1.2 Gbps radio link implementation in THz band based on IEEE 802.11n standard

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***Abstract*—In this paper, we propose the principle of construction wideband high data rate wireless communication system based on multiple low rate IEEE 802.11n modems (up to 150 Mbps each) with transferring the group signal into THz band. Proposed approach allows to build high speed (1.2 Gbps and more) wireless transport networks for distances around 1 km. We developed two laboratory transceivers accordingly to proposed approach, and tested the forming of wideband group signal in 2.4 GHz band with subsequent transferring it to carrier in 130 GHz band and receiving data on the recipient side.**

Keywords—IEEE 802.11n, basic 150 Mbps data rate, multiple modems, group 1.2 Gbps data rate, wideband signal, conversion to 130 GHz band, THz band high data rate wireless communication system.

I. Introduction

THz and sub-THz frequencies for several years are seen as ways to implement high throughput communication channels for using in locations where the laying of fiber-optic cable is difficult or impossible. THz range is almost never used today for communications. THz frequency range is located between 100 GHz and 10 THz. Bottom band frequency (100 GHz) is defined by electronic transitions in semiconductor structures, and on top band frequency (10 THz) is defined by the maximal wavelength in quantum transitions of laser structures. High carrier value in THz range allows to use the signal with wide bandwidth what radically increases data rate in communication channel [1-3].

Communication systems constantly require increasing throughput and improve data rates. We selected the frequency range 130-134 GHz for current work [4-5].

II. Problem Statement

A. *Problem Formulation*

The existing problem now is that radio band 3-3000 MHz is overcrowded. Television, radio, mobile telephony, Bluetooth, GPS, Wi-Fi and other devices consume resources in band 3-3000 MHz.

The goal is to develop a new hardware solution for advanced telecommunications in THz range for new generation wireless networks.

The object of study is the process of design and operation of broadband radio telecommunications system in the THz frequency range.

The subject of research is the principle of telecommunication systems construction with Gbps broadband access in frequency range 130-134 GHz and strategy for its further development to address the overload of frequency bands used today; significant increasing data rate in wireless communications; providing backup for optical fiber lines and microwave links creation for new generation of radio-relay links.

B. *Tasks*

To meet the defined goal, the following tasks are defined:

- Develop technical solutions to build radio-relay systems in THz range.
- Simulate main functional units of equipment for THz frequency range.
- Design receivers, transmitters, optimize parameters of devices and their parts.
- Test the developed digital microwave system in THz range, explore further ways to implement proposed solution in THz range for high throughput radio-relay links and radio access networks.

C. *System Requirements*

- Designed digital radio relay system should ensure the transmission and receiving digital information on rate 1 Gbps or more in frequency range 130-134 GHz.
- Acceptable BER level is less than 10^{-6}.
- Expected communication range under normal conditions should be within 1 km.

D. Methods and Results

We decided to use multiple individual channels with low rate in one system, so the full multiplexed data rate will be 1.2 Gbps. Individual channels have the maximum rate 150 Mbps.

The object of this utility model is the transceiver development with latest advances in communications. Transceiver has high throughput and low cost, so could be used for transport channels and for serving traffic in multiservice networks. We solved the above task by using technical solutions in transceiver based on chips developed in massive production and that are used in 802.11n networks. For example, the modem Mikrotik R52nM provides the maximal data rate 150 Mbps and is developed based on 802.11n standard. The modem Mikrotik R52nM works with modulations per standard 802.11n (the top one is 64-QAM) and uses frequency band 40 MHz.

Increased spectral efficiency is achieved by using multiposition modulation 64-QAM. Further speed increasing is achieved in the communication channel by combining frequency bands into a common data stream in multi frequency transmitter. The resulting rate of eight streams with modulation 64-QAM is 1200 Mbps (600 Mbps in one direction). Total frequency band is less than 400 MHz.

III. Link Budget Calculation And 1.2 Gbps Wireless System Modeling In THz Band

We use the method with the following parameters for link budget calculation: interval is at least 1 km, data rate is up to 1.2 Gbps, output power is 50 μW (-13 dBm), vertical polarization, modulation types are the lowest QPSK and the highest 64-QAM, channel noise temperature is 5000 K, frequency range is 130-134 GHz. Power link budget calculations at the receiver input (1):

$$P_r = P_t + G_t + G_r - L_0 - (\gamma_r + \gamma_a + \gamma_{fog})\cdot d, \qquad (1)$$

where P_t – transmitter power; G_t and G_r – antenna gain on transmitter and receiver sides, respectively; L_0 – attenuation in free space; d – distance in kilometers; γ – atmospheric, fog and rain attenuation. Since the QPSK signal to noise ratio is 12 dB (for BER=10^{-6}), we have a power reserve about 17 dB with system readiness 99.99%. For QAM modulation power reserve is 5 dB. So, setting up a communication for 1 km distance is possible.

We performed simulation of wireless system that operates at frequency of 130 GHz with modulation 64-QAM in AWR software tool (Fig. 1) [6]. We also analyzed the influence of nonlinearities on the performance of amplifier system. Channel model is presented by white noise channel model (AWGN). The research results allowed to us define requirements for system components in the form of quality indicators (characteristics, parameters) and put design and development tasks for amplifiers, converters, mixers, filters, and other elements for THz system.

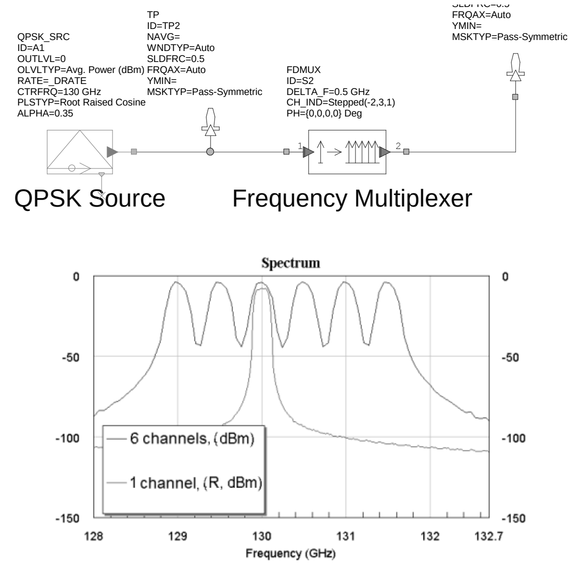

Fig. 1. Scheme of channels multiplexing to transfer the total bit rate of 900 Gbps after multiplexing using QPSK modulation based on modulators with data rate 150 Mbps

IV. Forming The Group Signal In 2.4 GHz Range

Transceiver consists of the receiving and transmitting paths and is different from other known solutions, so far as it includes *n* Mikrotik R52nM modems that form *n* frequency separated low-rate flows (150 Mbps). These low rate flows are united in group flow with data rate 1.2 Gbps [7-9].

A. Parameters of basic modem R52nM

The main parameters of modem Mikrotik R52nM are following: mini PCI bus; supported standards are 802.11a/b/g/n; frequency bands are 2.4 and 5 GHz (both frequency bands could be used in transmitter and receiver circuits); output power is 25 dBm; OFDM [10-12]; modulations: BPSK, QPSK, 64-QAM, 64-QAM; frequency band is 40 MHz. Data rate is 150 Mbps with using modulation 64-QAM.

To reduce possible interferences, spacing 5 MHz between frequency bands is selected (Fig. 2). It means that if we use eight basic modems R52nM on transmitter side and eight modems R52nM on receiver side, then total achieved rate is 1.2 Gbps in each direction. Required bandwidth could be realized by moving group signal from 2.4 GHz frequency range to 130 THz range. The modems R52nM need pre-configuration actions in order to work in separate frequency channels and form high-speed channel.

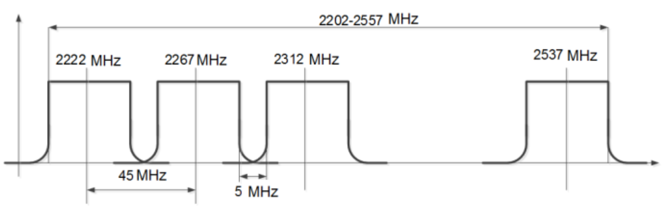

Fig. 2. Frequency plan for using *n* basic modems with 40 MHz band

B. The principle of forming group Gbps data rate flow

Request from subscriber to access services comes in Ethernet format; then it is routed through data link to the radio module input. Then request passes to radio module the series of procedures on transport level: OFDM with appropriate subcarriers modulation. The resulting stream in frequency band 2.4 or 5 GHz comes to analog adder input. All *n* flows from different modems with basic data rate are united in analog adder to a common wideband multi frequencies stream, and then pass further to linear input of subscriber station. The frequency bands for modems should not intersect each other, but at the same time should lie closely one to one for the purpose of effective spectrum usage; e.g. for 40 MHz signal bands the 5 MHz guard intervals are used between bands. This technical solution allows to create multi Gbps links in desired frequency range, for example, by heterodyne conversion to the desired frequencies band, including the 130-134 GHz as shown in current paper [13].

We used routers Mikrotik RB800 to form data flow on Ethernet level. Mikrotik RB800 has four mini-PCI slots with set up transceivers Mikrotik R52nM what creates two duplex channels. Access to each transceiver provided with a separate Ethernet interface in router RB800.

We used router Mikrotik RB1100Hx2 to combine all channels from RB800. RB1100Hx2 aggregates all flows and provides single interface for external connection. Described configuration provides expected performance while keeping relatively low cost of building such modem. Also, it’s possible to increase modem speed to 1.2 Gbps in each direction in case of doubling the number of sets of routers Mikrotik RB800 and modems Mikrotik R52nM.

C. Laboratory study of Gigabit Modem

We developed two probationary high speed devices for testing data rate, and optimized settings for these laboratory samples for maximum throughput. Device is shown on Fig. 3 and functional scheme is shown on Fig. 4.

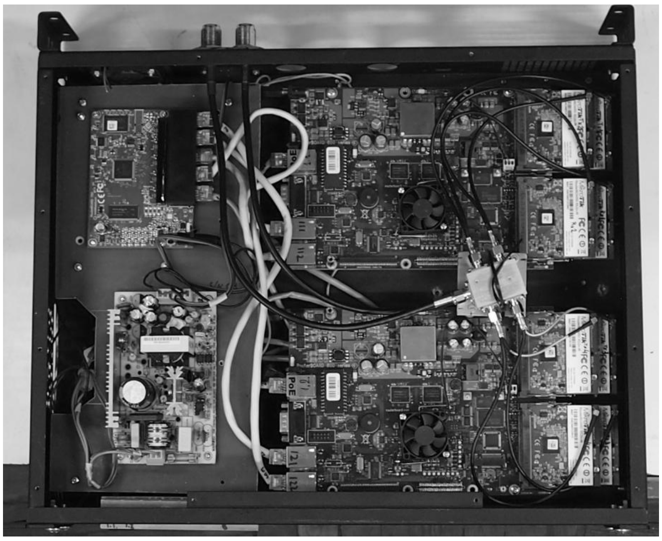

Fig. 3. The view of probationary device for wideband high speed data rate transmission based on MikroTik modems and routers

Channel modem with speed 1.2 Gbps was configured in duplex mode under the simplified scheme that is half configuration (just eight low-speed modems used in system: four on transmitter side and four on receiver side). Probationary laboratory instances include two high data rate transceivers, which are able to work in full-duplex mode. The outputs of each low-rate modem connect to analog adder, and then output of this analog adder connects to divider input on receiver side.

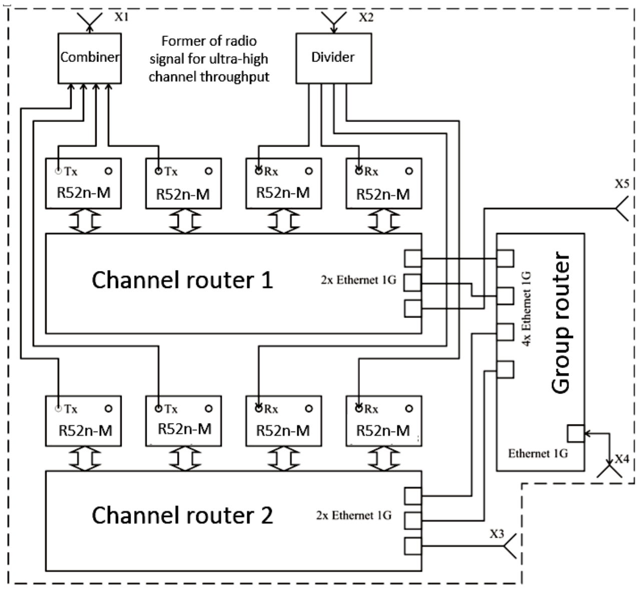

Fig. 4. Functional scheme of device for wideband high speed data rate transmission based on MikroTik modems and routers

We studied the data rate transmission in full duplex and simplex directions (Fig. 5). Measurements were carried out mainly on the router RB1100Hx2 as it has the interface with aggregated data flow. We performed data rate testing based on the built-in “Bandwidth Test” tool in RouterOS operating system for Mikrotik devices; the UDP and TCP modes used for data rates tests.

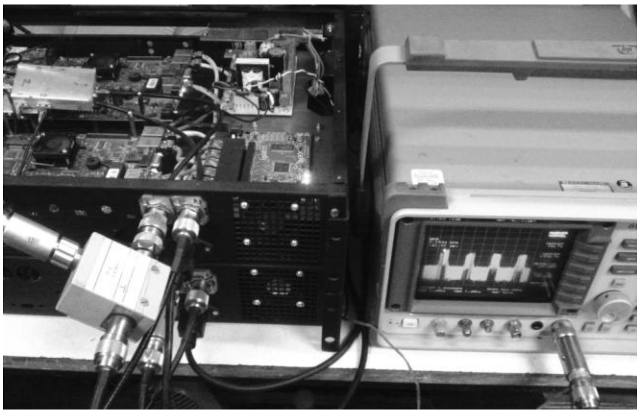

Fig. 5. Research of broadband high speed wireless communication system with four 802.11n channels

The frequency band width occupied with the guard intervals is acceptable for the construction of telecommunication systems in THz range (Fig. 6).

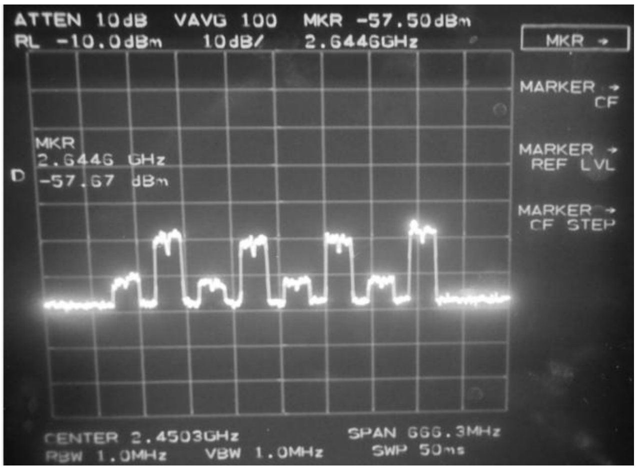

Fig. 6. Signal spectrum in frequency range 2.4 GHz (8 channels; 4 channels in each direction) that is ready for heterodyne conversion to 130 GHz band

As we noticed from experiments, aggregated data rate is a little bit lower than sum of two of four separated radio channel rates, but at the same time the difference is acceptable for following such approach and develop scalable devices based on multiple modems. The aggregation data rate losses are smaller than 4%, what may be neglected. Performed tests showed the possibility of building a high-speed modem for wireless communication systems based on low rate 802.11n modems, and with possible scalability to achieve data rates up to 1.2 Gbps in duplex mode and above by combining individual low rate channels.

V. Transferring Signal To THz Range

Eight low rate modems 802.11n and analog adder form a group signal for forward link, which includes eight bands of 40 MHz with distance between center frequencies of 45 MHz (Fig. 2). Group signal in band 2.172-2.527 GHz is supplied to the transmitting unit (converter), which transfers it to the range 130.000-130.355 GHz. Capacity of the direct channel is 8x150Mbps=1.2Gbps. The signal of return channel range 133.500-133.855 GHz received and transferred into frequency band 2.172-2.527 GHz. Capacity of the reverse link is too 8x150Mbps=1.2Gbps. In the laboratory instances just half of such configuration implemented, so maximal full-duplex data rate is 0.6Gbps in one direction and 1.2Gbps in both directions.

A. *Block diagrams of transmitter and receiver oscillator paths for THz band*

Transmitter and receiver paths implement the analog (linear) part of radio relay system. We built these paths based on heterodyne scheme and provided group signal transmission to THz band 130-134 GHz. Intermediate frequency range is 2.4 GHz.

Transmission path block diagram is shown on Fig. 7 and contains the following functional units: intermediate frequency amplifier (IFA), frequency converter (FC), oscillator (Osc.), band pass filter (BPF), output power amplifier (PA), transmitter antenna (TA) [14-15].

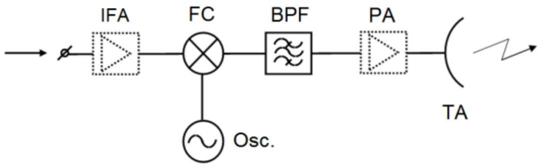

Fig. 7. Block diagram of transmitter oscillator path for THz band

Group signal 2.172-2.527 GHz comes to the input of the transmission path former to THz band, IPA could be applied in case additional signal gain is needed.

Block diagram of the converter path from 130 GHz band to 2.4 GHz band is shown in Fig. 8. It consists of the following components: receiving antenna (RA), low noise amplifier (LNA), band pass filter (BPF), frequency converter (FC), oscillator (Osc.), intermediate frequency amplifier (IFA).

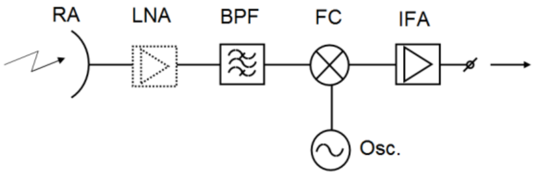

Fig. 8. Block diagram of receiver oscillator path from THz band

Low noise amplifier, as well as power amplifier in transmitter path, implemented based on existing instances. The remaining parts of transmitter and receiver paths, namely converters, mixers, oscillators, band pass filters, intermediate frequency amplifiers we developed on in the Electronics and Communications Institute within this work.

B. *Research and testing developed high speed wireless system in range 130-134 GHz*

Developed laboratory instance of THz transceiver is shown on Fig. 9. Transmitter and receiver paths have the same structural arrangement.

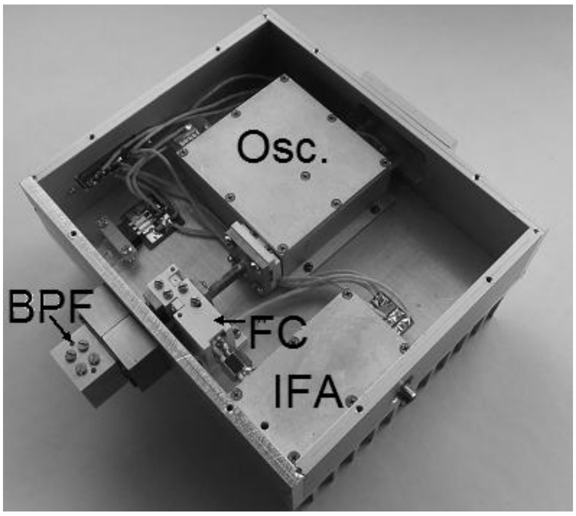

Fig. 9. Transceiver implementation for THz band

According to measured frequency dependence K(f), transceiver path in THz range has a total transmission gain at least 18 dB, and the irregularity of transmission gain in the operating frequency range is less than 3 dB.

The view of transmitting (receiving) tract of THz wireless system is shown on Fig. 10.

Fig. 10. The view of developed transmitting (receiving) tract of THz wireless system

So, including researched system parts, i.e. local oscillator, frequency converters (converter down and mixer), splitters and combiners, Mikrotik 802.11n modems and routers, we developed the laboratory samples of digital wireless high speed telecommunication system with gigabit bandwidth in frequency range 130-134 GHz, and worked out the technique of designing and testing laboratory samples of high-speed digital radio telecommunications system in THz range.

CONCLUSION

In this paper, we conducted theoretical research and experimental design of major components for THz wireless telecommunication system transceiver tract with Gbps data rate in the frequency range 130-134 GHz based on the analysis of existing electronic components and using Mikrotik R52nM modems that fit 802.11n standard in connection with Mikrotik routers.

We developed in the Electronics and Communications Institute within this work the following parts for THz band transmitter and receiver paths: converters, mixers, oscillators, band pass filters, intermediate frequency amplifiers. Based on mentioned parts, we created laboratory samples of digital telecommunication broadband radio system with Gbps data rate in THz range.

Proposed technical solution allows to create high data rate transport wireless communications systems in desired frequency range, for example, by converting low-frequency heterodyne (e.g., 2.4 GHz) band to the THz frequency range.

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