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PASSIVE-ACTIVE MM WAVE RADIOMETER FOR DETECTION OF MINES INSTALLED ON THE GROUND SURFACE

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Abstract

In this paper is considering a new method of anti-tank mines reconnaissance, which are installed on the ground surface, with use of the passive-active mm wave radiometer. An experimental mock-up consisting from radiometer and noise illumination generator was created. The experimental mock-up is scanning in two dimensions. It gets passive images and active images when noise illumination generator is switch on. An algorithm of joint processing images was proposed. The mine detector of this kind can be used in peacekeeping and humanitarian operations.

Introduction

It is well known that in the course of large-scale military operations anti-tank mines are usually installed on the ground surface, which is related to high efficiency of the given method of installation. Besides that, the remote-acting mine installation facilities (aviation, artillery, salvo missile systems, etc.), having the highest capacity, install mines on the ground surface alone.

The usage of passive millimeter-wave radiometric sensor is one of the possible means for detection of mines with metallic cases installed by random throwing on the ground surface [1]. The radiometric sensor registers the own and reflected radiation of mines in the HF range.

Radiometry is in many respects similar to radiolocation. Just as classic radiolocation, radiometry is intended for determination of coordinates of remote objects. The basic distinction between the methods lies in that radiolocation uses the radiation generated by radar proper in the capacity of the radiation source illuminating the target. The detection of objects by the radiometer uses the natural radiation of the objects themselves and the sky as the illumination source. In this respect radiometry is similar to operation of the passive infrared detectors but employs radio frequency in the capacity of the working range of the wavelengths.

Theory Component

It is widely known that the thermal radiation of bodies is super broad band. At temperatures close to 300°K the maximum of the radiation falls on the infrared part of the electromagnetic radiation spectrum. Thanks to this, infrared sensors are widely adopted for the detection of objects under the natural conditions in the nighttime. But with the drop of temperature the radiation maximum moves to the long-wave part of the spectrum. Thus, at the temperature of 1°K the radiation maximum is found in the millimetric range.

In quantum mechanics the dependence of the radiation density on its frequency and temperature is given by Planck radiation formula:

$$R_0 = \frac{2\pi f^3 h}{c^2 \cdot \left\{ \exp\left(\frac{hf}{kT}\right) - 1 \right\}} \quad , \qquad (1)$$

where	$\boldsymbol{h} = 6.62\cdot10^{-34}$ [j·s]	is Planck constant,
	$\boldsymbol{c} = 3\cdot10^{5}$ [km/s]	is the velocity of electromagnetic waves in vacuum;
	$\boldsymbol{k} = 1.38\cdot10^{-23}$ [j·deg]	is Boltzmann constant;
	$\boldsymbol{T}$ [°K]	is the absolute temperature of the radiating body;
	$\boldsymbol{f}$ [Hz]	is frequency;
	$\boldsymbol{R_o}$	is the spectral density of radiation equal to power radiated on frequency $\boldsymbol{f}$ in the band of 1.0 Hz by 1.0 sq.m of the radiator.

The frequency $\boldsymbol{f_m}$ on which the spectral density of radiation has the maximum is determined by Wien formula:

$$f_m = 1{,}03 \cdot 10^5 \cdot T \quad . \qquad (2)$$

It follows from the relations (1) and (2) that the spectral density corresponding to $\boldsymbol{T}\approx300$°K has the maximum in the infrared sector and its value in the range of centimetric and millimetric waves is less by a factor of several thousand. Despite the relatively low power of thermal radiation in the HF range, the sensitivity of the up-to-date radiometer's sensors is such that the given radiation can be detected at great distances. The weak attenuation of radio waves in the atmosphere as compared with that of infrared radiation also enhances this. Another asset of the radiometric sensors lies in the possibility of natural selection of metal objects against the background of the underlying surface.

Let's mention that the formula (1) presents the spectral density of radiation $\boldsymbol{R_o}$ for the so-called absolutely black body, that is the perfect radiator. For real bodies it will be necessary to make a correction for the emissivity factor in this case. In the given case

$$R = \alpha \cdot R_0 \quad , \tag{3}$$

where **R** is the spectral density of radiation of the real radiator;

$\alpha < 1$ is the absorption factor depending on the frequency.

It should be also noted that in the range of the temperatures characteristic of the natural state of the ground surface there would be no necessity to use the sufficiently complex Planck radiation formula for computations in the HF range. Taking into account that the given temperature range is ***hf/kT***<<1 and that the exponential term is expanded into a series, the equation (1) is transformed into the form of

$$R_0 = \frac{2\pi}{\lambda^2} \cdot kT \quad , \tag{4}$$

where λ is the wavelength of radiation.

Under the real conditions the radiation flux received by the sensor from the examined body will include the component related to the re-reflection of the outer radiation in addition to the object own radiation. The sky, the radio brightness temperature of which is much lower than the temperature of the ground cover and depends to a considerable degree on the state of cloud coverage, can be used as the source of outer radiation [2]. Besides, the illumination can be implemented with the aid of a man-made source. A noise signal generator emitting in the band of the reception of radiometer can be such a source. Given that man-made sources of illumination are available, the summary spectral density of own and reflected radiation can be recorded in the form of

$$R_\Sigma = \frac{2\pi}{\lambda^2} \cdot k \cdot \left(\alpha T + \rho_s T_s + \rho_i T_i\right) \quad , \tag{5}$$

where **ρ_s** is the factor of reflection of the sky radiation by a body;

T_s is the radio brightness temperature of the illuminating sky radiation;

ρ_i is the factor of reflection of the illumination radiation by a body;

T_i is the radio brightness temperature of the illuminating radiation.

A diagram of reception of the radiometric signals of various origins radiated and reflected by the body is presented in Fig. 1.

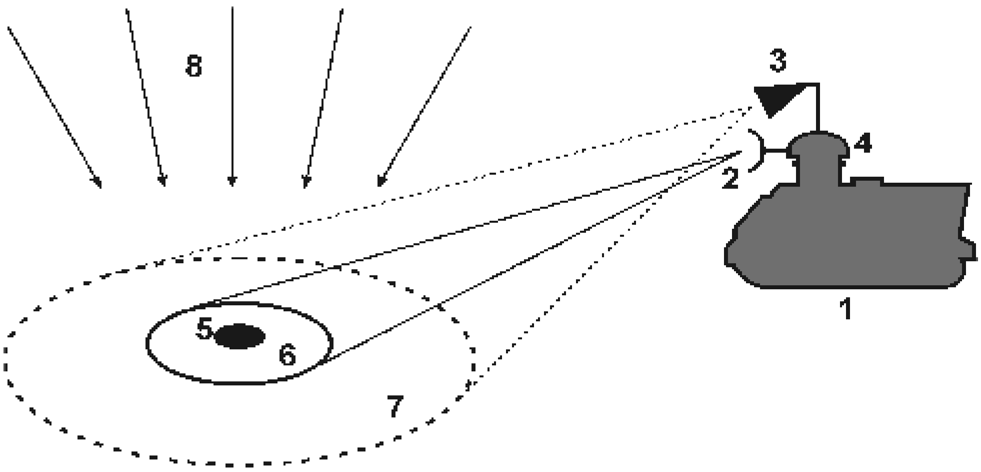

Fig. 1. Diagram of reception of radiometric signals of various radiation sources from the land carrier

1 - equipment carrier;
2 - radiometer antenna;
3 - antenna of illumination noise generator;
4 - scanning device;
5 - observation object (mine) on ground surface;
6 - observation sector of main lobe of radiometer antenna on ground surface;
7 - sector of ground surface radiated by antenna of noise generator;
8 - sky radiation.

This figure also has a diagram of arrangement of the radiometric sensors on a land carrier that includes a noise illumination generator the radiation pattern of the main lobe of the antenna of which is wider than that of the radiometer antenna. The noise generator and the radiometer are uniaxially anchored on the scanning device to ensure the survey of a terrain sector in front of movement of the land carrier along an azimuth. A line-by-line scanning is provided thanks to movement of the carrier. Such a selection of the parameters and positioning of the devices assure the condition of uniform illumination by the noise generator of a section of the ground surface observed by the radiometer antenna.

In the general case the reflection factors of sky radiation ρ_s and illumination radiation ρ_i differ. This is related to the form of the reflecting body. Since the sky radiation is scattered and illuminates an object from the upper hemisphere more or less uniformly, the radiation reflected by the body will be omnidirectional. The illumination radiation is focused and directed away from the noise generator, and the object of the flat form may reflect it away from the receiving radiometer antenna. In this case ρ_i will be equal to zero.

Experimental Instalation

An experimental radiometer complex of the mm wave range was developed in mid' 80s to check the possibility of detection of mines with metal cases. The mockup of the radiometer mine detector is shown in Fig. 2.

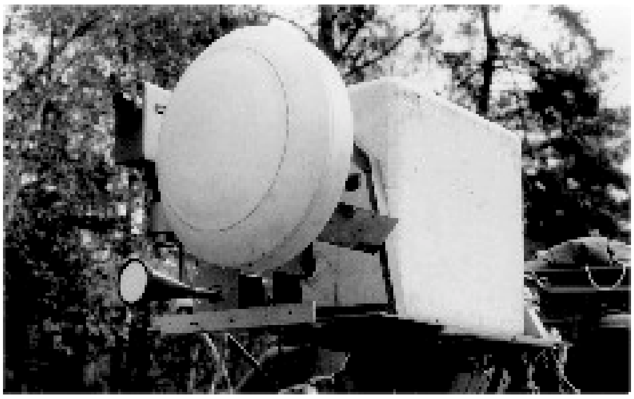

Fig. 2. General view of experimental installation

The selection of the wave range was related to the fact that high contrast of anti-tank mines installed on the ground surface can be provided in this range with an acceptable aperture of a radiometer antenna. The employment of a passive-active mm wave radiometer was proposed to improve the detection parameters. The complex included an 8-mm wave range radiometer, a noise generator of the same range and a TV camera. All these devices were coaxially secured at a mechanical appliance, which provides for scanning in two planes: according to the elevation angle and to the azimuth.

By doing so, the possibility of survey in a terrain sector from a fixed carrier was ensured. A main lobe of the radiometer antenna was 1.0 deg and of the noise generator antenna - about 10.0 deg. The relative positions of the generator and radiometer antennas were selected in such a way that a minimum level of the direct signal from the noise generator to the radiometer was achieved. The TV camera allowed an operator to compare images obtained in the HF and visual ranges.

It should be noted that the usage of the noise generator with the spectrum filling the entire reception band of the radiometer in the capacity of a terrain illumination source is a must. Otherwise the image obtained as a result of scanning is random in character and cannot be identified with the observed objects if a monochromatic generator is used. It is because of coherent summation of the signals reflected from the observation object and the direct transmission of the signal from the illumination noise generator to the radiometer's receiving antenna.

The operation of the equipment provides for simultaneous generation of two images: one in the passive mode when the noise generator was switched off and the other one in the active mode when the illuminator was switched on.

The picture of a proving ground is seen in Fig. 3. Nine Russian metallic anti-tank mines of TM-62M type were laid in three staggered rows on the ground surface in the foreground. The distances from the nearest and most distant mines to the radiometric complex were 10.0 and 22.0 m, respectively. The mines in the right row were installed on supports and inclined towards the radiometric complex to enhance contrast.

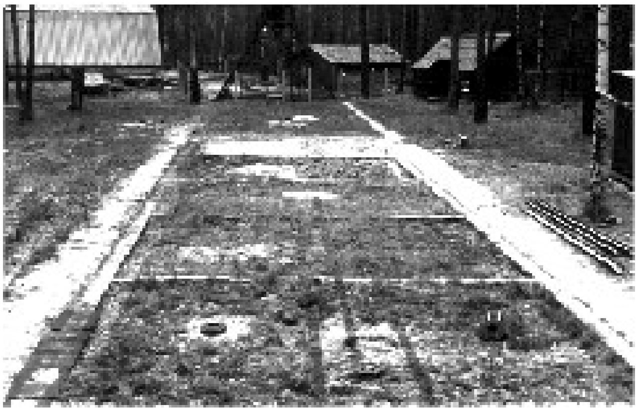

Fig. 3. General view of proving ground with mines

The row of metallic plates can be seen in the left bottom corner of the picture. At the background of the picture a metal tower (in the center) and a flat metal roof (in the left corner) are visible.

Experimental Results

The results of survey of the terrain in the passive mode and in the mode with illumination are illustrated in Figs. 4 and 5, respectively. Gradations of brightness in these figures are chosen so that darker sections of image correspond to objects with lower radiometric temperature. Since metal objects have the reflection factor equal to 1 in the HF range, they look darker on the radiometric image, reflecting the sky radiation the radio brightness temperature, which is lower than the temperature of the ground cover.

Fig. 4 clearly demonstrates the mine nearest to the radiometer and the mines of the right row the contrast of which is higher. The row of metallic plates is seen to the left of the minefield, and the metal roof of a building and the outline of a tower are clearly visible in the background. The produced image shows that the contrast of mines laid in parallel to the ground surface is sufficient for their detection at a distance up to 15.0 m only with the specified parameters of the radiometric sensor in the passive mode. At greater distances their contrast lies at the level of the natural variations of radio brightness temperature of the underlying surface.

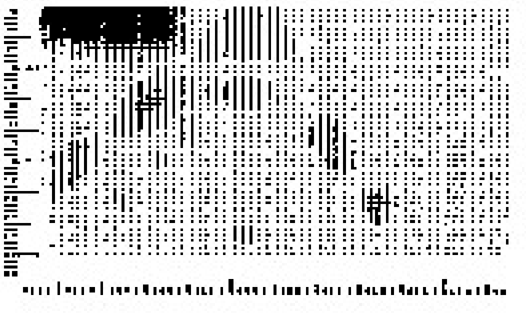

Fig. 4. Passive radiometric image of proving ground

When the noise generator is switched on, the image changes qualitatively. The contrast of metal objects with respect to the background depends not only on the type of the surface but also on the shape of objects observed. Thus, flat objects, which reflect the radiation of the noise generator with a high brightness temperature like a mirror, can be viewed in the image as objects having low brightness temperature. It can be explained by the fact that the sky radiation alone is reflected in the direction of the radiometer antenna. The metal roof of the building and the metal reference mark are such objects in the image.

The objects of complex shapes, being sets of "brilliant points", reflect the illuminator radiation in the direction of the radiometer antenna as well. Such objects change the contrast relative to the background when the noise generator is switched on. The active radiometric image of the same proving ground can be seen in Fig. 5.

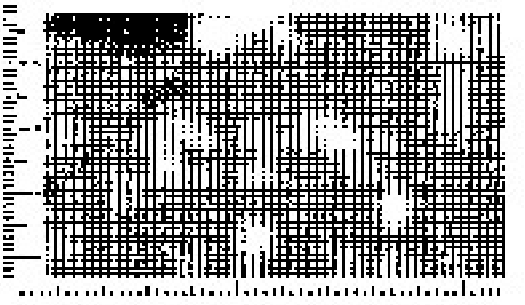

Fig. 5. Active radiometric image of proving ground with noise generator being switched on

Mines and the tower change their contrast but the row of plates and the flat roof keep contrast in this picture. We can see various reflections from local objects on the ground.

For the selection of complex-shaped objects like mines an algorithm was proposed which operates in accordance with a scheme of coincidences and separates only those objects in the images which change their contrast relative to the background when the illuminator is switched on. Fig. 6 demonstrates effectiveness of the proposed algorithm.

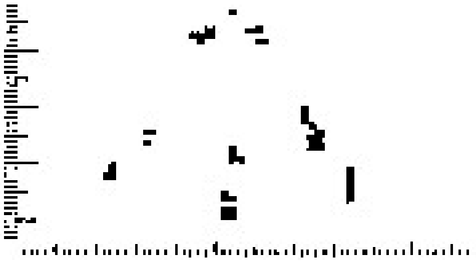

Fig. 6. Results of co-processing scenes in Figs. 4 and 5

In this picture we can see only six mines and the tower. All the other objects have vanished from the image. This algorithm is more effective for mine detection and differs from one proposed in [3].

Conclusion

It is necessary to note that the proposed method of detection of metal objects against the background of the underlying surface can also be used for other types of the military equipment, such as tanks, artillery guns, etc. For this purpose the illuminator should operate as a stroboscope. Thus, when the noise generator is switched off and the radiometer antennas are in fixed positions, an element of the passive radiometric image will be registered, but when the mentioned generator is switched on, an element of the active radiometric image will be recorded. With proper selection of the switching frequency of the noise generator, a complete matching of both images can be obtained in the course of their subsequent processing.

Acknowledgment

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