ANTENNAS FOR NEAR-FIELD RADIOTHERMOMETRY[1]

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ABSTRACT

The application of electrically-small antennas in the area of subsurface radiometry make possible measurements of the quasi-stationary field of a thermal emission (evanescent modes at interface) [1]. New one-wavelength methods of non-invasive temperature sounding of absorbing media, such as water and living tissue can be developed using such measurements. The quasi-stationary field component is formed in media in another way in compare with the ordinary used wave (propagating) component. Our theoretical analysis 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.

THEORETICAL ANALYSIS

The main technical problem of these measurements is to achieve a good matching and high efficiency of electrically-small antenna in the near-field region above absorbing media taking into account the strong influence of the media on antenna parameters. The measured antenna temperature T_a can expressed for contact measurements as

$$T_a = (1-R)[\eta T_{eff} + (1-\eta)T(0)] + RT_{ns} \tag{1}$$

where R is the reflectivity from antenna, h is efficiency, T_{ns} is the temperature of radiometer noise at the antenna, $T(0)$ is the temperature of antenna at the medium surface. The good matching minimizes the reflectivity R. At $R \to 0$ and $\eta \to 1$ one has T_a=T_{eff}. The efficiency of electrically-small dipole antennas falls proportionally to the factor $(l/\lambda)^4$. Our analysis shows that the antenna efficiency is much higher in vicinity of a lossy medium in comparison with the antenna in free-space. The efficiency depends also on antenna material. In Fig.1-2 the results of theoretical analysis are shown for achievable efficiency of the simple dipole antennas with the matching resonant circuit (made using the ordinary copper (Cu) at two different temperatures and using high-T_c superconductor film (YBaCuO)) as a function of the size and the height above the medium surface. It is possible to see that the minimum achievable size of antenna at wavelength λ = 30 cm could be about 1 mm. Also it is difficult to obtain the high enough efficiency without the superconductor technology at the antenna heights above 1 cm. But it is clear that just now it is possible to have a good efficiency at contact measurements using the ordinary copper antennas in the wide region of antenna sizes. It is also achievable to enhance the efficiency by means of the more sophisticated antenna design. The results of our first attempts to build such antennas form the main contents of this paper.

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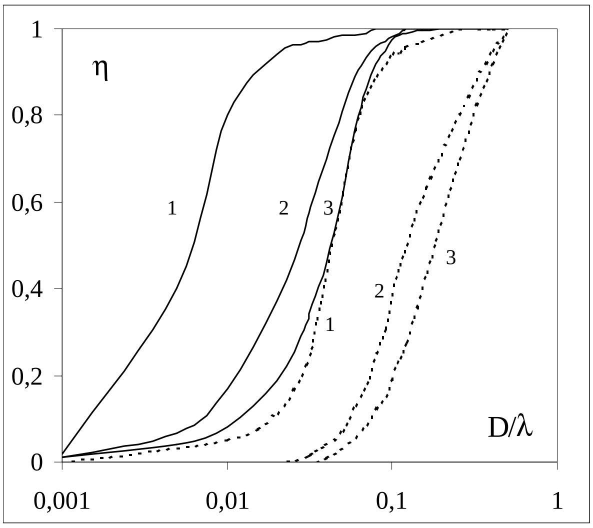

Fig.1. Calculated antenna efficiency as a function of the size-wavelength relation: 1 –superconductor, 2 – copper at 77 K, 3 – copper at 290 K. Solid lines – contact measurements (h=0), dashed – free-space.

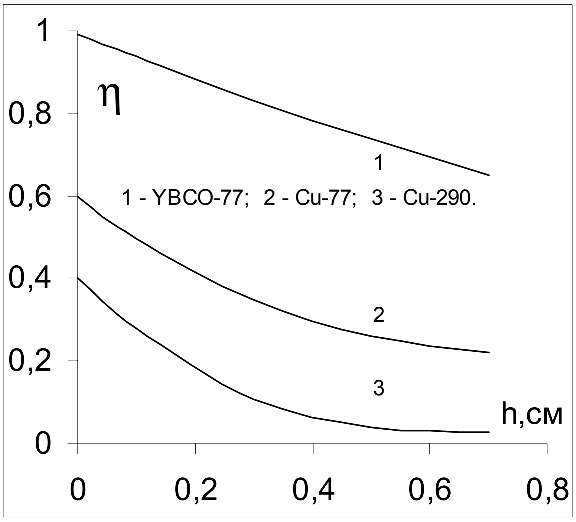

Fig.2. Calculated efficiensy of 1-cm dipole antenna as a function of the antenna height at λ = 30 cm.

ANTENNA DESIGN AND TESTING

We have developed antennas with high enough efficiency. These copper antennas include two stripline planar dipoles and the resonant circuit to achieve the antenna-medium matching. The antenna schema is shown in Fig.3. Effective sizes of antennas are about 1 cm, the operating frequency is 950±100 MHz (frequency band of the radiometer). The reflection coefficient, efficiency, and sensitivity of antennas have been studied in dependence on the frequency and the dielectric parameters of the measured medium (see in Fig.4,5). The water was chosen as a medium the dielectric parameters of which have the strong dependence on the temperature and the salinity. So, the temperature and salinity dependence of antenna parameters was investigated. Antenna in the contact with the living tissue also has been investigated. In Fig.6,7 one can see the reflection coefficient R, efficiency η and sensitivity dT_b of radiometer (all the parameters averaged over the radiometer band). These parameters are practically independent on the temperature and the salinity of water.

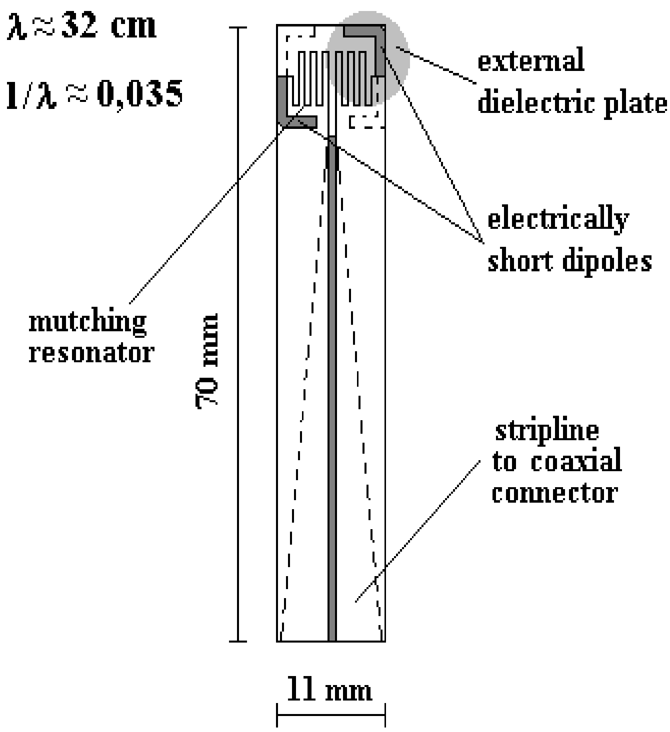

Fig.3. Near-field antenna design.

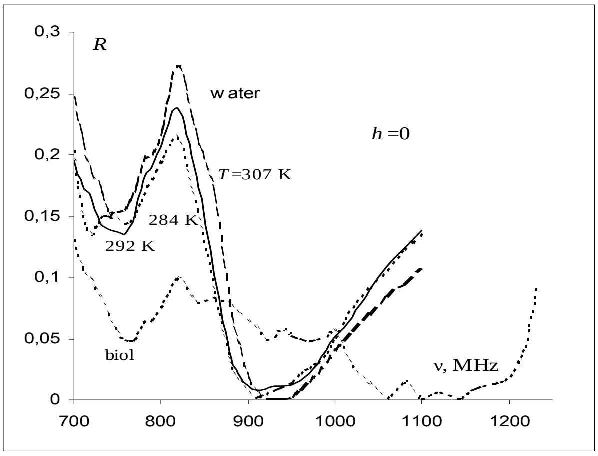

Fig.4. Frequency dependence of the antenna reflectivity at three different temperatures for water medium and for living tissue at 37 C.

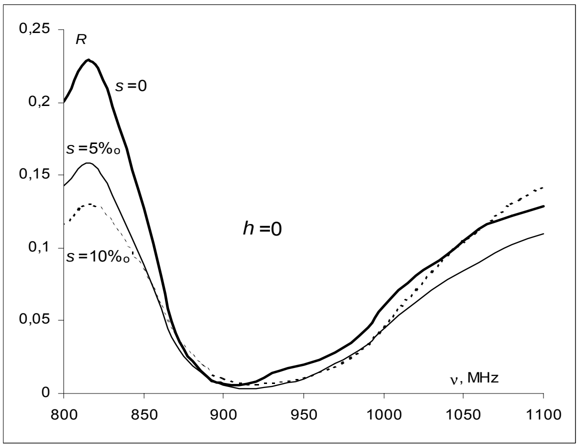

Fig.5. Salinity dependence of the antenna reflectivity at three different values of water salinity.

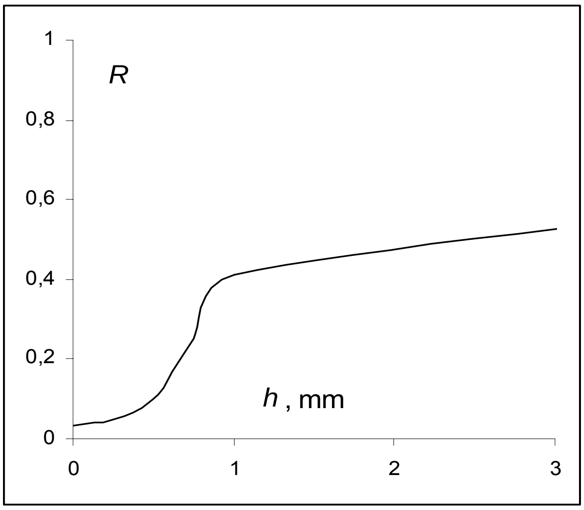

Fig.6. The height dependence of antenna reflectivity in the radiometer frequency band.

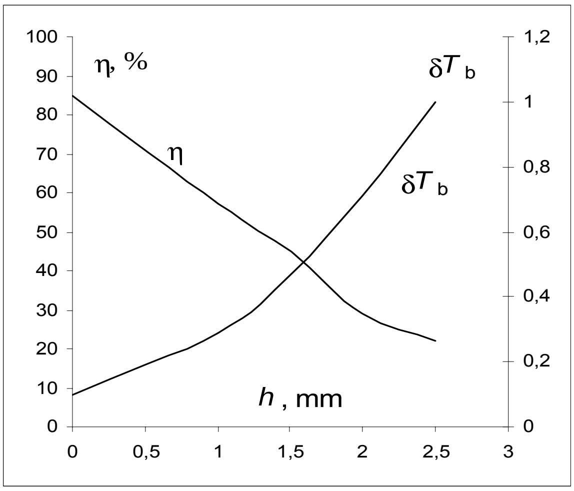

Fig.7. The height dependence of antenna efficiency and radiometer sensitivity in the radiometer band.

All the parameters are very suitable for contact measurements at h = 0 (on the water surface) but they fall drastically with the increasing of the antenna height up to 1 mm. Of course, it is possible to improve these parameters on the base of antennas with a tunable resonant circuit to match they at each height independently. For the further matching improvement in future the possibilities of antennas based on high-temperature superconductor technology [2] should be used. But the achieved antenna parameters permit to solve the main problem – to detect near-field effects at large temperature gradients in the temperature-stratified water.

Also, it is important to mention that the reflectivity has strong enough dependence on the dielectric parameters outside the radiometer frequency band (see in Fig.4, 5), so it is possible to use this dependence for media parameters diagnostics.

REFERENCES

1. Gaikovich K.P., Reznik A.N., Vaks V.L. Near-Field Effects in Thermal Radio Emission (present issue).
2. Abramov V.I., Klimov A.Y., Reznik A.N., Tagunov B.B. Electrically small strip antenna of a high-temperature superconductor. Tech. Phys. Lett., 1994, 20(10), 792-794.