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APPLICATION OF TERAHERTZ WAVES IN AVIATION SECURITY

Abstract. *In recent years, the increasing threat of plastic explosives has posed significant challenges to aviation security agencies, emphasizing the critical need for their timely detection and neutralization. Simultaneously, interest in the terahertz region of the electromagnetic spectrum has grown considerably. This study investigates the potential of terahertz time-domain spectroscopy (THz-TDS) for detecting the spectral signatures of concealed plastic explosives and their compounds. Additionally, the article presents the conceptual design of a terahertz spectrometer specifically developed for identifying concealed hazardous substances.*

Key words: *aviation security, terahertz spectrometer, femtosecond laser, GaSe, InSe crystals, plastic explosives, HMX, RDX, TNT*

Introduction. Terahertz radiation refers to electromagnetic waves within the frequency range of 0.3–10 THz, or 0.3×10^{12}–10×10^{12} Hz, corresponding to a wavelength of approximately 1 mm. This range lies between the infrared (IR) and microwave regions of the electromagnetic spectrum, often referred to as the far-IR or submillimeter range. The terahertz range encompasses the radiation spectra of various astronomical objects and complex organic molecules, including proteins, DNA, certain explosives, and atmospheric pollutants (e.g., harmful substances).

Advancements in modern technologies have enabled the creation of quantum-scale structures such as quantum dots and quantum wires, widely utilized in nanotechnology. The excitation energy of quantum dots aligns with the photon energy of terahertz radiation, allowing coherent control of these structures using terahertz rays. Furthermore, the non-ionizing nature of terahertz radiation ensures its safety for human use, facilitating its application in diverse fields such as medical diagnostics, modern security systems, environmental monitoring, quality control of pharmaceuticals and food products, and high-speed communication systems.

In recent years, the interest in terahertz technologies, imaging, and protection systems has grown significantly, driven by three primary factors:

- Terahertz radiation can detect concealed non-metallic weapons, as material like cardboard, clothing, and footwear are transparent to it.
- It enables the remote (standoff) detection and identification of explosives and drugs due to their characteristic spectral lines in the terahertz region.

- Terahertz radiation is safe for human exposure, making it suitable for practical applications [1].

The main part. In recent years, plastic explosives, chemical bombs, and biological weapons have increasingly become tools utilized by terrorists, while the expanding illegal drug trade poses a growing global threat. Addressing these challenges requires the development of effective methods for the rapid detection and neutralization of such threats.

One promising approach is the use of terahertz electromagnetic waves, as the materials of interest exhibit unique absorption and reflection characteristics within the terahertz frequency range (0.5–10 THz). Explosives such as C-4, HMX, RDX, and TNT, as well as various illicit drugs, possess distinct absorption and reflection spectra that differentiate them from materials like clothing and human skin. Terahertz radiation's ability to penetrate non-metallic substances enables the identification of these hazardous materials, even when concealed, based on their terahertz spectral signatures.

The influence of atmospheric conditions is a critical factor in distance measurements involving terahertz radiation. Figure 1 presents the results of experiments measuring atmospheric transmittance within the 300 GHz to 4 THz frequency range.

As illustrated in Figure 1, numerous absorption lines are observed across the terahertz spectrum, primarily attributed to water vapor in the atmosphere. Nevertheless, under conditions of relatively short distances (50–100 meters) and moderate humidity levels (<58%), which are adequate for standoff detection, the terahertz range remains sufficiently transparent for the identification of concealed objects.

The study identifies at least five atmospheric transparency windows within the 1.4–4 THz frequency range, demonstrating the viability of this spectral region for practical applications in standoff detection systems.

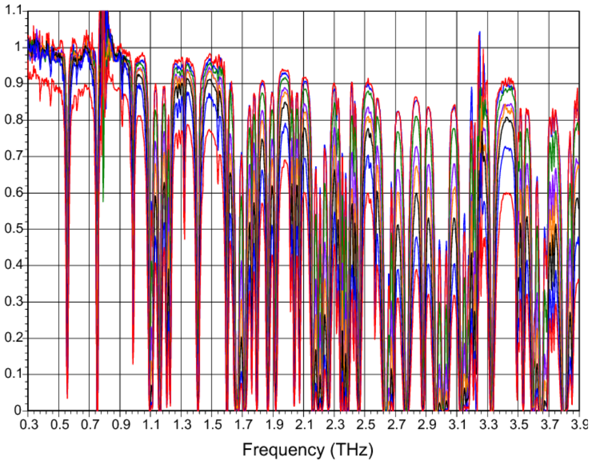

Figure 1. The emissivity of the atmosphere within the frequency range of 0.3–4 THz varies depending on the relative humidity, ranging from 5% (upper curve) to 58% (lower curve), with emissivity at 0.3 THz normalized to unity [2].

Figure 2 presents the absorption spectra of various plastic explosives and their components, as determined through experimental measurements [3]. Each explosive exhibit distinct spectral characteristics. For instance, RDX-based explosives display a resonance peak in the 820 GHz region, allowing for their identification. However, while the presence of a spectral feature is a critical indicator, it alone is insufficient for the definitive identification of an unknown substance.

The primary challenge in explosive detection lies in differentiating the spectra of non-hazardous materials with similar properties from those of explosives. As demonstrated in Figure 3, the terahertz range effectively satisfies these conditions, enabling accurate distinction and identification.

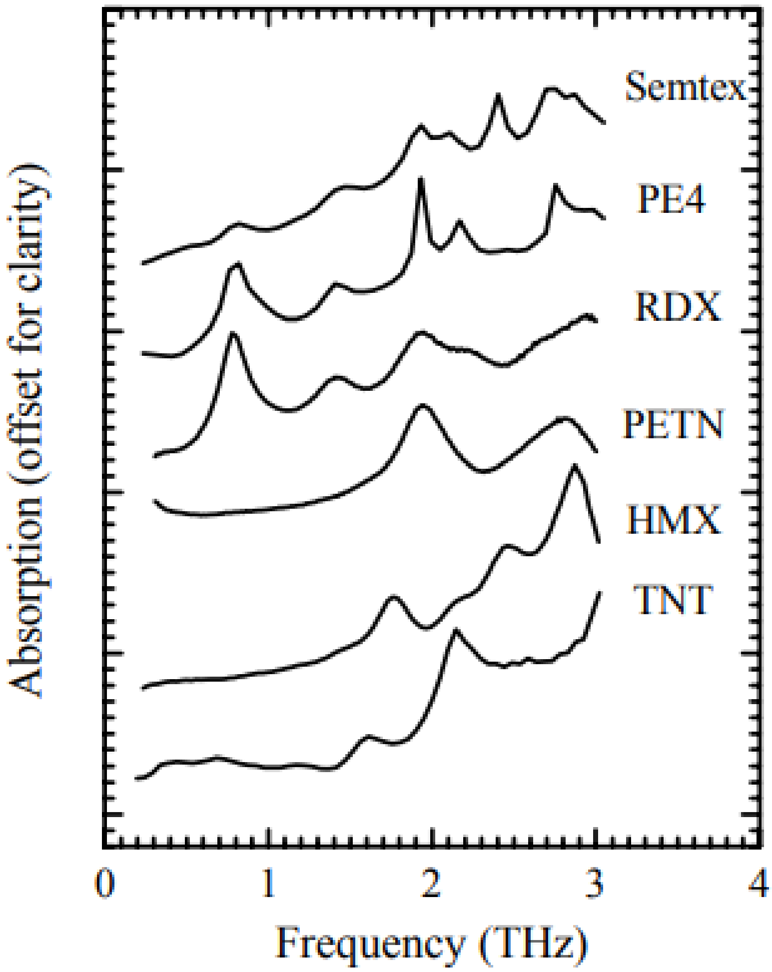

Figure 2. Absorption spectra of plastic explosives and their components

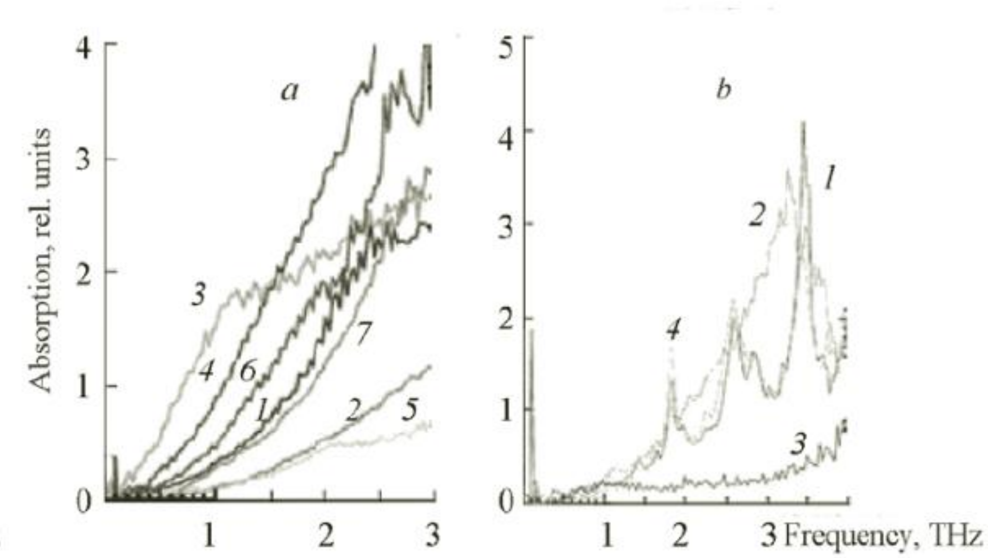

Figure 3. Absorption Spectra of Materials: (a) Materials commonly used in packaging and clothing (1 – cotton; 2 – silk; 3 – wool; 4 – leather; 5 – nylon; 6 – polyester; 7 – polyester/cotton), (b) Materials that may interfere with the identification of explosives (1 – milk chocolate; 2 – vitamins; 3 – granulated sugar; 4 – powdered sugar)

The frequency range from 6 THz to 10 THz exhibits numerous spectral features for explosives; however, moist air is not transparent to radiation in the 2–3 THz range. Therefore, for standoff detection applications, only a relatively narrow portion of the terahertz spectrum, specifically 0.3–3 THz, is suitable.

Terahertz generation method relies on the generation and detection of coherent terahertz pulses using femtosecond laser pulses (10–100 fs). In this setup, the laser beam is split into two components: one generates an ultrashort terahertz pulse using a photoconductive antenna, while the other records the time delay with a photodetector. The photoconductive antenna consists of a semiconductor plate with two parallel metal electrodes spaced 50–200 μm apart. When a constant voltage is applied between the electrodes, the antenna acts as a terahertz pulse generator. Upon exposure to femtosecond laser pulses, charge carriers are generated in the semiconductor, producing a surface current.

In the absence of an applied voltage, the antenna functions as a terahertz radiation detector. In this configuration, the charges generated in the semiconductor by the incident laser pulse are displaced by the terahertz pulse, which arrives with a delay relative to the laser pulse. The resulting current between the electrodes is proportional to the electric field strength of the terahertz pulse. This process is referred to as terahertz spectroscopy. Additionally, this detector can measure not only the amplitude of the radiation passing through and reflected from the sample but also its phase.

In the experiments conducted for the generation and detection of terahertz radiation, a Ti: sapphire femtosecond laser from Toptica, model FFPRONIR (FemtoFiberproNIR), was used, operating at wavelengths of 1560 nm and 780 nm. The laser had an average power of 360 mW, a spectral width of 108 nm, and a pulse duration of 10 fs. Terahertz radiation was generated and detected using GaSe crystals with thicknesses of 45 μm and 35 μm, respectively. For InSe crystals, the corresponding thicknesses were 40 μm and 32 μm. The results of the experiments confirmed that both GaSe and InSe crystals are suitable as generators and detectors in the 0.1–6 THz frequency range [5].

The remote sensing system using terahertz (THz) beams is illustrated in Figure 4. The Ti: sapphire femtosecond laser beam is split into two components by a beam splitter: one acts as the absorption beam (20%) directed at the photoconductive antenna, while the other serves as the sample beam (80%) for detecting the THz beam reflected from the target object.

In the sample beam channel, fixed delay lines of 1000 mm and a frequency-varying delay of 15 THz are incorporated, forming a time-strobe mechanism (comprising mirror-angle reflectors in the assembly). To enhance the collection efficiency of THz radiation, hyperhemispherical lenses made of high-resistance silicon are placed on the surface of the photoconductive elements. For collimation and focusing of THz beams, two parabolic lenses with an aperture ratio of f/1 are employed within the measurement setup.

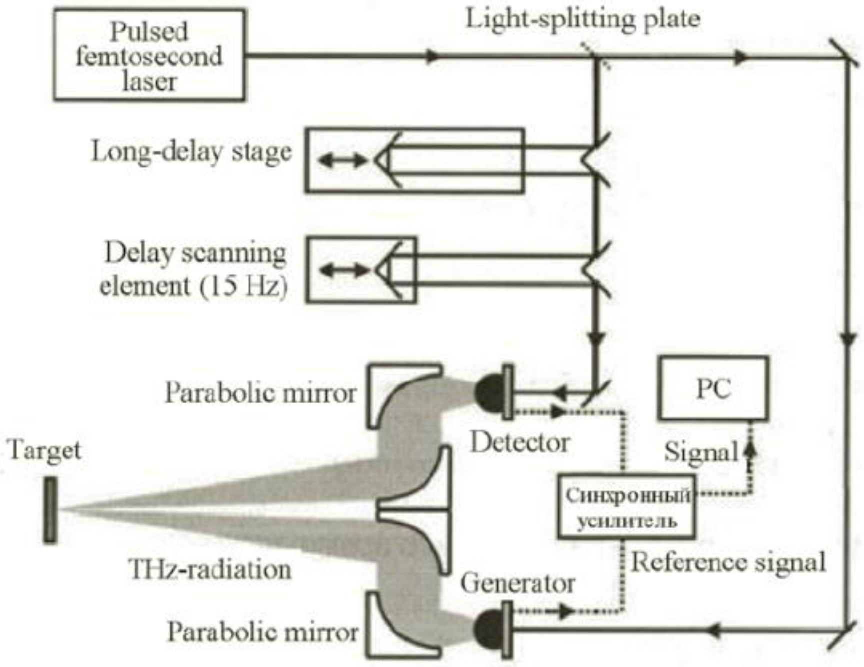

Figure 4. THs system for remote detection of explosives [6]

The measurement results for two different explosive samples are presented in Figure 6. As shown in the figure, there is good agreement with the calculated results. In both cases, characteristic features were observed at frequencies of 0.8, 1.05, and 1.4 THz. Since RDX was the primary component in both samples, these frequencies are consistent [6].

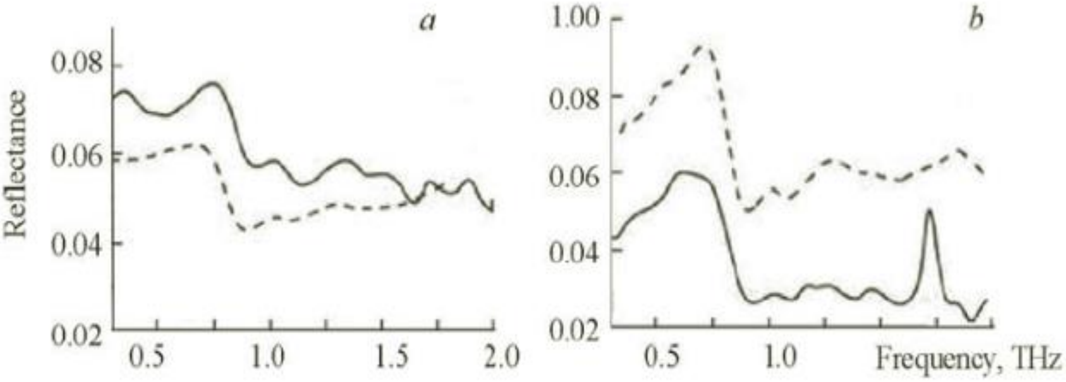

Figure 5. Reflectance spectra of Semtex-H (1) and SX2 (2)
measured from a distance of 1m (solid curve);calculated (dashed curve) [6]

Conclusion. Based on the studies conducted, it can be concluded that, under the given conditions, terahertz (THz) radiation presents a promising approach for the detection of concealed explosives.

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АВИАЦИЯЛЫҚ ҚАУІПСІЗДІКТЕ ТЕРАХЕРЦ ТОЛҚЫНЫНЫҢ ҚОЛДАНЫЛУЫ

Аңдатпа. *Соңғы жылдары пластикалық жарылғыш заттардан туындайтын қауіп-қатер авиациялық қауіпсіздік органдары үшін елеулі қиындықтар тудырып, оларды дер кезінде анықтау және залалсыздандыру қажеттілігін айқындап отыр. Сонымен қатар, электромагниттік спектрдің терагерц аймағына деген қызығушылық айтарлықтай артты. Бұл зерттеу жасырын пластикалық жарылғыш заттар мен олардың қосылыстарының спектрлік ерекшеліктерін анықтау үшін терагерц уақыттық спектроскопиясын (THz-TDS) қолданудың мүмкіндіктерін қарастырады. Сонымен бірге, мақалада жасырын қауіпті заттарды анықтауға арналған арнайы әзірленген терагерц спектрометрінің тұжырымдамалық жобасы ұсынылған.*

Түйін сөздер: *авиациялық қауіпсіздік, терагерц спектрметрі, фемтосекундтық лазер, GaSe, InSe кристалдары, пластикалық жарылғыш заттар, октоген, гексоген, тротил.*

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ПРИМЕНЕНИЕ ТЕРАГЕРЦЕВЫХ ВОЛН В АВИАЦИОННОЙ БЕЗОПАСНОСТИ

Аннотация: *в последние годы растущая угроза, исходящая от пластиковой взрывчатки, создала серьезные проблемы для органов авиационной безопасности, подчеркнув острую необходимость их своевременного обнаружения и нейтрализации. Одновременно значительно возрос интерес к терагерцовой области электромагнитного спектра. В данном исследовании рассматривается возможность использования терагерцовой спектроскопии во временной области (THz-TDS) для обнаружения спектральных характеристик скрытых пластиковых взрывчатых веществ и их соединений. Также в статье представлен концептуальный проект терагерцового спектрометра, специально разработанного для выявления скрытых опасных веществ.*

Ключевые слова: *авиационная безопасность, терагерцовый спектрометр, фемтосекундный лазер, кристаллы GaSe, InSe, пластиковая взрывчатка, октоген, гексоген, тротил.*

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