Electromagnetic Radiation of Terahertz Band

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Abstract. Paper is devoted to study of possibilities of methods and means based on application of terahertz radiation with respect to solution of problems of search and detection of prohibited objects in optically nontransparent media.

Interest displayed to terahertz band is explained by new opportunities in solution of multiple problems in electromagnetic spectrum areas, which were not used previously. Currently, terahertz band is understood to be the part of spectrum approximately from 0.1 to 10 THz.

During solution of the number of anti-terroristic problems, we have used active reflection method in the long-wavelength section of the terahertz band spectrum (λ ≈ 3 mm). For visualization of radio-images, multi-element receiving line based on the Schottky-barrier diodes was applied. In-crease of image contrast was achieved due to application of polarization method.

Experimental 3 mm band installation contains single transceiver module, scanning device and visualization means. Transceiver module has dielectric lens for radiation focusing at the distance of 250 mm in order to ensure resolution at various depth of object occurrence. Polarization of receiving element is selected to be orthogonal to incident radiation.

Scanning was performed with a pitch of 2.2 mm. Test object was located on the table of scanning device, while hidden embeddings were positioned at different angles in respect of orthogonal transceiver pair of module. Following amplification and digitization, valid signal was supplied at the input of personal computer.

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![THz band](image)

Recently there are many publications about the development of Thz band of electromagnetic radiation, about the possibilities of its wide application to solve a number of important tasks, and about specific practical developments. The interest in the specified Thz band is due to the fact that it was almost barely studied because of the lack of reliable and affordable means of generation and detection, on the other side it is promising in the
field of remote spectroscopy and non-invasive imaging of objects hidden from optical control.

In a literal sense the indication of the boundary of THz band is within the optical range of electromagnetic radiation spectrum, from 1 THz (wavelength is 0.3 mm) to 300 THz (wavelength is 1 μm), but in fact from 0.1 THz (3 mm) to 10 THz (30 μm). The second variant of indication the boundaries of THz band is used by those authors and companies which are involved in the specific applied research and development of THz devices [1,2]. Previously in Russia this THz band was classified as millimetric, submillimetric and optical (far IR-band), but in the foreign literature it is known as microwaves. The central part of the spectrum (submillimetric and far IR-band) does not have the reliable tunable sources and uncooled radiation detectors, especially in the form of matrix. That’s why their development is intensive [3,4].

Let’s spotlight the basic features of practical application of THz-band electromagnetic radiation.

There are reasons to consider that "terahertz" is perspective in the development of devices for remote detection of hidden packages of explosives, because their absorption and reflection spectrums, necessary for detection and identification of explosives, are located within this THz-band. Some researchers experimentally determined the individual frequency characteristics of the most common and dangerous explosives, and protecting materials (packaging and textile) are radiotransparent in some ways, so information signals can be effectively detected [2,5]. The lower frequencies are used, the less attenuation of the wrapping material and more consistent is the useful signals recept. Besides, it is proved that the water vapor absorption spectrums are displaced with respect to the absorption spectrums of explosives, it allows to detect and identify the explosives remotely, at least at the distance of 1-3 meters. So it is possible to make counterterrorism devices based on THz spectroscopy. It is also considered that the methods of THz spectroscopy allow to detect and identify narcotic and dangerous biological substances.

High attention is paid to the development and research of imaging methods for objects hidden from optical observations. There is a number of research works [5,6], devoted to this topic, they demonstrate the ability to get high-quality images of prohibited items hidden under clothes, in shoes, packaging, etc. (metal and ceramic weapons, explosives and drugs). Visualization of images, based on the reception and processing of the backscattered radiation, is made by mechanical or electromechanical scanning of send-receive elements relative to the object of inspection. There are no commercial variants of matrix reception uncooled modules, but such works are already under way and will be completed with the development and on the basis of nanotechnologies.

One of the important directions is the traditional use of terahertz devices in non-destructive testing and technical diagnostics for defectoscopy and structuroscopy of thin-film materials and nanostructures made of metals, semiconductors, dielectrics, composites, etc. There are some interesting and useful practical developments and the new ones will follow [7, 8]. One of them is THz microscope.

There are some other possible applications of terahertz radiation, for example in medicine, but the success will entirely depend on the radiotransparency of environments in the chosen THz-band range. So, the main possible areas of the practical application are: remote spectroscopy, coherent tomography and nanoscopy, anti-terrorist equipment and security systems, diagnostic and criminalistic equipment, non-destructive testing.

It is paid special attention to the technical means of customs control. The relevance of non-invasive screening of fences, luggage, clothes and shoes of passengers also increased. There are four main directions in the development of control devices: usage of metal detectors, development of traditional X-ray methods, radiospectroscopy application and electromagnetic radiation usage, including THz band. The first three directions have some
known limitations, so we will focus on the application of THz-radiation. The development of these methods is in progress now, and some commercial projects have appeared mostly from the foreign companies: Tera View, API, Millivision, Riken, Thru Vision. The analysis of the results shows the ability to detect not only metal, but also the most difficult to identify non-metal hazardous parts in the interior components, clothing and footwear by visualization of electromagnetic radiation of THz band.

The example of such image, obtained by Tera View, is shown in Figure 2, it shows the hidden parts (razor blade, bag with explosives and ceramic plate) inside the shoe heel. THz image is on the bottom left picture and on the bottom right picture there is a visible image (heelpiece is removed). This result confirms the possibility of the problem solution, because textile and shoe materials (fabric, leather, rubber, plastic, etc.) are generally radiotransparent.

![Fig. 2 Hidden parts (razor blade, bag with explosives and ceramic plate) inside the shoe heel.](image)

The choice of particular operating frequencies is very important because it is connected with the quality of radio image and detection depth during one-sided access to the object of control. It is more reliable to use the range of 0.1 - 0.15 THz to ensure the desired depth of control, and the image quality can be improved through software. This range was used for experiments with THz-module (Figure 3a) and scanner for detection of metal and dielectric elements, covered with shoe materials. Figure 3b shows the radio image of hidden items: metal plate, ceramic strip, metal ring and rectangular frame made of hardened paper. Radio image shows the presence and shape of these items.

![Fig.3a — THz-module, b — Radio image of hidden items.](image)

The development of this method and its successful implementation is because of the antenna system development (at least in the form of matrix line) with fine-pitch location of receivers for high-quality images with the limited control time.
Figure 4 shows the THz image of ceramic knife through the sole and heel of the shoe. Linear antenna was designed as a single line of elementary receiving antennas - special diodes [4] and it scanned the controlled object.

The 6-channel THz-unit with a single THz-radiation source was developed on the basis of another polarization method. The polarization planes of emission and reception differ by 90° (Fig. 5a). When scanning the surface of the object by the module, analog and digital signals from all channels were recorded on the laptop screen (Fig. 5b). The presence and "traces" of the detected metal and dielectric lines (wires, cables, fiber optics, etc.) are shown.

Microwaves, including THz-band, are widely used for different control processes of dynamic character such as speed measurement of moving and rotating items, their displacement, change of position, vibration, etc., and recently bioradiolocation is in the process of development. The usage of electromagnetic radiation is based on the analysis of back-scattered radiation by amplitude, phase, frequency and polarization according to the classical electrodynamics principles.

One of the interesting and important trends is the usage of microwaves to control the combustion parameters, such as solid fuel. The combustion front behind the barrier is reflecting, and therefore, can be controlled by the speed and uniformity of its displacement.

The combustible fuel compositions have different absorption degrees in the microwave range of radiowaves, so the experiments were made in three range points including the frequency of 100 GHz (0.1 THz). Rather sensitive microwave circuit based on waveguide tourniquet connector was chosen, Figure 6. The transducer was placed on the outer edge of the fuel sample (from heat shielding side). The dynamic combustion process and, consequently, the changing of the distance from the combustion front to the outer edge of burning was continuously recorded, Figure 7, then the primary processing of results was made.
The distance between the extremums (maximum or minimum) is half the operating wavelength in the dielectric (fuel). Knowing the dielectric capacitiviy of the fuel and fixing time, it is relatively easy to determine the combustion speed, or the residual fuel thickness after forced stop of the process. The tests were made using the samples and real constructions. The experiments showed the irregularity of combustion process (using some technologies in preparation of mixtures) and, on the other side, the process can be controlled if there is control equipment.

One of the effective ways to obtain images in millimeter and submillimeter wavelengths in real time is the method based on the conversion of radiation of specified range to infrared radiation. Converter MM\text{→}IR [9] is a thin-film metastructure, resonantly absorbing MM-radiation of the given wavelength with the absorption coefficient close to 100\%, the thermal heating is further recorded by highly sensitive infrared camera. So, the spatial intensity distribution of the radiation incoming on the MM-converter, is shown in the intensity distribution of its thermal field (Fig. 8). The main feature of absorbing metastructure is its small thickness \(d\) as compared with the working length \(\lambda\) of millimeter radiation. It allows to provide low heat capacity and thus high sensitivity and speed of the bolometric detector.

Another way is to create two-dimensional receiving cell array 8 x 8 (16x16), each element is a modified slot antenna, loaded with the detector with Mott planar diode [10]. The exclusive features of receiving system are: significant volt-watt sensitivity of diodes around the frequency of 94 GHz (about \(10^4\) V / W) and quick data capture from the matrix provided by the modern ADC (Fig. 9).

The analysis of the results of THz-radiation application for the solution of different problems and tasks shows the future trends.
References:


[3] Xi-Cheng Zhang. THz Technology, Center for THz Research, Rensselaer Polytechnic Institute, USA.


