TELECOMMUNICATIONS

PRINCIPLES OF DEVELOPMENT OF THE TERAHERTZ BAND TELECOMMUNICATION SYSTEM BASED ON THE TECHNOLOGY OF HARMONIC SIGNAL AS THE INFORMATION CARRIER

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Physical principles of introduction and reproduction of the information transmitted using the harmonic signal as the information carrier, are analyzed. Based on the performed theoretical calculations confirmed by the results of modeling, there are formed the principles and rules of determining optimal parameters of the ultra-wideband terahertz frequency range communication system on the basis of the technology of electronics using the harmonic signal as the information carrier. The necessity of using the terahertz frequency band while deploying future super high throughput rate telecommunication systems is reasoned. Analysis of the state-of-the-art problem is performed, the direction of research is selected and the mission is set with regards to creation of the terahertz band broadband access telecommunication system with the Gigabit throughput rate within the operating frequencies range of 130…134 GHz. Characteristics of the signal propagation path and defining of the signal losses under the conditions of the terahertz frequency band radio relay system operation are analyzed. On the basis of the analysis performed it is shown that operation of radio relay links in the terahertz band allows practically disregarding the refraction and interference of the electromagnetic waves reflected from the obstacles in the radio signal propagation domain that occurs primarily under the conditions of a dense urban building. The domains of the terahertz band frequencies, which are most of all suitable for use in the radio relay communication lines, are determined. Physical modeling of the super high data rate former is performed on the basis of the multifrequency multiplexing of the OFDM-modulated digital flows, testing at the experimental stand and the optimization aimed at attaining of the maximal throughput capacity of the channel used for transmission of the digital information of the flow are fulfilled in the Ethernet format using the developed software means. The created software and hardware means allowed attaining, for the first time, the general channel data rate of up to 1.2 Gbps at the full duplex. There are developed the block circuit diagram of the system transceiver path – the frequency converters with subharmonic pumping, the heterodyne using a high-stability setting quartz oscillator with the subsequent circuitry of multiplying and amplifying cascades, the bandpass filter using a thin metal plate in the E-plane of the 1.6x0.8 mm waveguide channel, and the horn-lens antenna.

KEY WORDS: *terahertz band, wave propagation, attenuation, telecommunication systems, super high data rate, signal code structures, functional design, modeling, transceiver path*

1. INTRODUCTION

By now several main trends have been formed in the theory and practice of development of the telecommunication systems in the terahertz frequency band [1-8].

These are primarily the telecommunication systems on the basis of the technology of electronics using the harmonic signal as the information carrier, the origination of which is related the invention of the lamp generator of the non-fading oscillations [9] that resulted in substitution of the broadband signals with the narrowband ones for more than 40 years.

A significant success is achieved in the sphere of creation of the systems with the noise-like (pseudo-noise) signals [10-14]. The investigations related to the sphere of using truly noise (stochastic) signals as the information carrier [15-16] have also become more active during the recent decade.

An alternative way of formation of the signal with a broad spectrum is related to using of short and ultrashort pulses [17].

Spending of the frequency resource for transmission of information along the data network channels requires expansion of using the non-licensed frequency resource up to the terahertz wave range. For that in order to spare the frequency resource it is necessary to provide for minimization of the occupied frequency bandwidth, acceptable quality of transmission as well as the efficiently resistance to the distortion factors. One of the most promising approaches in creation of the high rate wireless networks with the increased throughput capacity is the terahertz telecommunication systems on the basis of the technology of electronics using the harmonic signal as the information carrier. Primarily, it is explained by those basic particularities, which are provided for the communication system by the harmonic carrier:

1) Extremely high level of development of the physical principles of introduction and reproduction of the information transmitted using the harmonic signal as the information carrier;
2) Affordability of the electronic component base;
3) Comparatively simple structure of the transceiver devices.

A conclusion can be made that development of the high-speed systems on the basis of the technology of electronics using the harmonic signal as the information carrier is an important problem of development of the theory and engineering of the telecommunication systems.

This paper is related to the analysis of the state-of-the-art of the problem, selection of the research way, the most recent researches and achievements in the sphere of implementation of the completely electronic wireless THz communication systems at the carrier frequencies of over 100 GHz with application of the technologies of electronics using the harmonic signal as the information carrier.

The objective of this paper is to analyze particularities of propagation of the terahertz band radio waves, their application under the real conditions of operation, estimation of characteristics of the transmission channel to be created (primarily, the energy characteristics), influence of the factors distorting the channel upon main characteristics of the communication channel and offering of the engineering solution for creation of the transmission channel in the terahertz wave band.

2. PARTICULARITIES OF USING THE TERAHERTZ BAND IN TELECOMMUNICATIONS. MAIN DRAWBACKS AND ADVANTAGES OF USING THE TERAHERTZ (THZ) WAVES AS COMPARED TO THE INFRARED WAVES

High rate of data transmission in the optic fiber networks attaining the levels of Petabits per second [18] results in increasing of the requirements set to the data transmission volumes and rate in the wireless access networks [19-22].

Using of the infrared band for the high-speed data transmission seems impossible because the data transmission rate within the given band is limited by hundreds of Megabits per second [23]. It is related to low sensitivity of the receivers, diffusion losses for reflection, availability of strong light noise in the environment as well as to limitations in terms of the emission power due to the danger of hurting the organs of sight [24]. Therefore, in order to attain the data rates of 10…100 Gbps two ways can be used in the wireless networks: the first one envisages increasing of the communication channel spectral efficiencies up to tens of bit per second (bps) Hz; the other is in broadening the frequency bandwidth to several tens of gigahertz. The latter approach is the most reasonable and foresees using of the terahertz frequency band (0.1…3 THz), because the domain of the unused spectrum with the required dimensions is located right in this band.

There also exist other advantages of applying terahertz waves in the wireless communication lines as compared to the near infrared (IR) spectral band. First, the THz signals are less affected by attenuation as compared with the IR signals under the same weather conditions – for example, during the fog [25]. Second, fluctuations of the amplitude and phase caused by local variations of the atmospheric refraction parameter also exert no practical influence upon the THz emission propagation, however, they restrict application of the systems based on the infrared emission [25,26]. The above advantages are typical for the frequencies hitting the transparency windows of the atmosphere and namely within the bandwidths of 75…100; 110…150; 200…300 and 600…700 GHz [27]. At such broad accessible frequency bandwidths the data transmission rates of tens of Gigabits per second [28] could be attained even at application of the simplest amplitude modulation. Another advantage of the THz communication links is in the possibility of creation of the protected communication systems [29] on their basis.

Attenuation of the terahertz waves to the frequencies of 300 GHz occurs in the atmosphere mostly due to the influence of rain and presence of the oxygen and water vapors in the air. Other gases make an inessential contribution to the value of attenuation of the terahertz waves. Figure 1 shows the results of investigation of the dependence of the radio wave attenuation values upon the frequency performed by the International Telecommunication Union (hereinafter referred to as the ITU) at propagation of the waves in the troposphere in the direct vicinity of the Earth in 1996. The results showed that the peaks of attenuation due to the resonance interaction between the radio wave and the oxygen molecule were created within the frequency bandwidth of 50…70 GHz with the maximums at the frequencies of 60 GHz and 118 GHz. The peaks of attenuation due to the interaction between the electric moments of the water and the radio wave occurred at the frequencies of 22.2 GHz and 183 GHz.

Lower values of attenuation were observed at other frequencies; therefore, while selecting the frequencies available in the radio window one can substantially decrease the influence of the atmosphere parameters upon the radio link.

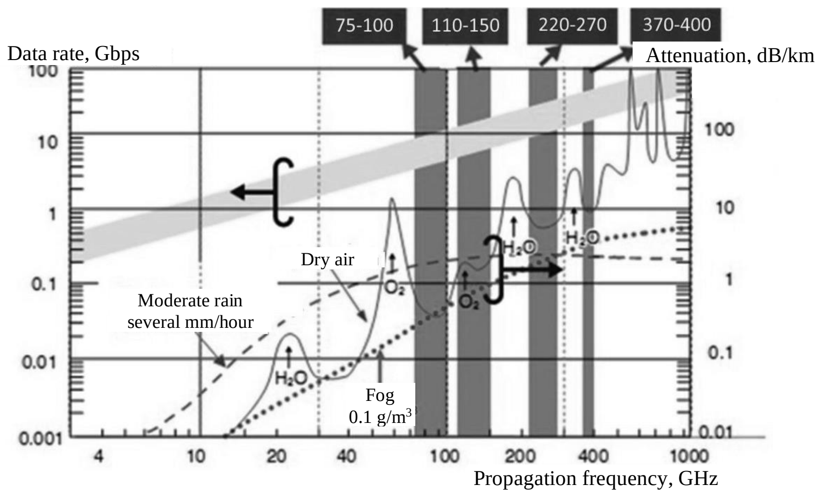


FIG. 1: Dependence of the attenuation upon the frequency considering the influence of the rain

Based an the dependences in Fig. 1 and considering the models represented in the recommendation P.838 ITU-R, as well as based on the results of the investigations performed, one can consider as the most acceptable and perspective at designing of the high-speed ultra-wideband wireless telecommunication systems the frequency bandwidths of 110…150 GHz and 220…270 GHz, where broad bandwidths of 40…50 GHz can be used for an essential increase of the informational capacity, increasing of the parameters of secrecy and protection from detection and unauthorized access to the transmitted information.

Due to the fact that the THz emission is strongly attenuated at propagation in the atmosphere the area of application of the THz communication is limited primarily to the wireless access networks operating under the real conditions at short ranges (within the limits of up to 1…3 km).

3. APPROACHES TO IMPLEMENTATION OF THE THZ-BAND WIRELESS COMMUNICATION LINES

The THz wireless communication systems are subdivided into optical, electronic and hybrid depending upon the components used. Up to the present moment the hybrid (combined) systems got the widest application because it is exactly combining of electronic and optic devices allows attaining record values of data transmission rates at the given stage of development of the photonics and electronics.

The hybrid wireless THz communication line can be implemented on the basis of two approaches depending on the method of the THz signal generation. Under one of the approaches the THz signal generation is executed using the technologies of photonics, and under the other the technologies of electronics used. It is shown that the approach to the THz signal generation on the basis of the technology of photonics is the most reasonable from the point of view of the width of the used frequency band, the possibilities of restructuring and stability, and it can be applied in order to attain the data transmission rates of up to 10 Gbps and more, because of availability of the telecommunication components, such as lasers, modulators and photo diodes operating at the above rates. Along with the above, research and development of the high-speed systems on the basis of the technology of electronics using the harmonic signal as the information carrier remains an important problem for development of theory and engineering of the telecommunication systems.

4. DEMONSTRATIONS OF THE THZ-BAND WIRELESS COMMUNICATION SYSTEMS

The THz wireless communication system with the frequency of more than 100 GHz was represented by the Japanese company NTT [30] for the first time in 2000. The system was represented by a wireless line with the frequency of 120 GHz, in which generation and modulation of the signals was executed using the means of photonics. Attaining of the unprecedented data transmission rate of 10 Gbps accelerated development of the electronic components for the wireless communication systems. Later on it was already developed the completely electronic wireless system on the basis of CMOS (complementary metal-oxide-semiconductor) structure, with the help of which a real-time broadcasting of the Olympic Games in Beijing [31] was performed in 2008. After that development of the THz wireless communication systems continued at high rates – the results of the experiments related to data transmission at the carrier frequencies of 75…110 GHz [32,33], 140 GHz [34], 200…240 GHz [35], 250…400 GHz [24,36,37], 625 GHz [38] were published during the following years.

A number of research groups are engaged in development of the wireless communication systems on the basis of the approaches of photonics within the 75…110 GHz frequency bandwidth (the W-band). There were demonstrated several such systems, for example, in the paper [32] it is described the 100-Gbps hybrid wireless communication line on the basis of the optical heterodyne up-conversion of the 12.5 Gbps optical 16-QAM signal of main bandwidth with the polarization multiplexing at the ranges of up to 120 cm. After that, the same research group proposed the data transmission system in the W-band based on the optical comb generator, with the help of which it was performed the simultaneous THz signal generation with the bandwidth of 15 GHz upon three channels with the frequency and spatial multiplexing at the rate of 8.3 Gbps in each of the channels, and the transmission range attained the value of two meters.

Another research group represented the data transmission system in the W-band, where the transmitter and receiver were executed on the basis of the pulse radio architecture [16]. This system allowed attaining the rate of 10 Gbps both in the air and via the optic fiber. The paper [34] describes the wireless data transmission system at the frequency of 140 GHz with the maximal data transmission rate of 10 Gbps to the range of 1.5 km. The 16-quadrature amplitude modulation was applied in order to attain the spectral efficiency of 2.86 bps Hz.

Developments of the wireless communication systems are actively performed within the 200…240 GHz frequency band [35,39]. The paper [39] informs about attaining the data transmission rate of 100 Gbps at the frequency of 237.5 GHz that is generated by mixing of two subcarrier lasers with mode synchronization with the help of the UTC photodiode. It is expected that synergetic use of the THz photonics and electronics that got the name of “teratonics” has to result in the wireless transmission of several Terabit per second to the range of more than one kilometer.

The 300…400 GHz bandwidth is currently the most promising from the point of view of the attainable data transmission rates [40,41]. The authors of [42] describe the wireless transmission system with the data rate of 14 Gbps at the frequency of 300 GHz operating to the range of 0.5 m. The THz signal is generated by means of heterodyning the light from two sources with the re-adjustable radiation wavelength; then it is modulated by the optical intensity modulator on the basis of the pulse code generator, and, finally, the optical signal is converted into the electric one with the help of the UTC photodiode and generated into the open space with the help of the horn antenna. The Shottky barrier diode is used as the receiver.

The papers [42,43] demonstrate data transmission at the frequency of 300 GHz with the data transfer rate of 12.5 Gbps with the help of the transmitter based on the photonics technologies and the receiving module on the basis of the improved Shottky diode. It is noted that the possibilities of the given system are not limited by the attained transmission rate; further improvements would allow data transmission with the bitrate of up to 20 and more Gigabits per second.

The paper [36], the authors of which suggested the system of data transmission at the frequencies higher than 250 GHz using the amplitude modulation on the basis of the UTC photodiode equipped with the waveguide and Shottky barrier diode with the integrated antenna used as the receiver, can be noted among the advanced developments in the given frequency band. It was demonstrated a faultless transmission with the data rate of 24 Gbps at the frequency of 300 GHz to the range of about 50 cm. Besides, this research group developed a receiver based on the monolith microwave band integrated circuit using the modern InP technology of the bipolar transistor used at a heterotransition. To make the device compact, the antenna, radio frequency amplifier, amplitude detector and the amplifier were completely integrated in one printed circuit board.

The paper [37] describes the communication line with the data transmission rate of 3 Gbps on the basis of the higher order quadrature amplitude modulation (16-QAM) and the carrier frequency of 340 GHz for the future local wireless networks. This system applies the heterodyne transceivers and the equipment for parallel digital data processing. With the help of two specially designed Cassegrain antennas the transmission range of 50 m was attained. Besides, it is provided the prototype of the local wireless network at the frequency of 340 GHz on the basis of the IEEE 802.11 protocol with the data transmission rate of 6.536 Mbps to the range of 1.15 m.

5. DEPLOYMENT AND OPERATION PRINCIPLES OF THE TRANSCEIVER PATH OF THE TELECOMMUNICATION SYSTEM USING THE HARMONIC SIGNAL AS THE INFORMATION CARRIER

5.1 An Example of Implementation of the SDR Concept in the Gigabit Modem of the Terahertz Band Telecommunication System

With the aim to implementation of the SDR concept in the terahertz band telecommunication system, on the basis of the Wi-Fi technology it is created the G1 Gigabit modem [44,45] that can be used for connection of the remote territorial segments of the Ethernet 10/100/1000-BaseTx networks. Block circuit diagram of the G1 Gigabit modem is represented in Fig. 2 [47].

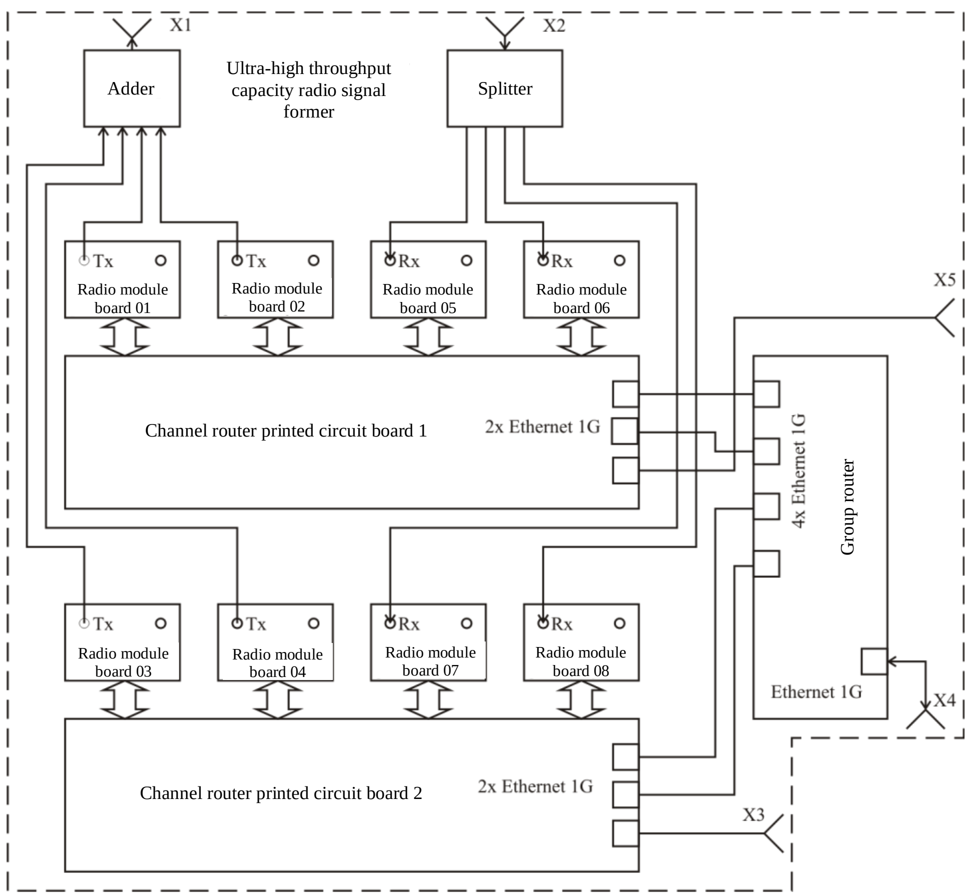


FIG. 2: Block circuit diagram of the Gigabit modem

Basic components of the Gigabit modem include the channel routers 1 and 2, as well as the group router. The input stream is automatically distributed upon all the channels and subsequently processed to form the radio frequency spectrum within the radio relay channel throughput bandwidth. The G1 Gigabit modem (Fig. 3) is executed in the metal case that allows its mounting in the rack or use as a desktop positioned device.

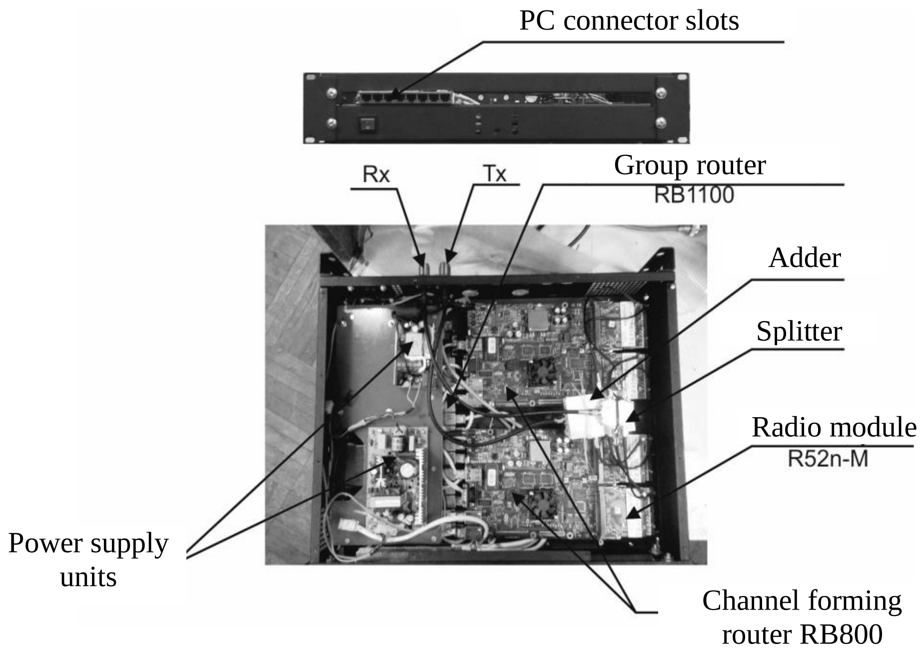


FIG. 3: Photographic image of the G Gigabit modem laboratory sample

Main technical specifications of the modem are provided in Table 1.

To provide for the channel data rate of 1.2 Gbps; the terahertz band radio relay link applies 8 standard 802.11n Wi-Fi transceivers in the 2.1…2.7 GHz band within the bandwidth of 40 MHz each having the channel data rate of up to 150 Mbps. The modem uses the "dual stream" mode at the Mikrotik equipment with use of two R52n-M receivers for creation of one duplex radio channel – one for reception and the other for transmission. To attain the total data rate of 1.2 Gbps there are suggested four duplex channels with 150 Mbps in every direction.

The Mikrotik RB1100Hx2 router providing for a single interface for the external connection is used for joining of all the channels. The given configuration of the modem provides for high efficiency and the claimed characteristics having, at that, relatively low costs of manufacturing of the Gigabit modem. It is also possible to increase the Gigabit modem channel data rate of up to 1.2 Gbps in every direction in the case of doubling the number of complete sets of the RB800 routers and the Mikrotik R52n-M transceivers.

TABLE 1: General technical specifications of the Gigabit modem

Description	Value
Power supply voltage, V	220
Modulation-demodulation mode control interface	Ethernet 10/100 Base-Tx, RJ-45 connector
Router control interface	Ethernet 10/100/1000 Base-T, RJ-45 connector
Data interface	Ethernet 10/100/1000 Base-T, RJ-45 connector
IF path interface	Coaxial, 50 Ohm path N-type connectors
IF path central frequency, MHz	2400
Frequency bandwidth occupied by the modulated signal at the maximal throughput capacity mode, MHz, not more	40
Modulation type	QAM-64
IF signal power at the modulator output, dBm	0 … -3
Sensitivity upon the IF demodulator input, dBm	-70
Maximally allowable IF signal level at the demodulator input, dBm, not more	-45
Modem weight, kg, not more	4

5.2 Designing of the Terahertz Band Transmitting and Receiving Radio Paths

5.2.1 Block Circuit Diagram of the Transmitting and Receiving Paths

Radio electronic transceiving devices capable of formation and transmission of the relevantly powerful for this frequency bandwidth modulated signals with the data transmission rate from 1 Gbps and reception of the signals with the acceptably high sensitivity are the key elements of the terahertz band radio relay communication system.

The transmitting and receiving paths form up the analog (linear) section of the radio relay system [46-50]. These paths are built on the basis of the heterodyne circuit and provide for transmission of the signals along the path within the limits of 130...134 GHz in the terahertz frequency band. The bandwidth of intermediate frequencies comprises 2...4 GHz. Block circuit diagram of the transmitting path includes the following functional nodes: intermediate frequency amplifier (IFA) (if necessary); frequency upconverter; heterodyne; bandpass filter (BPF); output power amplifier (PA) (under the possibility of acquiring the components); and transmitting antenna. The signal is supplied to the input of the transmitting path from the group radio signal former.

Block circuit diagram of the receiving path includes the following nodes: receiving antenna; input low noise amplifier (LNA) (under the possibility of acquiring the components); bandpass filter; mixer; heterodyne; and intermediate frequency amplifier.

5.2.2 Development of the Transmitting and Receiving Path Functional Nodes

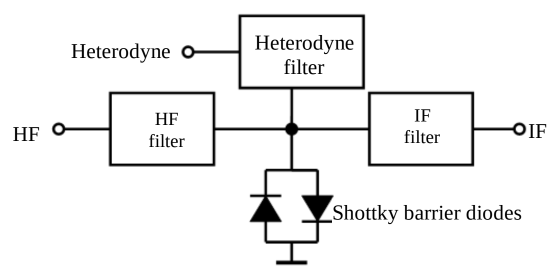
5.2.2.1 Signal Frequency Converters

The transmitting path frequency upconverter and the receiving path mixer operate under different modes and perform different functions; however, they possess the same unified block circuit diagram and design.

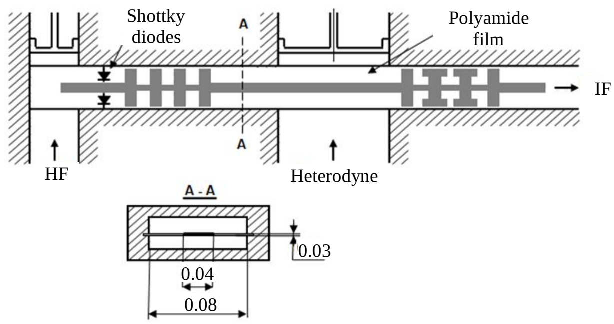
The converters are built on the basis of the chip gallium arsenide Shottky diode with the beam leads manufactured in Ukraine (PJSC NPP Saturn, Kyiv, Ukraine). The limit frequency of the above diodes amounts to 2.5 GHz that allows them operating at least in the lower part of the terahertz band. In terms of their electric and design parameters the developed diodes are at the level of their modern foreign analogs, for example, the gallium arsenide diodes manufactured by Hewlett Packard.

In order to implement the subharmonic circuitry of the converter with pumping at the half-frequency, two connected antiparallel Shottky diodes (Fig. 5) are applied as the linear element. The converter design includes two waveguide paths connected with the symmetrical strip line, upon which a pair of the chip Shottky diodes is mounted. The waveguide path with the channel cross-section of 1.6 x 0.8 mm is a part of the high frequency signal circuit.

The signal from the heterodyne is supplied to the diodes via the waveguide channel with the cross-section of 3.6 x 1.8 mm (Fig. 4a). The channel is evanescent for the IF signal and the separation between the heterodyne and the HF signal is provided for by the low frequency filter (LFF) with the cutoff frequency of 67 GHz performed at the section of the strip line between the waveguide channels. The IF signal circuit is completely realized upon the symmetrical strip line with the suspended substrate (Fig. 4в). The substrate is represented by the polyamide film with the thickness of 30 μm suspended in the rectangular channel with the cross-section of 0.8 x 0.4 mm that impedes origination of higher waveguide modes. The output LFF in the IF circuit with the cutoff frequency of 30 GHz disallows penetration of the heterodyne and HF signals into the intermediate frequency circuit.



a)



b)

FIG. 4: Block circuit (a) and design (b) diagrams of the converter

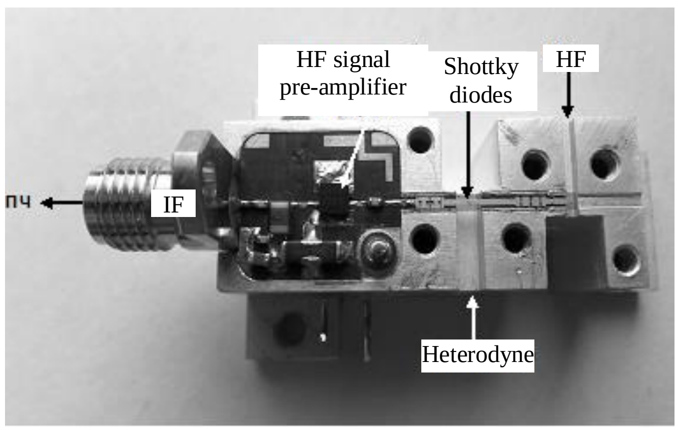


FIG. 5: Design of the frequency converter

The mixer design (Fig. 5) includes the intermediate frequency signal pre-amplifier. The power of the heterodyne necessary for normal operation of the mixer never exceeded 15 mW. The measured value of the conversion loss amounts to –11 dB that corresponds to the best achievements of foreign analogs.

5.2.2.2 Heterodyne

The beating oscillator is the most complicated device while developing digital telecommunication systems in the terahertz frequency band. It is explained by both the difficulties of attaining a sufficient level of power at rather high frequencies and by the necessity of providing for the high level of the heterodyne stability and low level of its phase noises. The heterodyne circuit for the frequency of 64.8 GHz was designed for the digital radio relay system of the 130...134 GHz frequency bandwidth. The structure of the heterodyne is based on using a highly stable setting quartz oscillator with the subsequent circuit of multiplying and amplifying cascades. The amplification level is set in order to provide for the optimal operating mode of the multiplying cascades and the required power value at the output of the heterodyne. This principle of construction of the local oscillator is much cheaper than development of the frequency synthesizer, and filtering of the signal after each multiplying cascade eliminates the presence of parasite harmonics and combinational frequencies.

The measured values of the local oscillator output powers for the paths of reception and transmission exceeded 15 mW that is quite sufficient for normal operation of the frequency converters in the receiving and transmitting paths. Therefore, as the result of the performed investigations it is projected, manufactured and tested the heterodyne, which is not inferior to its foreign analogs in terms of its parameters, in particular, the output power value.

5.2.2.3 Intermediate Frequency Amplifier

The intermediate frequency amplifier (IFA) circuit includes the preamplifier based on the TQP3M9037 integrated circuit, as well as the main amplifier developed on the basis of the FPD6836P70 transistor and the HMC313 integrated circuit. In addition to amplifying integrated circuits the IFA circuit contains monolith ceramic filters of high and low frequencies to form the necessary throughput bandwidth for the intermediary frequency path, the resistive attenuator for matching the output filter with the transmitting line, and also secondary power supply units forming up the stabilized voltage for the integrated circuits. The preamplifier is integrated structurally with the mixer to minimize the losses of the weak signal before amplification. Noise temperature of the amplifier amounts to about 50 K, and it determines, to a material extent, the sensitivity of the entire receiver. Basic amplification of the signal is executed right here. Total gain of the IFA comprises 47 dB.

5.2.2.4 High-Frequency Bandpass Filter

High-frequency bandpass filters (BPF) at the transmitting output and the input of the receiving paths must provide for separation of the signals in the given paths, as well as for a sufficient suppression of mirror channels and the heterodyne signals. Small value of the intermediate frequency ($F_{IF} = 2...2.5$ GHz) stipulates rigorous requirements set to the high-frequency BPF in terms of its selectivity.

The structurally developed six-resonator waveguide septum-filter is represented by a thin metal plate inserted into the E-plane of the waveguide channel. The plate contains the resonance windows, the coupling between which is determined by the width of the strips separating them. Obtained experimental results show that the filter satisfies the requirements to the selectivity in order to provide for a sufficient (by 20 dB) suppression of the mirror channel and the second harmonic of the heterodyne signal (129.6 GHz). Losses of the filter in the terahertz frequency band of the receiver do not exceed 4 dB that is a satisfactory result for such high frequencies. The AFC inhomogeneity upon the plane part is not exceeding 2 dB.

5.2.2.5 Conical Horn Antenna

The conical horn antenna with the dielectric lens concentrator was applied both in the transmitting and in receiving paths. In addition to the conical horn, the structure contains a transition from the circular waveguide to the rectangular one with the cross-section of 7.2 x 3.4 mm. Connection of the antenna to the transmitting or receiving path was executed with the help of the waveguide-to-waveguide transition from the waveguide with the cross-section of 7.2 x 3.4 mm to the waveguide with the cross-section of 1.6 x 0.8 mm. The antenna aperture is 245 mm. The calculations provide for the following characteristics of the antenna: the operating frequency bandwidth is 130…134 GHz; the input is represented by the waveguide channel with the cross-section of 1.6 x 0.8 mm; the gain ratio is at the level of 50 dB; the pattern width is no more than 0.60 degrees; and the SWRV is within the limits of 1.15 at the input.

6. ESTIMATION OF THE 130...134 GHZ BAND COMMUNICATION LINE LENGTH

On the basis of the G1 Gigabit modem with the installed Mikrotik R52n-M transceivers and the developed transmitting and receiving paths it is created the Gigabit-rate telecommunication system on the basis of the technology of electronics using the harmonic signal as the information carrier within the frequency bandwidth of 130…134 GHz with attaining of the channel data rate of up to 1.2 Gbps.

The communication channel power availability, signal parameters and the requirements set to the signal and the communication channel equipment are determined as follows: there are set the values of the acceptable signal carrier frequency, which is determined by fading of the radio signal in the propagation medium; the acceptable signal spectrum width, which is determined by the capabilities of the transceiver path as well as by the channel throughput bandwidth; the signal-to-noise ratio in the signal bandwidth; and the required data transmission rate.

At creation of the mathematical model it was applied the Friis formula that determined the power received by one antenna under the ideal conditions from another antenna separated by a certain distance at the known value of power at the output of the transmitting path. It is assumed that the communication line antennas are co-directional with respect to each other and matched in terms of their polarization.

In accordance with the known communication range equation the signal power at the input of the receiver is set by the following expression:

$$P_r = \frac{P_t \gamma_E G_t S_e}{4\pi R^2},$$

where P_t is the signal power at the transmitter output (at the transmitting antenna input), G_t is the transmitter antenna directive gain, S_e is the receiving antenna efficient area, R is the range between the transmitter and receiver, γ_E is the coefficient considering the signal energy losses in the medium due to absorption (usually, under the condition of absence of the factors that limit the openness of the path along the propagation path) accepted as exponentially dependent on the range:
$\gamma_E = e^{-0.23\alpha R}$, where: α is the specific attenuation per unit of distance.

In this conditions, specific attenuation of the signal would depend on the type of the signal and the conditions along the path. Subsequently, it is estimated the transmitter power necessary to attain the required level of the signal-to-noise ratio at the input of the receiving path.

The applied in the system protective coding allows compensating the effect of the noises to the level of about 5...7 dB. That is, the output power of the transmitter applied in the communication channel amounted to about 0.1 mW.

Taking into consideration that the transmission is performed separately upon each of the frequency channels and the signal level at the output of the transmitting path upon each of the frequency channels amounts to 1.25 mW then, considering the influence of noises, the level of the transmitter output power at the output of the transmitting path upon each of the frequency channels would amount to about 4 mW.

The noise coefficient of 7 dB corresponds to the value of the effective noise temperature (ENT) of the input 1200 K, i.e., within the frequency bandwidth of 4 x 10 MHz the value of the noise at the receiving path input would amount to about 7 x 10^{-13} W.

The acceptable power level at the transmitter output, and, thus, the communication channel stability are also influenced upon by the value of upper boundary of the receiving path dynamic bandwidth, which amounts while measuring with the help of the one-signal method (upon decreasing of the transmission coefficient by 1 dB) to 1 mW.

It means that the signal power at the input of the receiving path must not exceed 10^{-13} W. This parameter determines the minimal range at the unchanged scheme of the transmission channel, or regulates the communication channel composition. At transmission of the signal with the power of 1.25 mW the transmitting path must be characterized with the saturation level of not less than 20 mW upon the criterion of 1 dB.

Table 2 shows the results of calculation of the power losses while using modulation in the subcarriers of QAM 64 for the channel with the length of 1000 m at the signal frequency of 134 GHz and the total gain of the antennas amounting to 100 dB, the signal bandwidth of 400 MHz and the receiving path input equivalent noise temperature of 1200 K.

TABLE 2: The results of calculation of the power losses while using modulation in the subcarriers of QAM 64 for the channel with the length of 1000 m

Basic	Aggregate	Power of	ENT of	Signal at the receiver	Obtained margin of

losses (1000 m)	transmission coefficient	the transmitter	the receiver	input considering directivity of the antennas and basic losses	energy at the path length of 1 km
135 dB	-35 dB	-35 dBW	1200 K	-70 dBW	35 dB

Therefore, exceeding of the signal power over the power of the noise at the receiver input amounts to 35 dB; i.e., while using the 64 QAM modulation in the subcarrier flows and compensation of energy losses at taking into consideration of additional losses along the path and processing of the 64 QAM flow, the receiver is allocated 35 dB, of which 25 dB are spent for the signal demodulation and 10 dB – for compensation of the additional losses along the path.

Considering that the implemented antenna gain might be less than 50 dB by several dB, the obtained result shows the acceptable quality of operation of the transmission channel at the range of 1000 m with a little lower power availability that is acceptable under the conditions of the line-of-sight implementation.

7. CONCLUSIONS

1. Based on the performed analysis of the propagation path characteristics and determining the signal losses under the conditions of the radio relay system operation in the terahertz frequency band it is shown that operation of radio relay links in the terahertz band allows practically disregarding the refraction and interference of the electromagnetic waves reflected from the obstacles in the radio signal propagation domain that occurs primarily under the conditions of a dense urban building. The domains of the terahertz band frequencies are separated which are most of all suitable for use in the radio relay communication lines.

2. The analysis of the principles of construction of the telecommunication channels in the terahertz band is performed and it is suggested an option of construction of the communication channel for the ultra-wideband telecommunication system within the frequency band of 130...134 GHz on the basis of the technology of electronics using the harmonic signal as the information carrier for transmission of the information flow of a large (over 1 Gbps) throughput capacity based on the developed ultra-high throughput capacity former and the terahertz band linear transceiver path.

3. The power losses and the energy margin of the channel are estimated; it is performed an assessment of the communication line length within the 130...134 GHz frequency band, which assessment is based on the developed methods and on the results obtained during the investigations performed and the created transmission means applying the harmonic signal as the information carrier.

4. For the first time it is created and tested an experimental sample of the terahertz band transceiver (130…134 GHz), which might form the basis for development of the promising high-speed wireless telecommunication systems, in particular, of the digital radio relay communication systems.

5. It is reasoned that the terahertz band telecommunications represent the most promising technology for deployment of local wireless communication networks in terms of ever increasing requirements set to the data transmission rates. Integration of photonic and electronic devices using the advanced technologies of their manufacturing like silicon photonics, seems to be promising for creation of small-size and economically feasible THz transceivers. Development of the THz power amplifiers and low noise amplifiers for the transmitters and receivers on the basis of the high technology of electronics is very important.

6. It is demonstrated that the further increasing of data transmission rate of the information transmitted within the wireless networks can be provided for due to application of the THz pulse optics with the pulse spectrum from 0.1 to 1 THz. Due to a possible increasing of the transmitted pulse spectrum to the value of 0.1…10 THz attaining of the data transmission rate of up to 100 Tbps can be expected in local wireless networks and satellite communication systems.

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