NEAR-FIELD EFFECTS IN THERMAL RADIO EMISSION[1]

Gaikovich K.P., Reznik A.N., Vaks V.L.

Institute for Physics of Microstructures RAS, GSP-105, Nizhny Novgorod, Russia, 603600

Phone: 8312 327920, Fax: 8312 675553, E-mail: gai@ipm.sci-nnov.ru

ABSTRACT

Our research is related with a new idea in the area of subsurface radiometry. This idea is based on a specific character of the quasi-stationary part of a thermal emission field (evanescent modes at interface). It is formed in media in another way in compare with the wave (propagating) component. At first, the problem of the detection of the quasi-stationary field near the media surface has been formulated by S.M.Rytov (see, for example [1]), where it was shown that the energy density of this component enhances drastically with the decreasing of the distance above the surface whereas the energy density of the wave component is unchanged in the whole space. But till the present time this problem remained experimentally unsolved. The difficulty of these measurements is related to the strong influence of the media on antenna parameters, because the quasi-stationary field could be measured only at a small distance above the surface and only using electrically-small antennas (much less than wavelength in a medium) [2]. The theoretical analysis [2] shows that the effective depth of the formation of quasi-stationary component depends on the height of antenna above the surface of a medium and on the antenna size. At the surface this skin-depth could be very small (for small antennas); it increases with the antenna height, and at the height comparable to wavelength in the medium it converges to skin-depth for the wave component of thermal emission. So, it is possible to discover the influence of the quasi-stationary field by measurements of the temperature-stratified medium using for the calibration the same medium at two different constant temperatures. Two near-field effects could be detected: (i) the effective radiobrightness dependence on the height of the small antenna and (ii) radiobrightness dependence on the aperture size at small distance above the surface. These effects lead to new one-wavelength methods of non-invasive temperature sounding of absorbing media, such as water and living tissue [3].

THE INTEGRAL EQUATION AND EFFECTIVE RADIOBRIGHTNESS

The well-known solution of the emission transfer equation for radiobrightness is inapplicable for the case of quasi-stationary field measurements. The solution of this problem of electrodynamics has been obtained in [2] on the base of wave approach, and the expression for the effective radiobrightness temperature at given wavelength λ could be written in compact form as:

$$T_b(h,D) = \int_{-\infty}^{0} T(z)K(h,D,z)dz, \quad (1)$$

where h is the height of antenna above the surface of the half-space, D is the effective antenna diameter. It is possible to represent the kernel K of (2) as a sum of quasi-stationary field and wave field parts. The quasi-stationary component dominates, if $D << \lambda$ and $h << \lambda$. In this case the depth of layer which gives the main contribution in the value of measured

[1] This work is supported by Russian Science Ministry State contract *No*.107-3(00-P).

thermal emission in (2) (the effective depth of radiobrightness formation) $d_{eff} = \left| \int_{-\infty}^{0} zK(h,D,Z)dz \right|$ is much less than the absorption skin-depth d_{sk} = 1/γ (γ is the absorption coefficient). The wave field component dominates if $D \geq \lambda$ and $h \geq \lambda$, and $d_{eff} \rightarrow d_{sk}$. In any case because of near-field effect d_{eff} should be less than d_{sk}. Integral equation (1) has been applied in [3] for near-field effect calculations and for the statement and numerical simulation of the inverse problems of the temperature profile retrieval from the known dependence $T_b(D)$ or $T_b(h)$. It is used below for the comparison with the experimental results.

MEASUREMENTS. NEAR-FIELD EFFECTS

The measurements have been carried out using the high-sensitivity (0.05 K) radiometer at the frequency 950 MHz with the spectral band 200 MHz. On the first stage of measurements we use the temperature-stratified water as a media with well-known dielectric parameters. A special device has been worked out to create a stationary linear temperature profile in the water with the large gradient $dT/dz \cong 2.5$ K/cm and to manage the precise height h of the antenna above the water surface. The main technical problem was to work out the electrically-small antenna with high enough efficiency. The first examples of the stripline planar dipole antennas with the effective size about 1 cm has been developed [4] and applied in experiments. These copper antennas include the resonant circuit to achieve the antenna-water matching. In [4] the reflection coefficient R, efficiency η and sensitivity dT_b of the developed dipole antennas has been investigated. These parameters appeared practically independent on the temperature and the salinity of water in radiometer frequency band. The achieved antenna parameters permit to solve the main problem – to detect both the above mentioned effects at large temperature gradients in the temperature-stratified water.

Measurements have been carried out for the temperature-stratified water at three different values of salinity: S = 0, $1.8 \cdot 10^{-3}$ and $5.0 \cdot 10^{-3}$g/cm^3. At the water salinity S = 1.8 g/litre the skin-depth at the given frequency is temperature independent and the medium can be considered as a homogeneous dielectric. The results for the firs two values of salinity are shown in Fig.1,2. The measured temperature profile in the water is given in Fig.3. At S = 0 the temperature $T(z = -d)$ at the skin-depth was used to calculate the dielectric parameters.

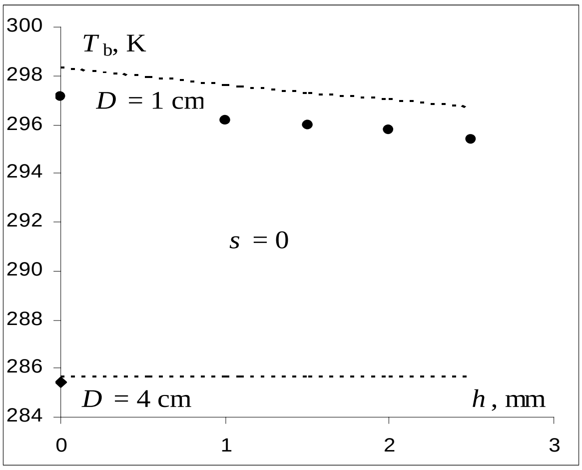

Fig.1. Measured dependence of radiobrightness on the antenna height at antenna sizes D = 1cm and D = 4 cm for the distilled (deionized) water (S=0). Circles-measurements, dashed line – calculation.

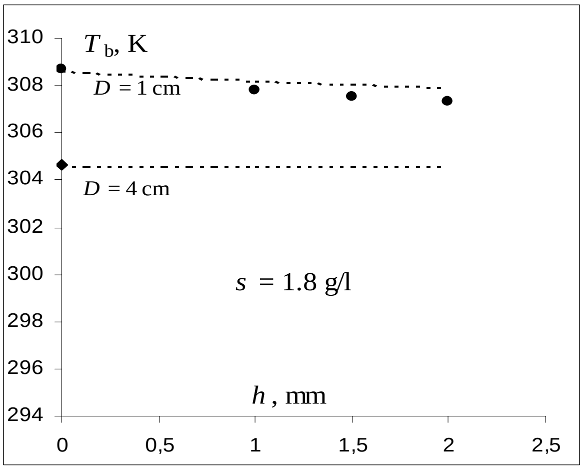

Fig.2. The same as in Fig.1, but at water salinity $S = 1.8 \cdot 10^{-3}$.

One can see in Fig.1,2 that the measurements and the results of calculation of T_b from the integral (1) are in very good correspondence. So, the dependencies of radiobrightness on the antenna height and size are successfully detected. More strong effects have been observed in distilled water, but in this case the dielectric parameters are temperature-dependent and it is difficult to get the high accuracy.

The calculated and the measured dependence of the effective depth d_{eff} of radiobrightness formation on water salinity at contact measurements (h = 0) along with the same dependence for the absorption skin-depth d_{sk} is presented in Fig.4. The well-detected difference between d_{eff} and d_{sk} is a demonstration of the near-field effect.

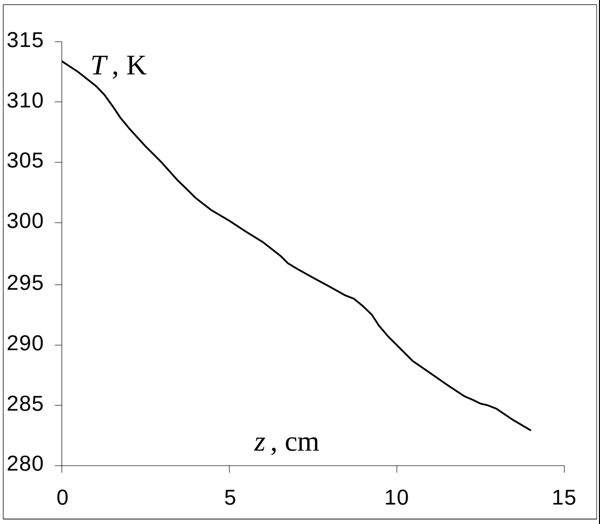

Fig.3. Temperature profile in water.

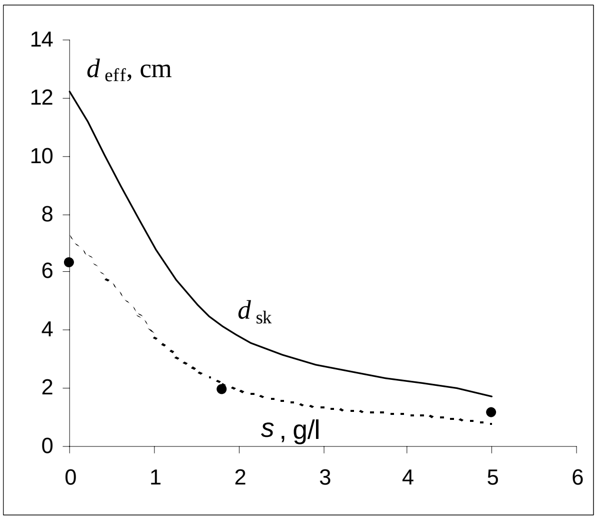

Fig.4. Measured (circles) and calculated (dashed) dependence of the effective depth of radiobrightness formation on water salinity. Solid line – calculated dependence of the absorption skin-depth.

METHODS OF SUBSURFACE RADIOTHERMOMETRY

It is possible to use the dependencies $T_b(h)$ and $T_b(D)$ for the retrieval of the temperature profile $T(z)$ from the solution of the integral equation (1). This possibility has been theoretically studied in [3] on the base of numerical modeling of retrieval from the solution of ill-posed Fredholm integral equation of the 1-st kind (1) using Tichonoff method. The first examples of the temperature retrieval by $T_b(D)$ are obtained. To use the height dependence $T_b(h)$ for temperature diagnostic it is necessary to work out the tunable antenna for matching at arbitrary height level h (in our measurements the antenna was matched for h = 0 only).

REFERENCES

1. Rytov S.M. Introduction in the statistical radiophysics. Moscow, Nauka, 1966 (in Russian).
2. Reznik A.N. Quasi-stationary field of thermal radiation in the theory of contact radiothermometry. Radiophysics and Quantum Electronics, 1991, v.34, No.5, pp.429-435.
3. Gaikovich K.P., Reznik A.N. Near-field subsurface radiothermometry. 8th International Crimean Conference "Microwave & Telecommunication Technology" CriMiCo-98 (14-17 Sept. 1998, Sevastopol State Technical University, Crimea, Ukraine), Sevastopol: Weber Co., 1998, v.2, pp.629-630.
4. Yurasova N.V., Gaikovich K.P., Reznik A.N., Vaks V.L. Antennas for Near-Field Radiothermometry. The present issue.