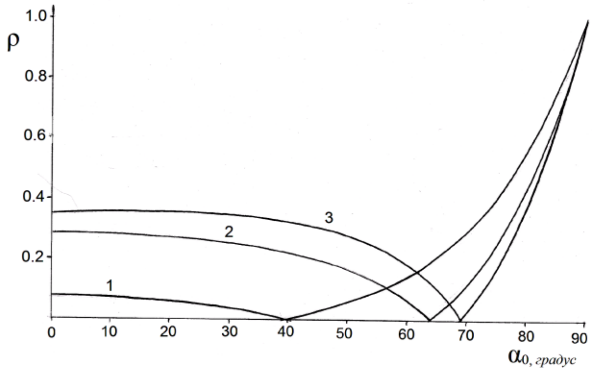


Fig. 6. Dependences of the wave reflection coefficient modulus ρ on the incident angle α_0 of a parallel-polarized wave for propanol (1, 2) and 2-ethylpyridine (3) for the thickness of the antireflection layer of the coating, corresponding to: angle of translucence (1) and Brewster angles (2,3). The dielectric constant of the coating material is ε_1 = 2.25; the wavelength of the incident radiation λ = 3.2 cm.

The third chapter analyzes the characteristics of the reflection of an electromagnetic wave from a plane layer of absorbing magnet[2] applied on an ideal metal substrate. The existence of normal and anomalous regions in these dependences, differing in the nature of the change in their extreme values with increasing layer thickness, has been established. The conditions and frequency band of the total absorption of electromagnetic radiation in a flat magnetic-metal system are found. Their dependences on the selective values of the magnetic properties and the thickness of the magnetic layer are investigated.

Figure 7 shows the dependence of ρ on x of the magnetic material of the coating. It follows from this that the conditions for the existence of the so-called zero minimum should determine the conditions for the appearance in the substance of the complete absorption of the electromagnetic radiation incident on it. The condition for complete absorption of the wave in the coating material will be determined by the equality:

$$th(2\pi xy + i2\pi x) = \frac{1}{n(1-iy)} \quad . \tag{16}$$

$$th\frac{\alpha + i\beta}{2} = \frac{1}{n(1-iy)} \quad . \tag{17}$$

$$4\pi xy = \ln(1/r) \;\; ; \;\; 4\pi x = -\varphi \;\; . \tag{18}$$

$$x_{\mathrm{m}} = \frac{N}{2} + \Delta_{\mathrm{m}} \;\; ; \tag{19}$$

$$2\pi N - \varphi = \frac{1}{y}\ln\left(\frac{1}{r}\right) \quad . \tag{20}$$

[2] David Jiles. Introduction to magnetism and magnetic materials. 2015, 626 pp.

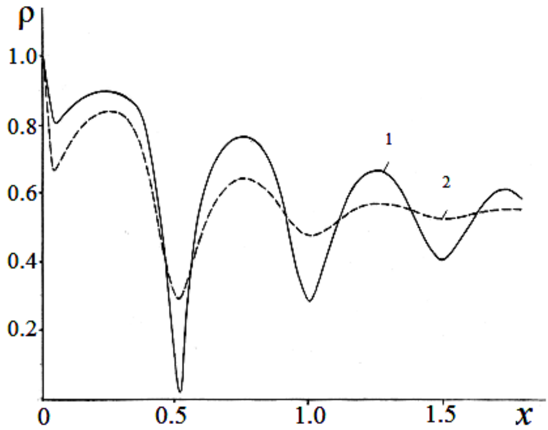


Fig.7. Dependences of the modulus of the reflection coefficient of the wave ρ on the thickness $x = l/\lambda_m$ of the liquid layer at μ′=10 , μ″ = 1 (1) and μ ′= 10 , μ″ = 2 (2); λ_m is the wavelength in magnet.

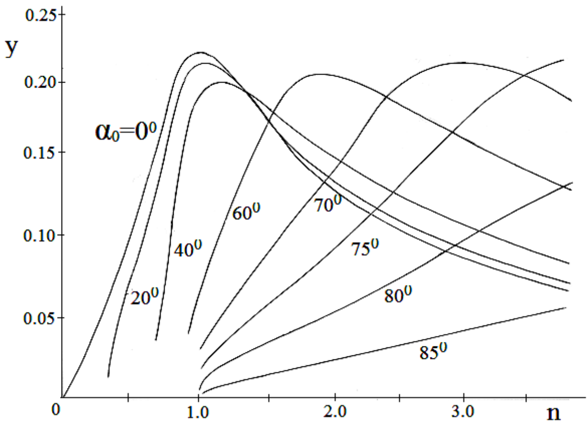


Fig.8. Dependences of the factor of magnetic losses *y* on the refractive index of the wave *n* of the material of the absorbing coating with complete damping of the wave incident on it at an angle α_0 transversely polarized wave

$$\Delta_m = -\frac{1}{4\pi} arctg \frac{2ny}{1-n^2\left(1+y^2\right)} \quad . \tag{21}$$

$$\frac{l_0}{\lambda_0} = \frac{1}{2\pi n}\left[\pi N - \frac{1}{2}\mathrm{arctg}\frac{2ny}{1-n^2\left(1+y^2\right)}\right] \tag{22}$$

This indicates that the complete absorption of electromagnetic radiation is possible even in coating materials that have magnetic losses that are insignificant in magnitude; in these cases, the effect of complete absorption of the wave is realized at increased values of the thickness of the reflecting layer of the coating substance.

The conditions for the complete absorption of electromagnetic radiation when it is incident at an angle onto a two-layer planar magnetic-metal system are determined(fig.8).

A difference has been established in the fall of parallel-polarized and transverse-polarized waves on such a system, which makes it possible to isolate with it the desired polarizing component of the incident radiation

The fourth chapter analyzes the characteristics of the reflection of an electromagnetic wave from a plane layer of an absorbing magnet applied on a non-absorbing semi-infinite dielectric layer. The boundaries are determined for the existence of normal and anomalous regions in these dependences, differing in the nature of the change in their extreme values with increasing layer thickness.
system are studied, depending on the selective values of the dielectric constant of the substrate, magnetic properties and the thickness of the magnetic coating layer.

It was found that during normal incidence of a wave on two-layer systems of magnetic-metal and magnetic-non-absorbing dielectric, its total absorption occurs when the thickness of the coating layer is close to a wavelength of material coatings.The same is occured when a wave is incident at an angle onto a two-layer magnetic-dielectric system, but with a coating layer thickness of a value close to 1/2 the wavelength in the coating material in the direction of wave propagation in it.

Table 4 shows the selective values of the wave incidence angles and coating layer thicknesses calculated on the basis of the obtained equations, for which conditions are created in the considered two-layer system for the complete passing of the parallel-polarized wave at its incidence angles $\alpha_0 > \alpha_Б$. Various polar liquids with dispersion in the range of microwaves were used as a coating material in the system, and a dielectric with a value of ε_1 = 2.25 was used as a substrate material. (fig.9).

The conditions and frequency band of the full absorption of electromagnetic radiation in a planar absorbing magnetic-dielectric

For the values of ε′, ε″ liquids indicated in the table, measured in the microwave range, the complete transmission of the parallel-polarized wave in these liquids can be expected in the range of α_0 and *l*, respectively, 30–70^0 and 0.4–4 cm.

Theoretical studies of the character of the reflection of electromagnetic radiation from an absorbing substance layer applied on an infinitely thick non-absorbing substrate layer confirm the existence of conditions and the possibility of experimental observation of the phenomenon of complete transmission of radiation a given frequency at strictly selective values of the thickness of the coating layer and the angle of incidence of a wave of a certain polarization.

Table 4.

The calculated values of the selective values of the angle of incidence of the parallel-polarized wave α_0 and the thickness *l* of the layer of polar liquid applied on a non-absorbing substrate with ε_1 = 2.25. Liquid temperature 20^{0}C, $\alpha_0 > \alpha_Б$, *N* = 1.

№	Liquid	λ, sm	ε′	ε″	α_0, degree	*l*,sm
1	Water	3.21	62.42	31.57	78.9	0.112
2	Methanol	20	27.5	11.3	73.7	1.08
3	Acetone	3.21	20.92	3.54	65.6	0.260

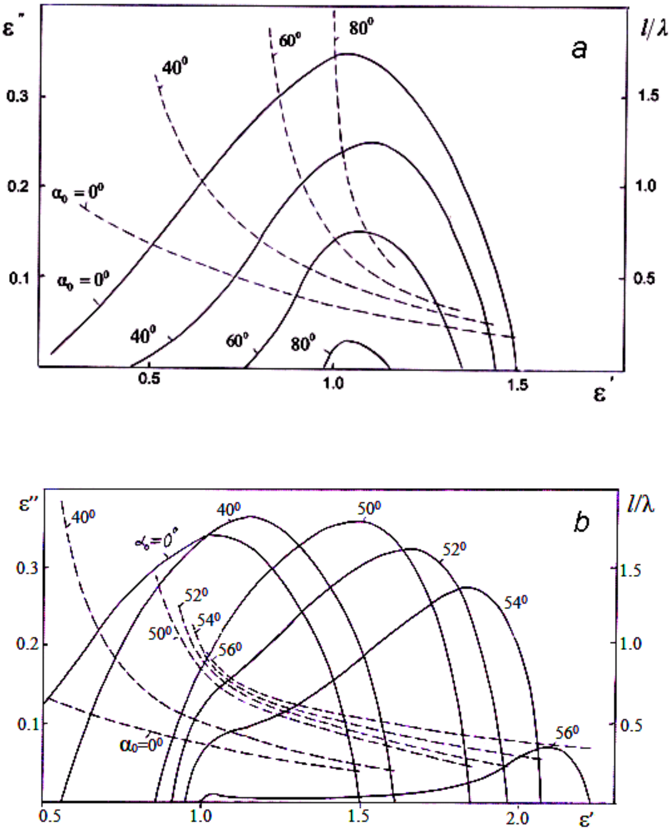


Fig.9. Dependences of dielectric losses ε″ (solid curves) and layer thickness l_0/λ (dashed lines) on the dielectric constant ε′ of the absorbing coating material with complete damping of the TP wave incident on it at an angle α0 (a) and PP wave (b). The dielectric constant of the substrate substance is ε_1 = 2.25.

In the fifth chapter, the dependences of the wave reflection coefficient on the layer thickness of a liquid absorbing dielectric[3] and a magnet in free space and in a TE waveguide are studied. The functional relationships between the position and the magnitude of the extrema of these dependences and the values of the dielectric or magnetic properties of the substance are determined.

They made it possible to develop, on their basis, exact microwave methods for measuring the dielectric and magnetic properties of liquids and solutions with $tg\delta < 0.8$, including using the effect of complete absorption of electromagnetic radiation in a layer of a substance. A number of microwave methods for measuring the dielectric properties of liquid and solid substances with $tg\delta < 0.8$,have been developed with the use of a resistance transformer in the measurement circuit.

Their practical application allows obtaining reliable information on the dielectric and magnetic properties of liquid objects of research, and on their basis about their molecular structure. In particular, the analysis of the behavior of the frequency and temperature dependences of the permittivity and dielectric loss of polar liquids and their solutions allows us to determine the dipole moments of polar molecules, polarizability, relaxation times, and energy activations of dipole relaxation, the nature of the orientations of the dipoles and a number of other important molecular characteristics of the substance. It is very promising to apply it, to assess the influence of the nearest environment on the relaxation processes of dipole molecules when analyzing the dielectric properties of concentrated solutions, the components of which have different molecular nature[4]. They allow to determine the possibility of the formation of molecular associates and complexes due to the action of inter- and intramolecular hydrogen bonds.

In this regard, one of the relatively simple methods for determining the wave impedance and the associated values of the

[3] Carmine Vittoria. Magnetics, Dielectrics, and Wave Propagation with MATLAB®Codes. 2010, 427 pp.. London.

[4] Касимова С.Р.. Методы измерения диэлектрических и магнитных свойств твердых и жидких веществ в диапазоне сверхвысоких частот // Монография. 2016. стр.175.

dielectric coefficients of a substance is the inserting of a thickness-adjustable, flat layer of a non-absorbing liquid located on the surface of the study into the measurement circuit blown substance.

Measurement scheme ε' and ε'' using a waveguide water-guiding system, in which as an analogue of a variable resistance transformer a flat quarter-wave non-absorbing dielectric that is adjustable in position is used the plate is shown in Fig. 10.

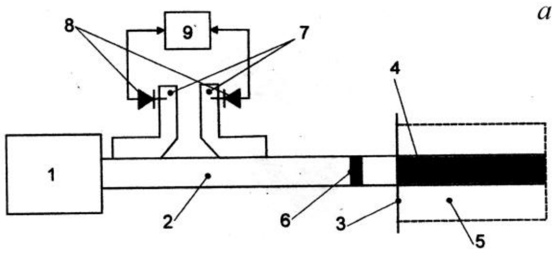
As matching liquid, it is permissible to use non-polar liquids that do not have absorption, for example, benzol, hexane, etc. To measure the standing wave coefficient, two directional couplers 10 are used, the outputs of the detector sections 11 of which are connected to the standard voltage standing wave meter 12.

The consideration of Fig. 11 implies the possibility at definite choices of the dielectric properties of the coating material to achieve one of the minima of the function $\rho(x)$ of zero value. It is characteristic that, with a decrease in wave attenuation in matter, the interface between the normal and anomalous regions shifts toward higher x values. The latter indicates that the conditions for the complete absorption of incident radiation in the dielectric layer are satisfied. It is associated with the appearance of zero minima of the function $\rho(x)$.

The sixth chapter discusses the application of the developed methods and technical means. The conditions for the complete passing of electromagnetic radiation through systems containing periodically alternating layers of absorbing dielectric or magnetic materials and non-absorbing dielectric layers are determined.

The optimal number of double layers (bilayers) was found, which ensures almost complete absorption of radiation passing through such systems.

The possibility of and the full passing of electromagnetic radiation through a plane layer of an absorbing dielectric applied on a quarter-wave non-absorbing dielectric substrate is theoretically substantiated. It has been shown that multilayer periodic structures formed on the basis of such a two-layer system make it possible to



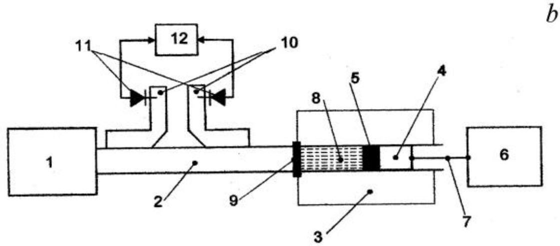


Fig. 10. Block diagrams of measuring the dielectric coefficients of highly absorbing solid and liquid substances using a panoramic standing wave coefficient meter and using a quarter-wavelength plate (a) and matching liquid (b). 1 - klystron generator with an attenuator and a wave meter; 2 - a directing path; 3 - directional coupler; 4 - detector; 5 – coefficient of stand wave's meter; 6 - plate; 7 - measuring cell; 8 - thermostat; 9 - measured substance; 10 - matching liquid; 11 - piston; 12 - micrometric device

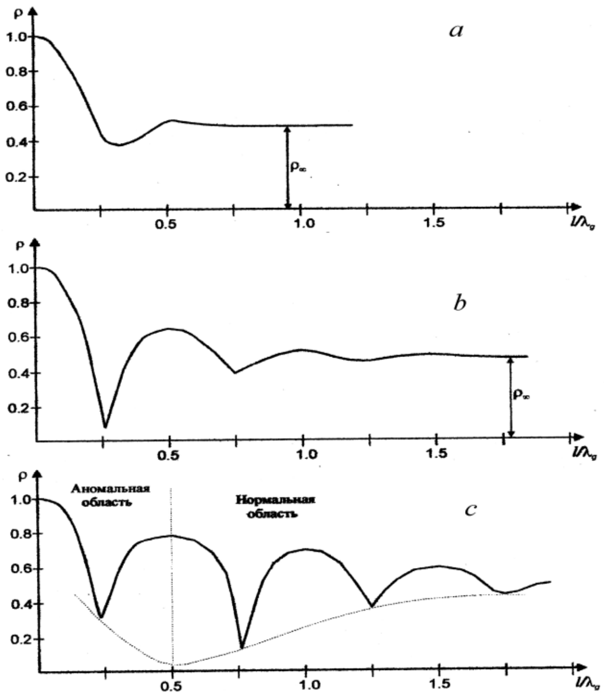


Fig. 11. The dependences of the modulus of the reflection coefficient of the wave ρ on the thickness of the layer *l* of the substance with values of its loss factor y equal to 0.6 (a), 0.3 (b), and 0.1 (c). λ_d is the wavelength in the substance.

ensure complete absorption of the electromagnetic radiation passing through them.

Fig. 12 shows a block diagram of an algorithm for calculating the dielectric coefficients of a highly absorbing substance using a quarter-wave plate in the measurement circuit.

Microwave absorbers of electromagnetic radiation, as a rule, are formed on the basis of a flat layer of a dielectric coating applied onto a metal substrate or dielectric layers containing absorbing highly dispersed metals Scales or magnetic fillers. In this case, the condition for the complete absorption of normally incident radiation is ensured by the appropriate choice of material, layer thickness, and filler content in them. At the same time, the use of a metal substrate as the supporting structure limits the applicability of such absorbers, since their location sensing makes it possible to detect them light-emittingly.

In this regard, periodic layered structures are becoming preferable, containing alternating absorbing and non-absorbing layers and ensuring the completeness of absorption of the electromagnetic radiation passing through them. As a first step in solving this problem, the possibility of obtaining two-layer non-reflective absorbers using a quarter-wave non-absorbing dielectric layer with a quarter-wave thickness l_1 thickness and a layer as its coating was considered dielectric[5] or magnet with thickness l , absorbing radiation passing through it.

Subsequently, such a two-layer system could be applied as an element of multilayer absorbing periodic structures.

As a reflectionless two-layer system, one can use a layer of an absorbing magnet applied on a quarter-wave non-absorbing dielectric substrate. From the condition of lightening such a non-absorbing system (for example, diamagnetic material is a magnet), it follows that in a real absorbing system the condition for complete absorption of the wave is realized when considering the inverse problem, namely, when the layer of the absorbing magnet applied on the front surface of the substrate.

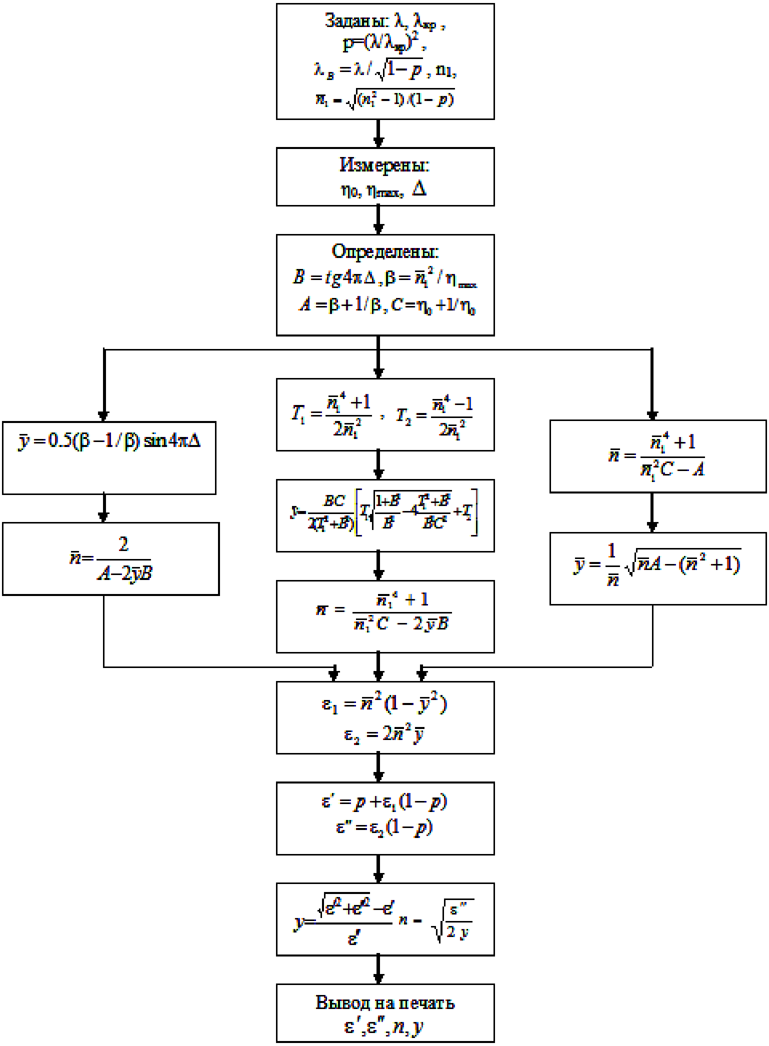


Fig. 12. Block diagram of the algorithm for calculating the dielectric coefficients of a highly absorbing substance using a quarter-wave plate in the measurement circuit.

A method of radar[6] control of the linear velocity of a weakly reflecting body is considered. The disadvantage of this method is the inability to determine the speed of the body, which moves against a background of mechanical noise that impedes the passing of electromagnetic radiation. The reflectivity of an object decreases if the observable body is a non-metallic or weakly reflective body. The objective of the invention is to ensure the reliability of the obtained information about the speed of a moving non-metallic or slightly reflective body.

In the proposed method for determining the velocity of a body by electromagnetic radiation of a radar, an object of observation is probed, while the electromagnetic radiation first passes through a flat non-absorbing quarter-wave plate, which is installed near the antenna of the radar.

Electromagnetic radiation reflected from the object enters the receiving device of the antenna, where the speed of the object, which is proportional to it, is determined by the frequency of modulation of the received signal. Fig. 13 and 14 will explain the effect of the proposed method.

It is known that the complex value of the reflection coefficient of a plane-polarized wave passing through a plane quarter-wave plate of non-absorbing material and then reflected from the object of observation is determined by the equation:

$$\hat{\rho} = \frac{Z_{вх} - Z_0}{Z_{вх} + Z_0}; \qquad (23)$$

where: $Z_{вх} = \frac{Z_1^2}{Z_0} \cdot \frac{Z_0 + Z_H th\gamma l}{Z_H + Z_0 th\gamma l}$ - input resistance of the layered system

[5] Kasimova S.R.. Measurements of the dielectric properties of strongly absorbing substances at microwave frequencies // Measurement Techniques. USA, New-York. 2016. Vol.58, Is.12, p.1372-1375. *(Thomson Reuters, Web Of Science, Scopus, Springer, JCR, RSCI, Impact Factor: 0.390)*

[6] Способ определения скорости движения тела // Евразийский Патент. *№022902. 31.03.2016. G01S 13/58.*

plate – air – object of observation; $\gamma = i\frac{2\pi}{\lambda}$ – the constant propagation of a wave in air; λ is the wavelength of the incident radiation; l – the distance between the antenna of the radiator and the object of observation (see Fig. 12).

Here: Z_0, $Z_1 = Z_0 / n_1$, Z_{H} are the wave resistances of the vacuum, the substance of the plate and the object of observation, n_1 is the refractive index of the substance of the plate.

Denote $x = l/\lambda$ and present the input impedance of the considered layered system in the form $Z_{\text{BX}} = Z_0(E + iF)$ ..

Then, the modulus of the wave reflection coefficient ρ of the considered planar system will be equal to:

$$\rho = \sqrt{\frac{(E-1)^2 + F^2}{(E+1)^2 + F^2}} . \qquad (24)$$

$$x_Э = \frac{1}{4\pi} arctg \frac{2ny}{1 - n^2(1 + y^2)} , \qquad (25)$$

where: n and y are the refraction and attenuation coefficients of the wave of matter of the object under observation.

$$x_Э = \frac{l}{\lambda} = \frac{m}{4} - \Delta , \qquad (26)$$

where: m is the extremum number; Δ is a constant and a small value determined by the optical properties of the object of observation.

$$\Delta = \frac{1}{4\pi} arctg \frac{2ny}{n^2(1 + y^2) - 1} . \qquad (27)$$

$$\frac{Z_{BX}}{Z_0} = M_Э = \frac{1}{n_1^2} . \frac{n}{1 + yntg 2\pi x_Э} . \qquad (28)$$

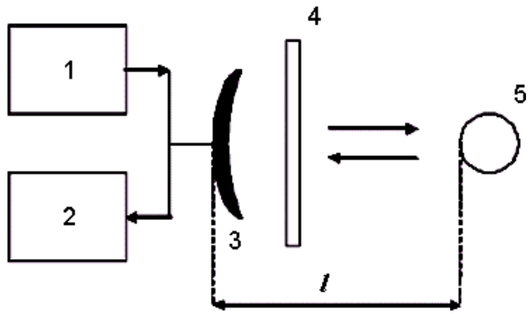


Fig. 13. The block diagram of the measurement of the velocity of the body:1 - microwave generator; 2 - receiver; 3 - antenna; 4 - quarter-wave plate of non-absorbent dielectric; 5 - object of observation

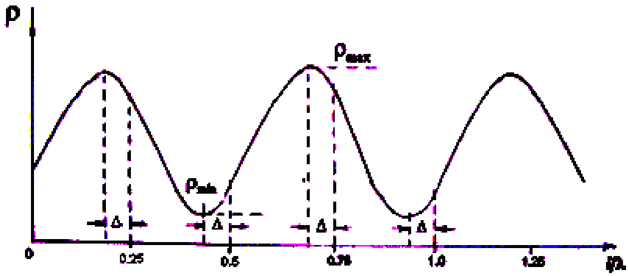


Fig. 14. The dependence of the reflection coefficient modulus ρ of electro-magnetic radiation on the distance *l* between the radiation source and receiver. Δ is the deviation of the maxima ρ_{max} and minima ρ_{min} depending on the value of a multiple quarter of the wavelength λ.

$$M_Э = \frac{1}{n_1^2} \cdot \frac{n}{1 + yn/tg2\pi\Delta}$$ at the points of maximum ρ,

(29)

$$M_Э = \frac{1}{n_1^2} \cdot \frac{n}{1 - yntg2\pi\Delta}$$ at the minimum points ρ.

$$\eta_{max} = \frac{1+\rho_{max}}{1-\rho_{max}} = \frac{1}{n_1^2} \cdot \frac{n}{1 + yn/tg2\pi\Delta},$$

(30)

$$\eta_{min} = \frac{1+\rho_{min}}{1-\rho_{min}} = \frac{n}{n_1^2} \cdot \frac{1}{1 - yntg2\pi\Delta}.$$

When the object moves relative to the source of electromagnetic radiation at speed *v*, the signal reflected from it with a frequency *f*, due to the presence of a plate on the signal path, will be amplitude-modulated. In this case, the modulation period τ will be equal to the ratio of half the radiation wavelength λ to the object velocity *v*. Therefore, the modulation frequency of the signal reflected from the object will be equal to:

$$f_c = 2f\frac{v}{c}, \quad (31)$$

where: *c* - speed of light, cm / sec; *f* is the frequency of the location station, GHz.

Thus, the very fact of the appearance of amplitude modulation indicates the existence of a moving object. In this case, the magnitude of the modulation frequency of the signal gives information about the speed of the object of observation, and the amplitude of the modulation is determined, according to expressions (30), by the ratio between the optical parameters of the plate materials and the object of observation.

The modulation frequency was estimated for sounding a weakly reflecting object with location signals of known frequency.

For ease of presentation, the speed of an object is expressed in km / h, and the station frequency in GHz. In this case, the magnitude of the modulation frequency f_c in MHz will be expressed by the relation:

$$f_c = 1.85 f v \cdot \qquad (32)$$

Example 1. Radar station of centimeter wave range: γ = 3 cm, f = 10 GHz.

№	v, km/h	f, mgh
1	100	0.00185
2	200	0.0037
3	500	0.00925
4	1000	0.0185

Example 2. Infrared Radiation Locator λ = 10 mkm, f = 3.000 GHz.

№	v, km/h	f, mgh
1	100	0.555
2	200	1.11
3	500	2.78
4	1000	5.55

A method for determining the dipole moment of non-polar liquids has been developed. During of the studies, it was found that some of the pure non-polar liquids used as solvents, such as benzol, dioxane, hexane and etc., had very little wave attenuation. It showed itself in fact that, depending on the reflected signal and the thickness of the substance, a stable anomalous region thereof has arisen. The boundary between the abnormal and normal regions selected for the examination of fluids lay within the 10-15th minimum number of this relationship. However, from the theory of transmission lines, it followed that in a metal measuring cell with a non-polar liquid that does not have absorption, the reflection coefficient of the wave

should be equal to 1 and be independent of the thickness of the liquid layer in the cell.
At first, it was assumed that the existence of weak wave attenuation in non-polar liquids was due to the use of not sufficiently pure products in which, for one reason or another, impurities of polar substances, for example moisture in benzol has appeared. However, as studies have shown by the Rayleigh light scattering method of the molecular structure of benzol and alkanes, that molecular or atomic formations with dipole moments can exist in these non-polar substances.

The idea of a method for proving theoretical assumptions of work using the measurement data known in the research studies e', e" of the liquids has been appeared. The calculations used the values of dielectric losses e" of a liquid measured at two spaced frequencies, and it was considered that the dielectric properties of these substances in the area of their dispersion are described by the Debye equation. In the Debye description of the dielectric properties of a substance, the values of their dielectric losses ε''_1, ε''_2, measured at two frequencies f_1 and f_2, are:

$$\varepsilon_1'' = \frac{2\pi f_1 \tau(\varepsilon_0 - \varepsilon_\infty)}{1 + (2\pi f_1 \tau)^2} \quad ; \quad \varepsilon_2'' = \frac{2\pi f_2 \tau(\varepsilon_0 - \varepsilon_\infty)}{1 + (2\pi f_{21} \tau)^2}; \qquad (33)$$

where: : ε_0, ε_∞ - static and high-frequency extreme values of dielectric permeability of substance;
τ is the macroscopic relaxation time.

If you enter the symbols $\alpha = \varepsilon_2''/\varepsilon_1''$ and $\beta = f_2 / f_1$, then from the joint solution of equations (33) it follows:

$$\tau = \frac{1}{2\pi f_2} \sqrt{\frac{\alpha - \beta}{1/\beta - \alpha}} \ . \qquad (34)$$

Since the ratios α and β are known, the macroscopic relaxation time τ is found from equation (34). To determine the dipole moment of the molecules of substance in the liquid phase, we use the Onzager-Kirkwood equation:

$$\mu^2 = \frac{(\varepsilon_0 - \varepsilon_\infty)(2\varepsilon_0 + \varepsilon_\infty)}{\varepsilon_0(\varepsilon_\infty + 2)^2} \cdot \frac{9kT}{4\pi N_A}; \quad (35)$$

where: k - Boltzmann constant; T - temperature;
NA - Avogadro number.

Since the permittivity ε' of the liquids in question varies slightly with frequency in the dispersion region, it is believed that the value ε_0 is slightly different from the value e. Then equation (35) takes the form:

$$\mu^2 = \frac{3(\varepsilon_0 - \varepsilon_\infty)}{(\varepsilon_\infty + 2)^2} \cdot \frac{9kT}{4\pi N_A} \quad : \quad (36)$$

From the joint solution of equations (33) and (34), it follows that

$$\varepsilon_0 - \varepsilon_\infty = \frac{1-\beta^2}{\varepsilon_2''} \cdot \frac{1}{\sqrt{(\alpha-\beta)(1/\beta-\alpha)}} \quad (37)$$

According to the difference $\varepsilon_0 - \varepsilon_\infty$ the value of the dipole moment of the selected liquid molecule is found according to equation (36). In this way, μ and τ of benzole and alkanes were found. Table 5 shows the results of calculations according to the proposed method of values of relaxation time and dipole moments of molecules of these liquids. The calculations used the research data of microwave measurements of the dielectric properties of these liquids[7] In alkanes, the values of the dipole moments of their molecules remain within 0.065D.

The above calculation method was also used to estimate the molecular relaxation time of polar substances based on the results of measuring the dielectric properties of their diluted solutions in non-polar solvents.

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[7]Ахадов Я.Ю. Диэлектрические параметры чистых жидкостей. М., Изд. МАИ. 2000, 854 с.

Table 5

Relaxation times τ and dipole moments μ of benzole and alkanes molecules obtained from the measurement of their dielectric losses ε''_1, ε''_2 at two frequencies f_1, f_2 and temperature 25^0C.

№	Substance	f_1, GHz	f_2, GHz	ε''_1	ε''_2	τ, 10^{12} s	μ, D
1	Benzol	24	70	0.0025	0.0059	1.20	0.1
2	Hexane	10	35	0.00058	0.00152	2.80	0.064
3	Heptane	10	35	0.00077	0.00163	3.97	0.066
4	Octane	10	35	0.00092	0.00156	5.13	0.068
5	Nonan	10	35	0.00102	0.00139	6.39	0.068
6	Dean	10	35	0.00106	0.00121	7.56	0.068

An express method of measuring the small content of the polar component in binary solutions has been developed. During studying of the reflection characteristics of the electromagnetic wave of binary solutions of polar substances in non-polar solvents, it was found that in solutions with a small content of the polar component, the oscillating and attenuating dependence of the reflected signal with an increase in layer thickness breaks down into two externally different regions. In the first of them, normal, lying at increased thicknesses of the solution layer, with an increase in the thickness of the layer, the values of the maxima of this dependence fall in magnitude and synchronously with them increase the values of the minima of the same dependence until they coincide in magnitude. In the second area, indicated by abnormal and lying at small thicknesses of the substance layer, with an increase in the thickness of the solution layer, a decrease in the value of maxima and minima of this dependence occurs in parallel. It is characteristic that an abnormal region of such dependence occurs at relatively low concentrations of the polar component of the solution, i.e. at a relatively small attenuation of the wave in the substance. By examining solutions with low concentrations of the polar component in them, it was found that the interface of the normal and anormal regions is shifted along the abscissa axis with a decrease in the concentration of polar matter in the solution. It has been found that for any selected binary solution, the product of the volumetric concentration of the polar component of the solution and the measured thickness of its layer corresponding to the boundary of these two regions remains constant. This fact made it possible to develop a fairly simple method for controlling the low concentration of polar substance in solutions. This method turned out to be in demand in determining the low moisture content (polar substance) in oil and oil products - one of the most important parameters used in the petrochemical industry.

MAIN RESULTS AND CONCLUSIONS

1. For the first time, the conditions for the complete absorption of electromagnetic radiation when it is incident at an angle on a flat, illuminated absorbing substrate are determined. It was established that, in contrast to the incidence of the parallel-polarized wave on such a system, the complete absorption of the transverse-polarized wave is possible not only at the antireflection angle, but also at an angle analogous to the Brewster angle for transparent media. The conditions for the selection of the desired polarization component of the incident radiation are found.

2. The analysis of the reflection characteristics of an electromagnetic wave from a flat layer of an absorbing magnet applied on an ideal metal substrate is carried out for the first time.It allowed to establish the existence of normal and anomalous regions in these dependences, differing in the charcter of the change in their extreme values with increasing layer thickness, and also that their minima are located near the layer thickness values that are multiples of half the wavelength in the magnet. The conditions and frequency band of the total absorption of electromagnetic radiation in a flat magnetic-metal system are found. Their dependences on the selective values of the magnetic properties and the thickness of the magnetic layer are investigated.

3. For the first time, the conditions for the complete absorption of electromagnetic radiation when it is incident at an angle on a flat

two-layer magnetic-metal system are determined. The difference in the incidence of parallel-polarized and transverse-polarized waves on such a system is established, which allows to isolate with its help the desired polarization component of the incident radiation.

4. The analysis of the characteristics of the reflection of an electromagnetic wave from a plane layer of an absorbing magnet applied on a non-absorbing semi-infinite dielectric layer is carried out for the first time. It allowed us to state the existence of normal and anomalous regions in these dependences, differing in the character of the change in their extremal values with increasing layer thickness, and also that their minima are located near the layer thickness values that are multiples of half the wavelength in the magnet. The conditions and frequency band of the total absorption of electromagnetic radiation in a planar absorbing magnetic-dielectric system are found. Their dependences on the selective values of the dielectric constant of the substrate, magnetic properties, and the thickness of the magnetic coating layer are investigated.

5. For the first time, the conditions for the complete absorption of electromagnetic radiation when it is incident at an angle on a flat two-layer absorbing magnetic-dielectric system are determined. It was established that, in contrast to the incidence of the parallel-polarized wave on such a system, the complete absorption of the transverse-polarized wave is possible not only at the antireflection angle, but also at an angle analogous to the Brewster angle for transparent media. The conditions for the selection of the desired polarization component of the incident radiation are found.

6. For the first time, rigorous analytical equations have been developed that describe the conditions for the complete passing of electromagnetic radiation through systems containing periodically alternating layers of absorbing dielectric and magnetic materials and a non-absorbing dielectric layer. The optimal number of double layers (bilayers) was found, which provides almost complete damping of the radiation passing through such a system.

7. For the first time, the dependences of the wave reflection coefficient on the layer thickness of a liquid absorbing dielectric and a magnet in free space and in a TE-type waveguide were studied.

The functional relationships between the position and magnitude of the extrema of these dependencies and the values of the dielectric and magnetic properties of the substance under study are determined. They allowed to develop on their basis exact analogous microwave methods for measuring the dielectric and magnetic properties of liquids and solutions with a loss tangent of $tg\delta<0.8$, including using the effect of complete absorption of electromagnetic radiation in a layer of a substance.

8. For the first time, informational software has been presented for a whole series of microwave methods developed for measuring the dielectric and magnetic parameters of substances. The software contains a set of computer programs that simplify finding the desired parameters of a substance in a wide range of changes in its loss tangent.

9. For the first time, systems of equations have been obtained that describe the conditions and frequency band of the total absorption of waves in a layer of an absorbing magnet applied on a metal and nonabsorbing dielectric substrate and the conditions for the complete absorbing of waves when they are incident at an angle onto an translucened absorbing substrate and absorbing layers of a dielectric and a magnet applied on metal and nonabsorbing dielectric substrates.

10. For the first time, the calculated equations for the conditions and the translucence band of both absorbing and non-absorbing substrates were obtained, and their behavior was analyzed depending on the thickness and properties of the coating and substrate.

11. For the first time, systems of equations have been obtained that determine the optical parameters of the substances of the layered system and the thickness of the layers of antireflection coatings under which the conditions for the complete absorption of a wave of a given frequency are satisfied.

12. For the first time, a number of microwave methods have been developed for measuring the dielectric and magnetic properties of liquid and solid substances.

13. For the first time, a method for controlling the linear velocity of a weakly reflecting body was developed and an estimate was made

of the modulation frequency when probing a flying weakly reflecting body with location signals of known frequency.

14. A technique for determining the dipole moment of molecules of low polar liquids has been developed.

15. It is presented an express method of determining small (0.01-1% by weight) content of polar substance in a non-polar solvent, for example, water in petroleum products.

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