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HYBRID TECHNOLOGIES FOR THE MILLIMETER AND TERAHERTZ RANGES RADIO SYSTEMS IMPLEMENTING

In the article hybrid technologies based on various properties and advantages of radio and optical systems are proposed for the implementation of telecommunication systems in the millimeter and terahertz ranges. It is shown that the use of different hybrid topologies network structures, optoelectronic methods of formation and signal processing, the formation of the directional diagrams of the antennas, and the use of compensatory techniques can improve spectral and energy efficiency of the advanced communication systems in the range of 75...110; 200...450 GHz.

Keywords: the millimeter range; the terahertz range; hybrid technology; optoelectronic methods for processing of radio signals; photonics; spectral efficiency; energy efficiency; radio-over-fiber.

Introduction

It is projected that mobile data traffic will grow three times faster than fixed IP traffic [1]. Emerging standards continue to increase the wireless transmission speed. However, the majority of them work in the microwave range from 2 to 5 GHz (fig. 1), which theoretically limits the potential resources to increase capacity.

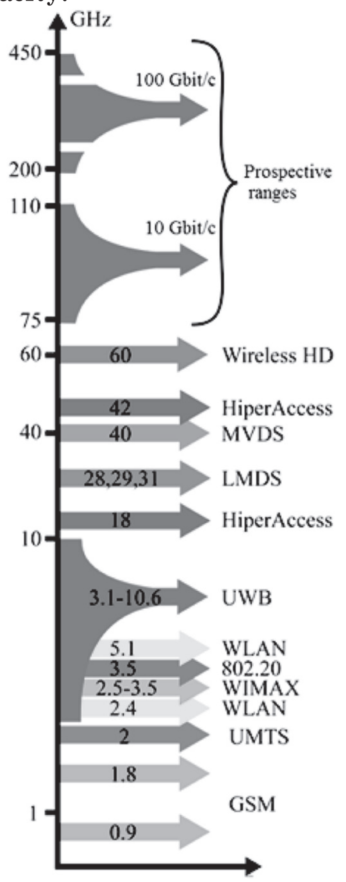

Fig. 1. The Use of spectrum by different radio performances. GSM: global system for mobile system; UMTS: universal mobile telecommunication system; WIMAX: worldwide interoperability for microwave access; WLAN: wireless local area network; UWB: ultra-wideband; LMDS: local multipoint distribution service; MVDS: multipoint video distribution system

Main part

As a rule of thumb, about 10% of the carrier frequency is available bandwidth of the radio systems. Consequently, the radio signals below 10 GHz can barely reach data transfer speeds beyond 1 Gbit/s. The terahertz and millimeter-wave (MMW) ranges are a promising solution for the rapidly growing demand for bandwidth, and are already used in some standards in the 60 GHz band. It's assumed that the bandwidth increase with the millimeter range (MMR) waves use will increase to 10 Gbit/s. However, the MMW distribution is limited by high losses in the atmosphere, urban areas, trees foliage, the human body, etc [2]. However, due to the characteristics of the MMR signals spreading (radiation) spectral efficiency increases with the increase of base stations (density phased emitting elements, antenna arrays) distribution density, which has contrast to the interference UHF band limitations for cellular communication. While there is no generally accepted model for energy budget and the such networks operation algorithm. Possible reasons are the insufficient study of the physical properties MMW distribution and hardware limitations, although the 2018–2020 years is already projected millimeter range in mobile systems use [3; 4].

The fundamental solutions for the MMD systems implementation are hybrid technologies such as [4–7]:

- optoelectronic methods for radio signals processing and generating;
- hybrid network topology RoF (radio-over-fiber, radiofiber-optical communication);
- hybrid analog-digital methods of the antennas directional diagrams formation (MIMO technology).
- radar sensing to the informational radio chanals.

In all of these technologies provides wide bandwidth for one channel up to 10 GHz. More important in the MMR development experts believe the ranges in the atmospheric transparency windows 75...110 GHz transmission capability up to 10 Gbit/s. For ultra-high performance network experts consider spectral windows in the frequency range from 200 to 450 GHz where the low additional losses due to water absorption, and at least you can organize the information transmission over short distances up to 100 m [6]. Each of these windows has a bandwidth of several tens gigahertzs, making them suitable for ultrahigh transmission of 100 Gbit/s without the use of high spectral efficiency formats modulate (e.g., 512-QAM).

Consider the basic solutions for implementing MMR systems.

Optoelectronic methods MMR signals processing and forming

Despite the many advances in semiconductor technologies, including graphene nanoelectronics, electronic devices may generate signals to MMR [8]. However, the MMW signals generation and modulation with sufficiently low noises by electronic methods, yet solvable task. Electronic devices generate stable signals with low phase noise only at MHz frequencies. And even if you multiply the frequency up to gigahertzs power phase noise increases by 6 dB for each frequency doubling [7]. The phase instability significantly limits the transport distance and information capacity of channels. Optical systems have increased the speed to tens of femtoseconds (if you compare this time to, for example, time-of-flight electron depleted region). This is due to the photon physical properties: the ability to exist only in motion at the light speed, electric charge and the rest photon mass is zero, which provides the least signal attenuation in the fiber, and the high spectral multiplexing possibility. Moreover, the signal processing speed corresponding to the tens Gbit/s transfer rate realizable in optical processors, and more generally in integrated optics.

Methods optoelectronic (photonic) signal, upconversion signal, conversion with decreasing frequency have considerable advantages in phase stability, performance, weight and size parameters, energy efficiency, bandwidth etc. Thus, increase the data transmission speed can be achieved with the photonic techniques for the MMW signals formation and processing use.

Basic methods of photon down-conversion frequency include an optical signal generation whose intensity is modulated on the radio frequency electro-optic modulator based on an Mach-Zehnder (MMZ) interferometer [7; 9]. The methods used to generate signals in the range 100 GHz to 5 THz, usually contain some kind of optical heterodyne scheme mixing the two lasers signals (fig. 2) or individual lines of the optical lattice generator signal. In the scheme a modulator used to encode the optical radiation intensity, the bandwidth only needs to match the data transmission speed, is followed by the millimeter range waveform photonic generator. Then the optical signal is sent to the remote or the adjacent photodiode, electrical output signal which is fed to a transmitting antenna. The photodiode in this case should to have of sufficient bandwidth to effectively generate a millimeter range signal from the optical modulated signal.

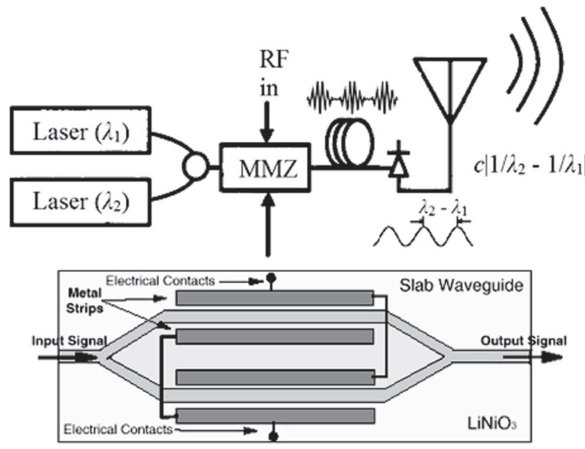

Fig. 2. Basic structural diagram of a wireless transmitter with the use of the output photon map, which gives an example of the millimeter range signal generation through the optical heterogeneous

If MMZ is based on the electro-optic material such as $LiNb0_3$, this relative phase can be controlled by applying voltage to one or both interferometer shoulders (see fig. 2). The applied voltage will change the refraction index, which in turn will adjust the phase. The photodiodes themselves can't demodulate the phase-modulated signal, so the MMZ scheme is used to transform electro-optical phase modulation in a modulation in intensity. Typically optical signals are transported in the fiber at a 193 THz frequency, where the fiber loss region is the lowest. For MMW there are many external types optical modulators for complex modulation schemes are used the MMZ cascades [7; 9].

Hybrid topology MMR networks

In the 90-s years were developed by the technologies LMDS (local multipoint distribution service) and MVDS (multipoint video distribution system) for cellular television, operating in the MMW range (see fig. 1) at distances of 3...10 km sight line, using analog and digital modulation [10]. In these technologies, it was assumed signal spectrum conversion coming from cable or satellite from a 50...860 MHz band strip to 2 GHz MMW range without the signal demodulation and demultiplexing. The main such systems advantages was not the noise of the MMW systems, as well as the multiplexing possibility. Power per channel was tens of milliwatts. Subsequently, cell TV technologies were used in the LTE standards and for the radio links organization (connections of the type «point-to-point or point-to-multi points»). At the same time, the experimental results conducted in New York show the possibility of signal transmission up to 200 m based on the signal reflections [11; 12]. In projects promising mobile systems offers connection MMR base stations picocells or femtocells by fiber optic lines to operate in the instantaneous bandwidth of up to 10 GHz with high speed signal processing and long-distance transmission, which could not provide the MMW range (see fig. 1) [13]. Crucial MMW use in cellular networks has focused transmission and hybrid analog-digital beamforming in MIMO technology, which also involved optoelectronic methods of microwave photonics (fig. 3).

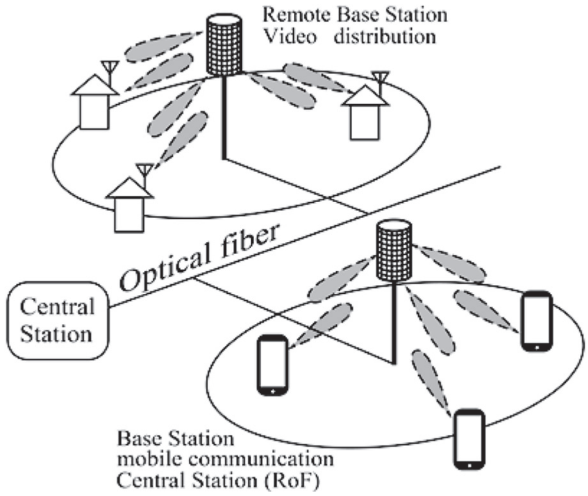

Fig. 3. Hybrid topology proposed for MMW

The main fiber-optic communication lines competitor can become stratospheric systems that use communication vertical channels with the repeaters at a height of about 20 km [14]. Stratospheric repeaters that can function as base stations, distributed in the horizontal circuit, the connection and the position adjustment occurs in the optical range. Vertical runs have an advantage in front of ground (terrestrial) ones because the atmosphere layer surface thickness is 1,5…2 km and diameter service areas is greater than 100 km [15]. The possibility of using MMD in the vertical stratospheric channels were considered in the 90-ies. It's now known, for example, that Google is testing in MMW in their stratospheric projects (Skybender) [16].

The main future networks elements operating in the millimeter and terahertz ranges can be picocells, transit transmission, radiobridges, last mile solutions, each item implements its functions. In addition, the decision and problems associated with data centers cooling problems, power supply and scope, discusses the use of terahertz for wireless close switching and short optical lines with the ultrawide spectral channels multiplexing.

Hybrid analog-digital methods of the antennas directional diagrams formation

In MMW communications, the underlying is MIMO technology (multiple inputs and multiple outputs), which allows to compensate for the MMW large losses in the atmosphere by the narrow directional diagram. Phased antenna arrays for the MMW can have hundreds of radiating elements in small-sized equipment. And with such a scalability perspective is the Photonics and hybrid analog-digital diagrammatology application. Diagrammatology in analog AESA-based Photonics has been identified as a promising technology application of the end last century [7]. Numerous photonic techniques were proposed for the phase shift based on optical delay lines or integrated parallel MMZ. To improve performance, coverage efficiency, transfer speed are offered hybrid analog-digital diagrammatology multi-player (single-user) spatial multiplexing various models for different signal power levels, for example (fig. 4) [17].

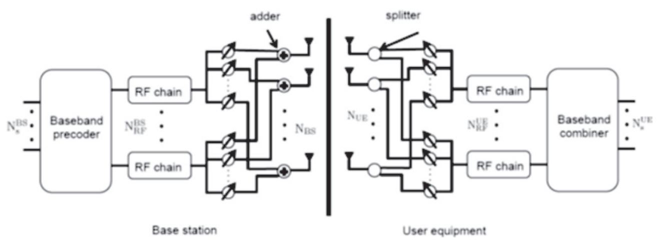

Fig. 4. A hybrid analog-digital MIMO technology to connect base stations and users

The use of hybrid technologies based on optoelectronic and electrooptical conversions gives great prospects in the MMW systems development. However, limiting factors to date, for example, the use of complex types (formats) for the MMR due to the phase noise modulation, I Q imbalance, nonlinear effects are also associated with further progress in the above mentioned hybrid technology and study of the MMW distribution physical features. The balancing techniques development, for example, shown in fig. 4, may contribute to the development of fully all of the frequency and MMR energy resource potential.

Limiting and compensating factors to evaluate network performance MMR are proposed in fig. 5.

Conclusion

The development of millimeter and terahertz range are necessary to further increase the telecommunication systems bandwidth. However, the MMW physical features, for example, diffusion and radiation, significantly distinguishable from the microwave range waves, hardware-based methods based on the photonic technology and optoelectronic conversion use and other hybrid technology can significantly affect on the work architecture and the quali-

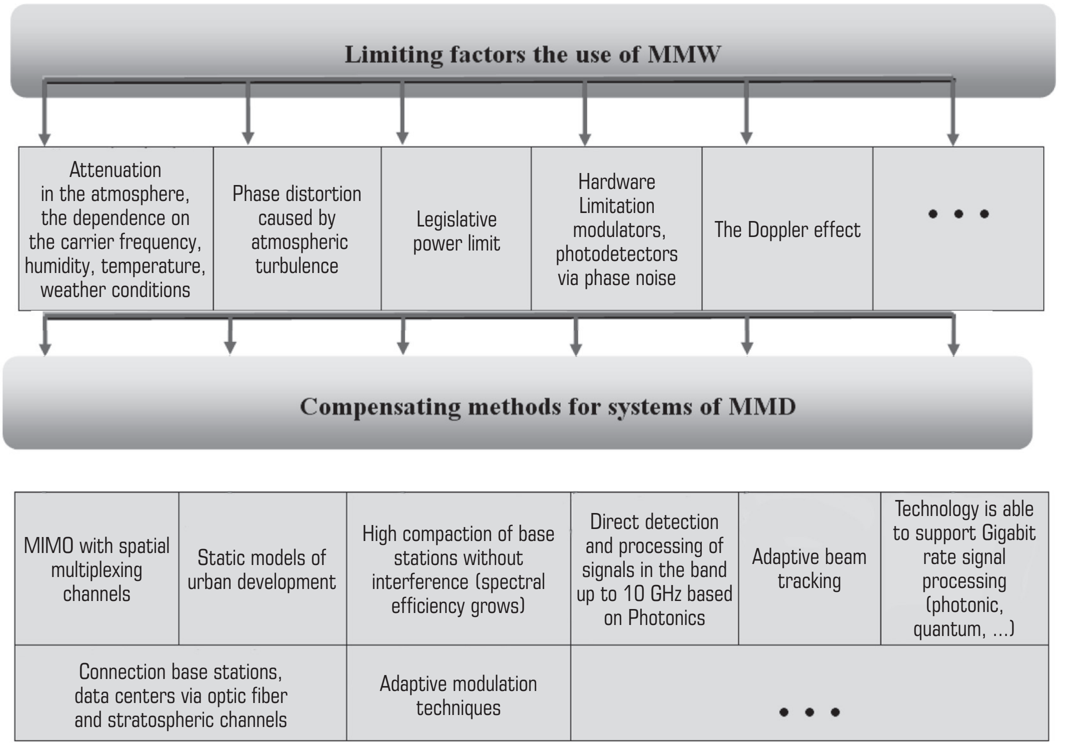

Fig. 5. Limiting and compensating factors to evaluate network performance MMR

ty of the MMW system. On the single channel model isn't possible to evaluate the network performance, spectral efficiency, power budget, and other characteristics. To create the model, architecture MMR and terahertz range systems, you should be mindful and compensating methods in each area associated with the development of these ranges.

References

1. **Cisco** *Visual Networking Index: Forecast and Methodology, 2014–2019 White Paper.— Online available:*

http://www.cisco.com/en/US/solutions/collateral/ns341/ns525/ns537/ns705/ns1175/Cloud_Index_White_Paper.html#wp9000816.

2. ***Пи, Жоую.*** *Введение в широкополосные системы связи миллиметрового диапазона / Жоую Пи, Фарук Хан.— Samsung Electronics, 2012.*

3. ***Adler, R.*** *Preparing for a 5G World. Communications and Society Program, 2016 / Richard Adler.— Online available:*

https://www.yumpu.com/en/document/view/55693626/preparing-for-a-5g-world.

4. ***Tractable*** *Model for Rate in Self-Backhauled Millimeter Wave Cellular Networks / [S. Sarabjot, N. Mandar, G. Amitava a. o.] // IEEE Journ. on Sel. Areas in Commun.— Oct. 2015.— Vol. 33, no. 10.— P. 2196–2211.*

5. ***An Overview*** *of Signal Processing Techniques for Millimeter Wave MIMO Systems / [R. W. Heath a. o.] // IEEE Journal of Selected Topics in Signal Processing, April 2016.*

6. ***Wireless*** *sub-Thz communication system with high data rate / [S. Koenig a. o.] // Nat Photon.— 7(12).— 2013.— P. 977–981.*

7. ***Основы*** *микроволновой фотоники / Винсент Дж. Урик-мл., Джейсон Д. МакКинни, Кейт Дж. Вилльямс; пер. с англ. М. Е. Белкина, И. В. Мельникова, В. П. Яковлева; под ред. С. Ф. Боева, А. С. Сигова.— М.: Техносфера, 2016.— 375 с.*

8. ***Манько, О. О.*** *Субміліметровий діапазон і новітні досягнення на базі нанотехнологій / О. О. Манько, Я. А. Кременецька, С. В. Морозова // Зв'язок.— 2015.— №2.— С. 42–49.*

9. ***W-band*** *technology and techniques for analog millimeter-wave photonics / [V. J. Urick, C. S. Sunderman, J. F. Diehl and N. D. Peterson] // Naval Res. Lab., Washington, DC, USA, NRL/MR/5651-15-9624, Aug. 2015.*

10. ***Микроволновые*** *технологии в телекоммуникационных системах / [Т. Н. Нарыткин, В. П. Бабак, М. Е. Ильченко, С. А. Кравчук].— К.: Техніка, 2000.— 297 с.*

11. ***Broadband*** *millimeter-wave propagation measurements and models using adaptive-beam antennas for outdoor urban cellular communications / [T. Rappaport a. o.] // IEEE Trans. Antennas Propag.— Apr. 2013.— Vol. 61.— P. 1850–1859.*

12. ***Rangan, S.*** *Millimeter-wave cellular wireless networks: Potentials and challenges / S. Rangan, T. Rappaport and E. Erkip // Proceedings of the IEEE.— Mar. 2014.— Vol. 102.— P. 366–385.*

13. ***Towards 5G:*** *A photonic based millimeter wave signal generation for applying in 5G access fronthaul*

/ [S. E. Alavi a. o.] // Sci. Rep.— 2016.— Vol. 6.— P. 19891.

*14. **Дружинін, В. А.** Можливості розширення зони обслуговування та радіочастотного ресурсу в стратосферних системах зв'язку / В. А. Дружинін, Я. А. Кременецька, О. Р. Жукова // Телекомунікаційні та інформаційні технології.— 2016.— № 2.— С. 23–26.*

*15. **Пирогов, Ю. А.** Микроволновые системы телекоммуникации / Ю. А. Пирогов // Вестн. Моск. ун-та.— 1994.— № 4.— С. 92–99.— (Сер. 3. Физ. Астрон).*

*16. **https:**//www.theguardian.com/technology/2016/jan/29/project-skybender-google-drone-tests-internet-spaceport-virgin-galactic.*

*17. **Kulkarni, M.** A comparison of MIMO techniques in downlink millimeter wave cellular networks with hybrid beamforming / M. Kulkarni, A. Ghosh, J. Andrews // IEEE Transactions on Communications 64 (5).— P. 1952–1967.*

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ГІБРИДНІ ТЕХНОЛОГІЇ ДЛЯ РЕАЛІЗАЦІЇ РАДІОСИСТЕМ МІЛІМЕТРОВОГО ТА ТЕРАГЕРЦОВОГО ДІАПАЗОНІВ

Розглянуто технології, що будуються на поєднанні різних властивостей і переваг радіо- та оптичних систем, які пропонуються для реалізації телекомунікаційних систем зв'язку в міліметровому і терагерцовому діапазонах. Показано, що використання гібридних топологій мережі, оптоелектронних методів формування і обробки сигналів, формування діаграм спрямованості антен, а також застосування компенсуючих методів може підвищити спектральну і енергетичну ефективність перспективних систем зв'язку в діапазонах 75...110; 200...450 ГГц.

Ключові слова: міліметровий діапазон; терагерцовий діапазон; гібридні технології; оптоелектронні методи обробки радіосигналів; фотоніка; спектральна ефективність; енергоефективність; radio-over-fiber.

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ГИБРИДНЫЕ ТЕХНОЛОГИИ ДЛЯ РЕАЛИЗАЦИИ РАДИОСИСТЕМ МИЛЛИМЕТРОВОГО И ТЕРАГЕРЦОВОГО ДИАПАЗОНОВ

Рассмотрены гибридные технологии, основанные на сочетании различных свойств и преимуществ радио- и оптических систем, предлагаемых для реализации телекоммуникационных систем связи в миллиметровом и терагерцововом диапазонах. Показано, что использование гибридных топологий сети, оптоэлектронных методов формирования и обработки сигналов, формирования диаграмм направленности антенн, а также применение компенсирующих методов — все это может повысить спектральную и энергетическую эффективности перспективных систем связи в диапазонах 75...110; 200...450 ГГц.

Ключевые слова: миллиметровый диапазон; терагерцовый диапазон; гибридные технологии; оптоэлектронные методы обработки радиосигналов; фотоника; спектральная эффективность; энергоэффективность; radio-over-fiber.

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PRELIMINARY TESTS THERAHERTZ 3D IMAGING RADAR

Were conducted preliminary tests terahertz 3D imaging radar for different system configurations and studied the properties of materials depending on the distance between the sample and the antenna.

Keywords: absorber; digital spectral analysis; electromagnetic simulator; horn antenna; far field and near field pattern.

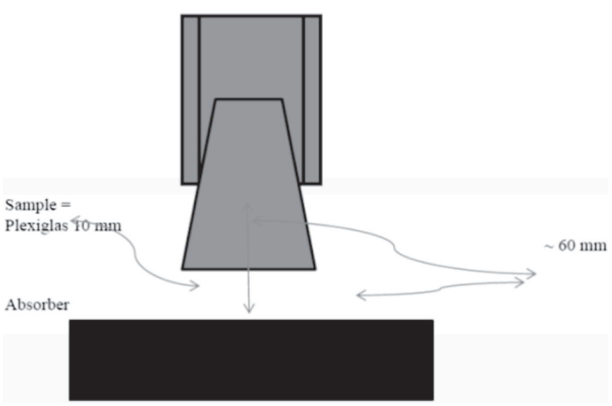

Fig. 1. Used conical horn antenna

INTRODUCTION

In scientific laboratories SPE «Quantor» designed and manufactured **FMCW** (*Frequency Modulation Continuous Wave*) radar with the following parameters: frequency band linear; frequency modulation — from 92 to 96 GHz; period (length of interval) — 1 ms; bit ADC — 16 to 32 bits; the number of cycles of accumulation — from 1 to 10 000; layers reflection — 3; distance to layers reflection — 0.095; 0.105, 0.106; wave propagation environment — air; signal-to-noise ratio — from 80 to 30 dB.

We used conical horn antenna (fig. 1). The main characteristics of the various methods of spectral estimation parameters of signals were tested in order to study radar system.