Terahertz Range Transceiver Module for Electromagnetic Protection of Objects*

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Abstract

The technical aspects of building a terahertz transceiver module for electromagnetic protection of objects from unauthorized penetration are considered. The new hardware and circuit design solution is based on the use of modern integrated circuits of terahertz transceivers in the 119–126 GHz range and a signal generation and processing board (frequency synthesizer board), interconnected by appropriate interfaces, and compatible with the Sirad Easy debugging kit from Silicon Radar. Mathematical modeling and simulation modeling of the electrical circuits of the transceiver module nodes were carried out using CAD NI Multisim, and 2D and 3D board models were designed using CAD Altium Designer, based on which electronic components were manufactured and mounted on the terahertz transceiver printed circuit board and the signal generation and processing printed circuit board of the transceiver module. A prototype of a terahertz range (119–126 GHz) transceiver module has been manufactured, in which the main ultrahigh-frequency components (frequency mixer, local oscillator, amplifier, etc.) are implemented using SiGe silicon-germanium technology entirely within one small-sized integrated circuit with an integrated antenna (overall dimensions do not exceed 35 mm in diameter and 10 mm in length), which, at an output power of 3 mW, provides the required (within 100–300 m) range of the module as part of a short-range radar with optimal values of the radio line energy resource and the practical absence of the possibility of detection and unauthorized access to information transmitted in the terahertz frequency range.

Keywords

cybersecurity, focused radiation protection complex, electromagnetic radiation, terahertz frequency range, short-range radar systems, transceiver module. bandwidth, range, noise protection

1. Introduction

Nowadays, the task of creating radio-electronic devices for promising applications in the field of cybersecurity, information protection from its detection and unauthorized access to it, and high-precision guidance and control systems, as well as the protection of movable and immovable property has become an extremely important necessity [1–3]. The solution to this problem is possible only with proper equipment of security systems with modern highly reliable technical means. The demand for the latest and highly reliable security systems is growing, therefore the development of means of electromagnetic protection of objects is a relevant topic.

The large bandwidth available at terahertz frequencies can offload low-frequency bands and provide ultra-high-throughput applications for future wireless systems, including massive multi-core wireless networks on a chip, broadband backhaul for rural Internet access, and high-speed inter-satellite connections.

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The need to provide higher wireless data rates for the ever-increasing number of devices connected to a wireless network stimulates the search for unused radio frequency spectrum resources. Due to the increasing number of telecommunication systems that use electromagnetic radiation of various frequency ranges, there is a need to create new wireless telecommunication technologies and systems that would allow to increase the amount of information transmitted and do it at an environmentally safe level of radio radiation. These requirements can be met by terahertz wireless telecommunication technologies and broadband radio access systems with gigabit bandwidth created on their basis for the implementation of ultra-high-speed (several Gbit/s and higher) local computer networks and wireless transmission of high-definition (HDTV) and ultra-high-definition (UHD) television programs, which require digital channels with a transmission rate of up to 6 Gbit/s [4].

2. Analysis of the known solutions

A known technical solution that provides the effect of electromagnetic radiation from a subterahertz (subTHz) radiation installation with a wavelength of 3..3.3 mm on the intruder, and the location of the hidden intruder is previously determined, the location of the subTHz radiation installation is calculated and the angle at which the electromagnetic radiation should be directed to the reflecting surface is calculated [5]. In this case, the calculations are based on the fact that the surface that reflects electromagnetic radiation is billboards located along pedestrian sidewalks, a metal body of a van parked near the site of a special operation. It is possible to use both a car that accidentally ended up at the site of a special operation, and a van with a metal body placed there intentionally. To determine the location of a hidden intruder, an observer is used, located on the roof or upper floors of neighboring buildings, and communicates its coordinates by radio to the operator of the sub-THz radiation installation.

There is a known method of protecting zones and objects from unauthorized penetration by focused radiation of the subterahertz range [6], in which the location of a hidden intruder is determined and the influence on it is carried out by electromagnetic radiation of the subterahertz range installation, taking into account the reflection of electromagnetic radiation from various surfaces in the frequency range of the "transparency window" 94–96 GHz, the location of the object-oriented surface that reflects the beam and is located on a high-elevated platform is calculated, and the angle of the direction of influence on the intruder is calculated, taking into account the reflection of electromagnetic radiation from the surface on the high-elevated platform.

The developed technology for electromagnetic protection of objects is based on the introduction of additional technological operations that involve the preliminary deployment of a radiating system based on the ground part and a high-altitude aerial platform (for example, a UAV), on which spatially separated low-power terahertz range emitting devices and terahertz range transceiver modules of the guidance and control systems of emitting devices are placed; a sensor wireless hierarchical network, which is divided into clusters, each cluster has a router-gateway acting as a main node and terahertz range sensors; placement of equipment for transferring the standard licensed frequency range to the terahertz frequency range and antennas for transmitting information in the terahertz range on the routers of the sensor wireless hierarchical network and the high-altitude aerial platform to create a communication channel in the terahertz range; placement on each high-altitude air platform of equipment that allows encapsulating data from the routers of the sensor wireless hierarchical network into data transmitted to the new generation LTE/5G mobile network; setting up an autonomous control system for the wireless communication network of the terahertz frequency range of the proposed solution, ensuring increased efficiency of the functioning of the security system infrastructure of the service area of particularly important special-purpose facilities in critical situations when a group of intruders penetrates a particularly important protected facility, and its scalability.

The key difference between this solution and traditional modern solutions used at particularly important special-purpose protected facilities is that the use of terahertz-band sensor devices provides a significant improvement in the delivery speed of routing protocols and power consumption when using the terahertz frequency range compared to frequencies below 6 GHz.

In addition, synchronously operating spatially separated low-power radiating devices of the terahertz range of UAVs allows for expanding the functionality and scalability of the radiating system using terahertz range transceiver modules for guidance and control systems of radiating devices by creating directed electromagnetic radiation by spatially separated radiating structure.

3. Formulation of the scientific problem in general form

With the development of science and technology, the terahertz wave range is increasingly used in various sectors of the national economy. A new technical result of the proposed innovative solutions is the possibility of creating radio electronic devices and radio communication systems in the terahertz frequency range for promising applications in the field of *cybersecurity*, *information protection* from detection and unauthorized access to it, and high-precision guidance and control systems.

The digital future of humanity depends on the growing number of devices, services, and products that rely on a limited radio frequency spectrum. Spectrum harmonization increases economies of scale and availability of devices and services. Identifying and agreeing on available spectrum for 5G and 6G communication systems with expanded coverage and bandwidth is essential for economic deployment in Ukraine and is the prerogative of the World Radiocommunication Conference (WRC), which regulates the use of the radio frequency spectrum and geostationary and non-geostationary satellite orbits. Currently, project groups, including the Electronic Communications Committee (ECC RT1) of the European Conference of Telecommunications Administrations (CEPT), in which Ukraine actively participates [7, 8]. The THz spectrum lies between the millimeter-wave (mmWave) and far-infrared (IR) ranges and has long been the least studied part of the electromagnetic spectrum and can complement the traditional radio frequency spectrum. However, recent advances in THz signal generation, modulation, and propagation techniques offer much higher bandwidth compared to the mmWave range and more favorable propagation conditions compared to the IR range. At the digital infrastructure level, new technologies beyond 5G, such as smart reconfigurable surfaces, integrated access, and backhaul, can increase the benefits of THz communications. At the algorithmic level, new signal processing techniques and network protocols can circumvent the quasi-optical characteristics of THz propagation and provide seamless connectivity. Higher frequencies in the THz range (0.1–10 THz) will play a central role in ubiquitous wireless communications in networks after the introduction of 6G generation networks. According to research by international leading companies exploring THz communications, including the 6G Genesis Flagship Program (6GFP), the H2020 ICT-09 THz Cluster EC [3], and China Broadband Communications and Next Generation Network Construction [5]. Efficient THz baseband signal processing can bridge the gap between the huge available bandwidth and the limited sampling rate that exists today.

In particular, THz frequencies promise to provide a wide spectrum, data rates of more than a hundred gigabits per second (Gbps), highly secure data transmission, mass connectivity, and denser networks. The U.S. Defense Advanced Research Projects Agency (DARPA) has identified THz technology as one of four major research areas and a key component of the next information technology revolution that could have a greater impact on society than the Internet itself.

The way modern society creates, distributes, and consumes information has led to an unprecedented increase in the total number of interconnected devices, as well as the data rates at which these devices transmit information. Considering the main areas of application of the terahertz range, the International Telecommunication Union (ITU) has identified several main areas, namely: enhanced mobile broadband (eMBB), massive machine-type communication (mMTC), and enhanced mobile broadband (eMBB). mMTC and ultra-reliable low-latency communication (uRLLC) are defined to support a wide range of traditional and emerging applications and services anytime, anywhere [3]. As mmWave communication becomes an industry standard, the IEEE ComSoc has defined a communication platform and there is a need to explore new wireless technologies operating in the THz range [9].

6G networks, which will become a key factor in the intelligent information society by 2030, are expected to provide higher performance than 5G in space, air, land, and underwater networks to ensure ubiquitous and unlimited wireless communication based on the integration of various promising radio access technologies for the 6G ecosystem, including THz communication [4, 10–14].

Already now, American scientists from NASA's Jet Propulsion Laboratory (JPL), who are engaged in the development and integration of aerospace warfare technologies, have managed to achieve terahertz signal transmission at a speed of 2 Gbit/s over a distance of 2.03 km without a bit error rate (BER), which may contribute to the development of 6G [4].

4. Terahertz transceiver module

Next-generation wireless communication networks and the 6G ecosystem in the scientific literature by foreign and domestic scientists [3, 15–20] consider the need to use subterahertz and terahertz frequency ranges from 100 GHz to 10 THz to ensure secure multi-gigabit-second subterahertz communication [21–26].

A mathematical simulation of the FMCW radar operation was carried out for the case of both the radar and the target motion, and the results of this simulation determined the main parameters of the probing signal, which will ensure the required range of the transceiver module as part of the guidance and control system. The SiRad Easy® Evaluation Kit was taken as the prototype of the terahertz transceiver module [3, 18–21]. The SiRad Easy® Evaluation Kit has a modular design concept: external lens antenna [27–29], radar transceiver board (Radar Frontend), board for generating LFM signals and processing received signals (Baseband board), microcontroller board. In laboratory conditions, the performance of the debugger was tested when it was located at a distance of 2 m from a metal reflector measuring 30×40 cm^2. To determine the distance to the reflector using the SiRad Easy set, the LFM signal radiation width was set to 5 GHz.

The block diagram of the terahertz range transceiver module, which includes a frequency synthesizer, is shown in Fig. 1.

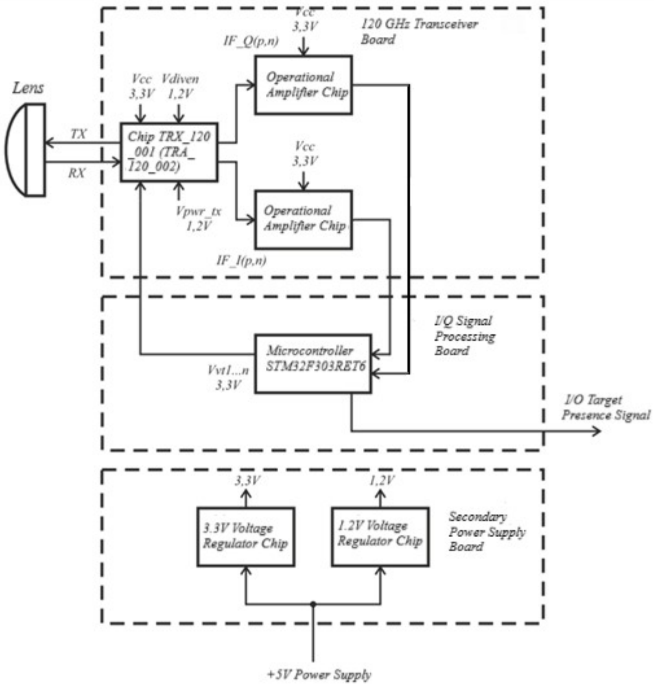

Figure 1: Block diagram of a terahertz range transceiver module with a frequency synthesizer, signal generation and processing boards, and secondary power supply

According to Fig. 1, the transceiver module consists of three main components: (1) THz transceiver board based on the TRX_120_001 or TRA_120_002 IC; (2) Signal formation and processing board; (3) External lens antenna (if necessary).

The frequency synthesizer is part of the signal generation and processing board and is designed to generate a LFM signal of the appropriate duration, time form, and frequency stabilization of the voltage-controlled generator (VCG) TRX_120_001 or TRA_120_002 based on a phase auto-tuning frequency ring according to signals generated by the control device.

The THZ transceiver board is designed for:

- Forming a carrier-frequency stable LFM signal with the appropriate radio frequency bandwidth using a VSG and a frequency doubler.
- Amplifying the LFM signal and emitting it in the form of electromagnetic waves in the direction of the target.
- Receiving a weak LFM signal reflected from the target and amplifying it in frequency.
- Forming I/Q signals that carry information about the beat frequency and phase for further determination of the range to the target.

In turn, the signal generation and processing board (frequency synthesizer and I/Q signal processing board) is designed for:

- Generating a LFM signal to control the operation of the VSG TRX_120_001 or TRA_120_002.
- Amplifying I/Q signals and matching their electrical parameters with the microcontroller interface.

The prototype of the THz transceiver board was taken from the Radar board of the SiRad Easy debugging layout from Silicon Radar. The Altium Designer computer-aided design (CAD) system was used to develop the electrical schematics of the transceiver module. This CAD allows you to perform the full range of operations necessary for the manufacture of the module, namely: to draw up electrical schematics, trace printed circuit boards, perform 2D and 3D visualization of the board, prepare printed circuit board files in the appropriate formats (Gerber) for the subsequent manufacture of photo templates for the boards, etc.

Fig. 2 shows a 3D model of the THZ transceiver board based on the TRA_120_002.

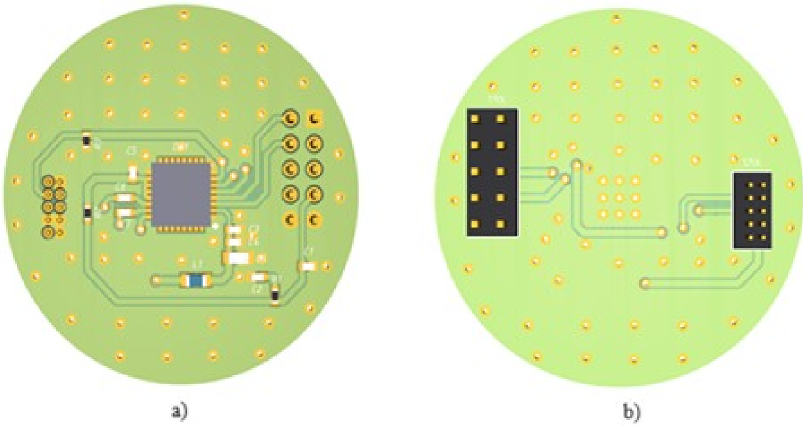

Figure 2: 3D model of the THz transceiver board based on the TRA_120_002 IC: a) top view; b) bottom view

Fig. 3 shows the transceiver module connected to the STM-32 Nucleo microcontroller using an external lens antenna and the results of measuring the distance to the target (the ceiling of the laboratory room).

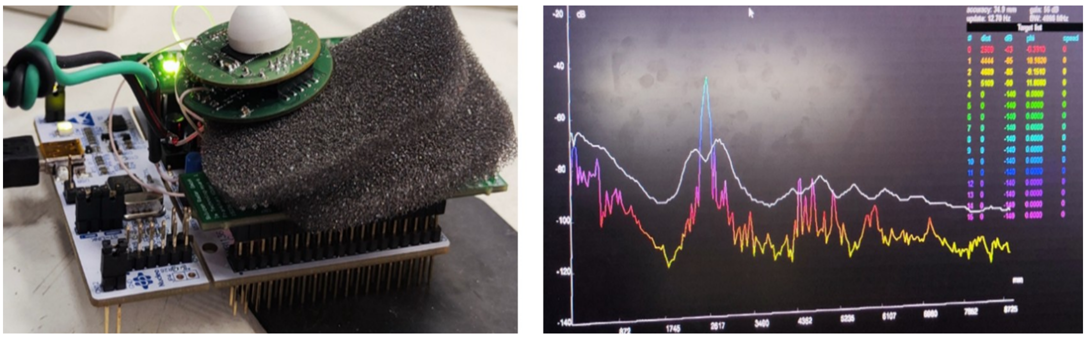

Figure 3: Photograph of the THz transceiver board connected to the Sirad Easy debugging kit (a) and the results of its preliminary test (b)

As can be seen from Fig. 3, which shows a photograph with the results of a preliminary test of the THz transceiver board with a display of the reflector distribution profile in the “signal level—distance” coordinates, the range to the target, which in this case is the ceiling of the laboratory room, is uniquely determined by the position of the maximum peak of the reflected signal on the personal computer screen.

The main result of the research is the development of a prototype of a terahertz range (119–126 GHz) transceiver module for guidance and control systems for various objects, the overall dimensions of which do not exceed 35 mm in diameter and 10 mm in length with an integrated antenna, which, at an output power of 3 mW, can provide a range of up to 100-300 m. Technical solutions for increasing the range of the terahertz range transceiver module by using an external lens antenna are substantiated and proposed.

Conclusions

The introduction of additional focused radiation of the terahertz wave range into the automated complex for protecting zones and objects from unauthorized penetration of the terahertz range receiver-transmitter modules of the guidance and control systems of UAV radiating devices and the development of an improved model of an integrated complex security system for a special object and information protection ensures an increase in the effectiveness of their application. The use of radio signals of the terahertz frequency range increases the sensitivity of receivers and reduces the impact of fading during multi-beam propagation of waves and, accordingly, ensures an increase in the noise immunity of information transmission, guidance, control, and management channels.

The terahertz range (119–126 GHz) transceiver module using silicon-germanium technology, the overall dimensions of which do not exceed 35 mm in diameter and 10 mm in length with an integrated antenna, with an output power of 3 mW, can provide a range of up to 100–300 m. The ability to operate with low radiated power provides, in addition to the secrecy of signal transmission, also miniaturization of equipment and economical energy consumption.

Synchronously operating spatially separated low-power radiating devices of the terahertz range of UAVs allow expanding the functionality and scalability of the radiating system using terahertz range transceiver modules for guidance and control systems of radiating devices by creating directed electromagnetic radiation by a spatially separated radiating structure.

The applied terahertz technologies create the prerequisites for the further development of highly competitive technological areas, the use of which contributes to solving the most important technological problems and implementing priority areas of development of various types of equipment.

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Declaration on Generative AI

While preparing this work, the authors used the AI programs Grammarly Pro to correct text grammar and Strike Plagiarism to search for possible plagiarism. After using this tool, the authors reviewed and edited the content as needed and took full responsibility for the publication's content.

References

[1] H. Avdiienko, et al., Receiver-transmitter module in the terahertz frequency range, in: Materials of the 10th International Scientific and Technical Conference "Information and Communication Technologies and Cybersecurity" (ICTC-2024), 2024, 46–53.

[2] M. Ilchenko, T. Narytnyk, R. Didkovsky, Clifford algebra in multiple-access noise-signal communication systems, Telecommun. Radio Eng. 72(18) (2013) 1651–1660. doi:10.1615/TelecomRadEng.v72.i18.20

[3] T. Narytnyk, Terahertz frequency communication systems: Monograph, Zhytomyr, 2015.

[4] Convergence of broadband and broadcast/multicast in maritime information networks. URL: https://www.sciopen.com/article_pdf/1425373508562079745.pdf

[5] O. Boiko, et al., Patent UA #2465650, IPC G08B 15/00, Method of non-lethal influence on a hidden person using millimeter-wave radiation, Patent owner: 12 Central Research Institute of the Ministry of Defense of the Russian Federation, Application date: 01.02.2011, Patent publication date: 27.10.2012.

[6] T. M. Narytnyk, et al., Patent of Ukraine for a utility model №138429, Ukraine, Method of protection of areas and objects from unauthorized penetration using focused sub-terahertz radiation, Patent publication date: 25.11.2019.
[7] M. Y. Ilchenko, et al., Environmentally safe communication line with a radiation power of 70 nanowatts for wireless local area networks, in: Materials of the 21st International Crimean Conference KryMiKo2011, 2011.
[8] M. Y. Ilchenko, et al., Transceiver for 130–134 GHz band and digital radio relay system, Telecommun. Radio Eng. 72(17) (2013) 1623–1638.
[9] T. M. Narytnyk, et al., Analysis of the prospects for using the terahertz frequency range for wireless communication networks of special purpose, Syst. Technol. Commun. Inf. Cybersecur. 5 (2024) 138–153. doi:10.58254/viti.5.2024.13.138
[10] Genesis flagship program: Building the bridges towards 6G-enabled wireless smart society and Ecosystem. URL: http://jultika.oulu.fi/files/nbnfi-fe2019081624413.pdf
[11] Y. Yashchyshyn, et al., New interference technique for determination of low loss material permittivity in the extremely high frequency range, in: IEEE Transactions on Instrumentation and Measurement, vol. 64(11), 2015, 3005–3012. doi:10.1109/TIM.2015.2437631
[12] M. Ilchenko, T. Narytnyk, G. Avdeyenko, Wireless communication systems of terahertz frequency range, Current Trends in Communication and Information Technologies, IPF, Lecture Notes in Networks and Systems, vol. 212, 2021, 189–222. doi:10.1007/978-3-030-76343-5_11
[13] H. Tran, G. Kaddoum, RF wireless power transfer: Regreening future networks, in: IEEE Potentials, vol. 37(2), 2018, 35—41.
[14] V. G. Saiko, T. M. Narytnyk Terahertz frequency wireless communication systems, Germany: LAP LAMBERT Academic Publishing, 2019.
[15] V. Saiko, et al., Radiating telecommunication system of the sub-THz-band to protect objects from unauthorized access, in: 2019 IEEE International Scientific-Practical Conference: Problems of Infocommunications Science and Technology, 2019, 698–702.
[16] T. Narytnyk, et al., Energy calculation of the terahertz radio link, Telecommun. Radio Eng. 78(6) (2019) 537–557.
[17] V. Saiko, T. Narytnyk, Model of a wireless terahertz network with increased communication reliability, Int. Sci. J. Eng. Agric. 2(2) (2023) 166.
[18] V. Saiko, T. Narytnyk, 5G Wireless method with increased reliability and energy efficiency using terahertz frequency range, Scientific foundations in research in Engineering: collective monograph, Int. Sci. Group, Boston, 2022, 609–625. doi:10.46299/ISG.2022.MONO.TECH.2
[19] N, Kukutsu, Y. Kado, Overview of millimeter and terahertz wave application research, NTT Technical Review, 7(3) (2009) 5–10. doi:10.53829/ntr200903sf1
[20] Terahertz radiation system market share 2023 in-depth analysis, growth opportunities, upcoming challenges, future trends, and forecast to 2029. URL: https://www.theexpresswire.com/pressrelease/Terahertz-Radiation-System-Market-Share-2023-In-depth-Analysis-Growth-Opportunities-Upcoming-Challenges-Future-Trends-and-Forecast-to-2029_18201986
[21] V. Saiko, et al., New Generation mobile communication networks 4G/5G/6G: Monograph, Kyiv, Pro format, 2021, 207–212.
[22] T. M. Narytnyk, V. G., Saiko Terahertz frequency wireless communication systems, International Book Market Service Ltd – LAP LAMBERT Academic Publishing, 2019.
[23] Documentation for TRX_120_001. URL: https://siliconradar.com/products/single-product/120-ghz-radar-transceiver/
[24] Documentation for TRA_120_002. URL: https://siliconradar.com/products/single-product/120-ghz-transceiver-tra_120_002/
[25] Collimator lens for SiRad® evaluation kits—Accessory for radar evaluation boards. URL: https://siliconradar.com/datasheets/Datasheet_Collimator_Lens_V1.1.pdf
[26] SiRad easy 300 GHz front end board. URL: https://siliconradar.com/wiki/SiRad_Easy_300_GHz_Front_End_Board