Radiometric detection of mines

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Abstract - The problem of mines detection, especially of anti-personal ones, is considered as one of the main problems of modern applied physics. Radiometric methods based on the measurements of thermal radio emission seem as possible to solve this problem.

I. Introduction

Radiometric methods are widely applied for remote sensing of soils (see, for example, [1]). The thermal radio emission is described by Plank low. In the microwave range the intensity of thermal radio emission of underground soils could be expressed in terms of radiobrightness (T_b). The radiobrightness of homogeneous soil with buried mine can be written (neglecting of scattering of radiowave emission) in three-layer approximation [2] for the case when the foot-print of antenna beam is less then mine diameter:

$$T_b = (1 - R)T_0 + RT_{back} \tag{1}$$

where (T_0) is medium temperature, R is reflection coefficient, T_{back} is radiobrightness of atmosphere. The radiobrightness contrast related with the buried mine is determined in above approximation as :

$$\Delta T_b = (R_2 - R_1)(T_0 - T_{back}) \tag{2}$$

where R_1 is reflection coefficient of homogeneous half-space without mine and R_2 is one for three-layer medium with mine presence. The value of radiobrightness contrast depends on mine depth, size, and its permittivity. It is more easy to detect large, metal, and shallow buried (few millimeters) tank mines. The corresponding estimations show that in this case the value of radiobrightness contrast could be measured at state-of-art radiometry technique, and this contrast should be greater than natural radiobrightness variations related with heterogeneity of medium permittivity.

For small plastic antipersonal mines with the permittivity, which is close to soil permittivity, the value of radiobrightness contrast could be comparable with natural variations. To detect such mines a new method is proposed based on increase of radiobrightness contrast by means of the emission of noise signal using the same antenna. In this case the received radiobrightness could be written approximately as :

$$T_b = (1 - R)T_0 + R(T_{back} + T_{ns}) \tag{3}$$

where T_{ns} is noise emission temperature at the surface level. The value of T_0 is typically about 300 K. So, it is possible to estimate the value of radiobrightness contrast :

$$\Delta T_b = (R_2 - R_1)(T_0 - T_{back} - T_{ns}) \tag{4}$$

It is clear from (4) that by means of noise emission it is possible to increase considerably the value of measured radiobrightness contrast. It permits to use also measurements at frequencies in strong atmosphere absorption lines (or indoors) where $T_{back} \cong T_0$, and where the value of radiobrightness contrast without noise emission is close to zero ($\Delta T_b \cong (R_2 - R_{1`})T_{ns}$).

II. Detection Methods

It is possible to estimate the radiobrightness contrast for some cases. For very shallow buried metal mines $R \geq 0.9$ and for soils the value of R is typically about 0.2. So, in this case it is easy to obtain from (2) that the value of ΔT_b could be about 200 K even without noise emission. Taking into account that it is possible to detect the radiobrightness variations of about 0.1 K, it is clear that shallow buried tank mines could be easy detected.

The case of antipersonal mines is more complicated. The radiobrightness contrast diminishes up to 10 - 30 K for shallow buried mines.

Along with increasing of mine depth the value of radiobrightness contrast also diminishes because of emission absorption in the soil. The skin-depth $l_s = 1/\gamma$ (γ is the absorption coefficient) determines the scale of thermal emission penetration in the ground. It is known that for the dry soils $l_s \cong 3.25\lambda$, where λ is emission wavelength. With the increasing of soil humidity the value of skin-depth l_s strong reduces. This parameter determines the exponential reducing of radiobrightness contrast of mine depth d. Moreover, because of antenna pattern effect due to limited horizontal mine size it should reduce much more rapidly. At $d > (2 \div 7)l_s$ the radiobrightness contrast diminishes up to natural variations value, and the problem of mines detecting becomes insoluble. Because of this reason it is necessary to enlarge the wavelength but it leads to enhancement of beam footprint and, hence, to poor measurements resolution. If the size of the footprint is less than the size of mine, it leads also to reducing of the radiobrightness contrast. So, it is clear that there is some optimum wavelength.

The effective noise emission temperature could be changed from zero up to some thousand K. It has a wide spectrum, and its power is some orders less than the power of any radar. It is easy to estimate the radiobrightness contrast from (4), and, obviously, this contrast could be made large enough to be measured even at very small difference in reflection coefficients ($\Delta R \leq 0.01$).

III. Experimental results

Taking into account that above quality consideration is given neglecting of the effect of radio wave scattering and antenna pattern effects, it is clear that it was necessary to carry out the experimental research.

The measurements have been performed indoors using the radiometer at wavelength 5 mm (in the strong absorption band of atmospheric oxygen) with the noise emission (T_{ns} = 50 K). The sensitivity of this radiometer is better than 0.03 K. It has been applied before for radiometric remote sensing of water temperature profile dynamics related with air turbulence. The size of beam footprint on the ground was about 10 cm. The mines were buried in loamy soil (the total depth of the soil layer was 1 m).

In Fig.1 the value of radiobrightness contrast measured in nadir direction along the line, passing through the anti-tank mine center, is presented. The mine with the diameter D = 30 cm was located at the depth h = 10 cm. The mine center position corresponds to the distance 100 cm in Fig.1.

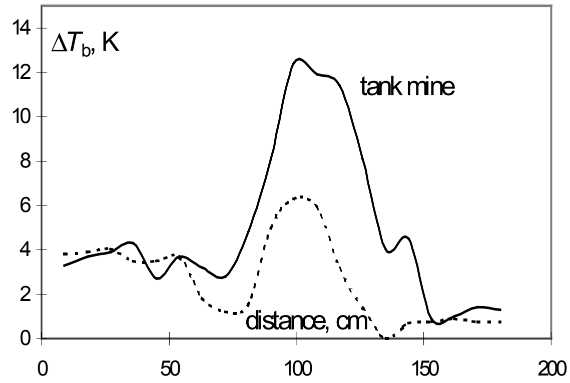

Fig.1. Detection of tank mine (solid line) and measurements of soil after mine extraction (dashed)

It is possible to see that the radiometer is able to determine the presence, the position, and (roughly) the size of the mine. The radiobrightness contrast, remaining after the extraction of the mine, is related with radiowave scattering on volume heterogeneities of disturbed soil (the soil surface was smoothed after the mine extraction).

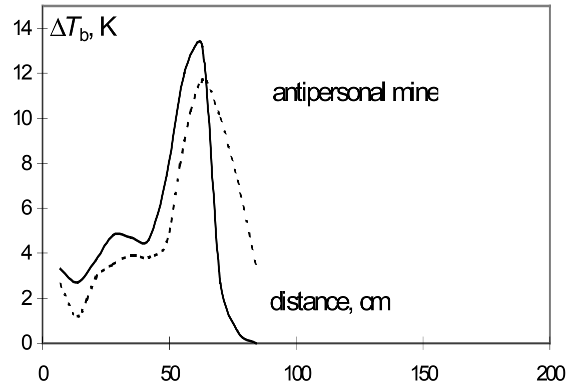

Fig.2. Detection of simulated antipersonal mine. Dashed line - after extraction of the mine

The second measurements, results of which are shown in Fig.2, has been carried out using the soap simulation of antipersonal mine with sizes 10 - 6 - 4 cm (the dielectric parameters of the soap are similar with ones for plastic explosive).

It is clear that in this case the presence and the position of the mine are well detected. Also the estimation of the mine size permits to distinguish tank and antipersonal mines. But in the case of antipersonal mine the difference between radiobrightness contrasts before and after the mine extraction is diminished. So, it is possible that in this case the main effect is related with the volume soil heterogeneities, appearing by mine burying and extraction. It is interesting to work out the methods to bury mines without soil disturbing to make possible measurements of mine radiobrightness contrast itself.

V. Conclusion

The experimental results permits to hope that radiometric methods could be applicable for the solution of the problem of mine detection, especially anti-personal plastic mines, because it is impossible to detect these mines using ordinary mine-detectors.

VI. References

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