COMPUTER-AIDED DESIGN FOR ANALOG WIRELESS FRONTHAUL OF B5G CELLULAR COMMUNICATION SYSTEMS

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Abstract – *Specialties of an analog fronthaul based on Radio-over-Fiber architecture and key principles of exploiting microwave photonics technology when designing a millimeter-wave Radio Unit (RU) are reviewed and discussed. To clarify, in this paper we perform a comparative simulation for a specific example of developing an obligatory RU's node as a reference oscillator with an output radio frequency (RF) of more than 100 GHz, which is typically implemented by means of a circuit that includes a relatively low-frequency RF oscillator followed by a high-order frequency multiplier. Following the principles and approaches outlined, we propose and describe two alternative schemes for implementing a frequency multiplier from 4.25 to 102 GHz using microwave-electronics or microwave-photonics approach. Further, using Cadence AWRDE software with an additional introduction of the previously proposed models of optoelectronic devices, their main characteristics are considered. To ensure the practical orientation of the model experiments, the parameters of each of the models used are selected based on the specifications of commercially available discrete components.*

Keywords – Analog wireless fronthaul, beyond 5G telecommunication system, microwave photonics, modeling, simulation experiment

1. INTRODUCTION

As well known, the most striking event for the world of telecommunications in the second decade of the 21st century is the gradual transformation of 5th Generation (5G) cellular networks from a distant perspective into reality, and now the first commercial 5G networks have already been put into operation in a number of industrialized countries [1]. In addition, smartphones and routers with 5G support have appeared on the market. The main motivation for 5G onrush is that although mature 4th Generation Long-Term Evolution (4G LTE) networks have provided high rates of data transmission, the exchange of data on the Internet is promptly increasing every year. Here are just a few illustrative examples:

– High Definition (HD) and FullHD videos are replaced by video standards that have many times a higher resolution: 4K UHD and 8K UHD;
– large volumes of personal and corporate data are stored on remote and "cloud" servers and require round-the-clock uninterrupted access;
– technologies of augmented and virtual reality are actively developing, which are planned to be used in the educational process and online games;

– recent advances show that unmanned vehicles that independently choose the route and actively exchange information with each other are no longer fiction, but the near future of mankind.

However, the resources of 4G LTE networks were not designed for the transmission of such huge amounts of information. Despite the use of various complementary technologies such as Multiple Input/Multiple Output (MIMO) and frequency aggregation, Base Stations (BS) in densely populated urban areas are often congested. The result is that newer devices demand faster mobile Internet with lower latency and improved reliability.

When developing 5G NR (New Radio) standards, the exact requirements that new technologies and industries place on mobile communications, were taken into account. Generally, the concept of 5G NR access networks implies three key service scenarios [2-6]:

enhanced Mobile Broadband (eMBB) that supports faster transferring large amounts of user data;

Ultra-Reliable Low Latency Communications (URLLC) that reduces latency, which is critical for the development of unmanned vehicles;

massive Machine Type Communications (mMTC) that increases connection reliability for different smart devices of the Internet of Things (IoT).

At present, the main interest of a 5G NR network's operators and users is focused on the first point in order to provide super-high-speed transmission of a huge amount of information. Following this need, unlike previous generations of cellular communications, the standard frequency allocation of the 5G NR wireless fronthaul is divided into two sub-bands: Frequency Range 1 (FR1) in the 1-6 GHz [7] and Frequency Range 2 (FR2) in the 24-71 GHz [8]. The rest of the service scenarios have their own, different from each other, requirements to the accommodating networks, and the Mobile Fronthaul (MFH) and/or Mobile Backhaul (MBH) should be optimized for their implementation [9].

As for a MFH design principle, centralized radio access network (C-RAN) architecture has been already introduced in 4G LTE systems, in which multiple Remote Radio Heads (RRHs) at antenna sites are connected to a single Base Band Unit (BBU) located at a central office so as to enable coordinated control of the multiple RRHs using the Common Public Radio Interface (CPRI) technical standard. However, there is a great issue referred to the link speed for CPRI, which is more than 10 times larger than that of the mobile user data rate mainly due to the quantization process of the radio frequency (RF) signal waveform, especially of millimeter waves (MMW). Since the maximum user data rate in 5G systems is assumed to be 20 Gbps [10], this interface seems to be unsustainable in 5G NR systems in their current form. To solve this problem, a so-called functional split of the BS configuration was recently standardized into the next generation RAN (NG-RAN) with the introduction of newer functional blocks, such as a Central Unit (CU), a Distributed Unit (DU), and a Radio Unit (RU) instead of a BBU and RRH [11-13].

To design optimally NG-RANs using analog Radio-over-Fiber (A-RoF) architecture, two options including Radio Frequency-over-Fiber (RFoF) and its derivative Intermediate Frequency-over-Fiber (IFoF) transmission architectures are considered as promising candidates [14]. In addition, the microwave-photonics (MWP) technology [15] is promising for designing the equipment for the RUs of the millimeter and sub-millimeter ranges, in which the updated 5G and new beyond 5G (B5G) MFH networks will operate.

Analysis of research articles [12, 13 and the references therein] and Internet communications referred to the latest developments in the field of 5G NR allows us to conclude that for today, world equipment manufacturers have fully mastered the FR1 compatible with 4G LTE and partially the FR2, mainly in its lower sub-band. In its upper part of far beyond 40 GHz, the network and user equipment has received the greatest development, providing wireless communications only with fixed network users. The implementation by mobile network users of the all allocated MMW band and prospective operating RFs up to and over 100 GHz using all three of the above service scenarios is considered as the crucial task for wireless fronthaul of 6th generation (6G).

A detailed study of existing approaches to the optimal configurations of B5G networks and our experience in researching the optimal principles for designing analog fronthaul networks with the distribution of RF signals in the MMW band [16-21] suggest that for an NG-RAN, the optimal approach would be to use A-RoF as an architectural concept and MWP as a technological concept for designing an RU containing both optoelectronic and microwave-electronic (MWE) elements. However, the developer of new MWE devices including MWP units is facing a problem of choosing an appropriate computer platform for their modeling and design. In particular, an RU designer is forced to use means of several computer-aided design (CAD) tools because the existing optical and optoelectronic CAD tools (OE-CAD) are not as developed as compared with the CAD tools intended for the modeling of microwave-electronics devices (ME-CAD) [22]. For example, well-known OE-CAD tool VPI Photonics Design Suite (PDS) allows executing in precision manner the modeling of a fiber-optic link with detailed study of optical units' performances, but RF and especially microwave and millimeter-wave functional units are represented in an idealized manner, without paying attention to the specialties of the microwave band. On the other hand, operating at a symbolic level modern high-power microwave ME-CAD tool Cadence AWRDE simply and with high precision solves this problem but there are completely no models of active optoelectronic components in its library. To fill this gap, we have developed by AWRDE and validated experimentally a number of the models for active and passive MWP elements, such as semiconductor laser, p-i-n photodetector, two types of optical

modulator, single and multi-core optical fiber, multichannel reflecting Bragg grating, and for some MWP devices using these models. The development results are summarized in [23]. In addition, in order to show the effectiveness and reliability of the proposed approach, a comparative study was carried out using a direct comparison of ME-CAD vs OE-CAD models when simulating both individual optoelectronic elements in a microwave bandwidth and some MWP devices based on them [24]. The result clearly showed that the optimal approach for this purpose was in using established microwave-electronic CAD tool Cadence AWRDE, especially during the modeling of MMW devices, as it is needed for designing analog fronthaul RU of B5G.

Nevertheless, this unit raises the question of choosing the optimal principle for designing its circuitry using an MWE or MWP approach. To clarify this, in this paper we perform a comparative simulation for a specific example of developing such an obligatory RU's node as a reference oscillator with an output frequency of more than 100 GHz, which is typically implemented by means of a circuit that includes a relatively low-frequency RF oscillator followed by a high-order frequency multiplier. Thus, the rest of the paper contains the following. Section 2 addresses the features of configuring an analog fronthaul network using the above two options of RoF architecture. In addition, the key principles of MWP-based hardware design are explained in Section 3. Following the principles and approaches outlined, Section 4 proposes and describes two alternative schemes for implementing a frequency multiplier from 4.25 to 102 GHz using MWE or MWP approach. Further, with the help of AWRDE software with an additional introduction of the previously proposed models of optoelectronic devices, their main characteristics are considered. To ensure the practical orientation of the model experiments, the parameters of each of the models used are selected based on the the specifications of commercially available discrete components. Section 5 concludes the paper.

2. A-ROF-BASED ARCHITECTURE FOR WIRELESS FRONTHAUL

In general, a NG-RAN of A-RoF architecture combined with a small-cell scenario is considered as the reliable way for the further development of cellular communication networks beyond 5G. At the same time, due to the relatively small number of user terminals in a picocell, the requirements for cost-efficiency of the RU equipment, in fact, representing the interface between the optical and RF sections of the transmission system come to the forefront. The most obvious solution to this problem is the ultimate simplification of the RU scheme, which is carried out by removing all the processing units (generation, modulation, demodulation, RF frequency conversion, etc.) to the CU or DU. That is, a package of modulated RF carriers with frequencies corresponding to the operating frequencies of the wireless fronthaul is inputted to the optical transmitters of the DU (downlink) and the RU (uplink). Therefore, the decisive influence on their characteristics effects the scheme of transporting digitally modulated RF signals through a fiber-optic cable between the DU and RU. Fig. 2 illustrates two possible options noted in the Introduction to design NG-RAN wireless fronthaul including RFoF (a), and IFoF (b). The following abbreviations are used in the figure: EA – electronic amplifier; EOM – electro-optic modulator; IFDM – IF demodulator; IFM – IF modulator; IF/RF – frequency up-converter; MIMO – multiple input/multiple output; MMW-RO – millimeter-wave reference oscillator; MW-RO – microwave reference oscillator; PD – photodetector; RF/IF – frequency down-converter; RFDM – RF demodulator; RFM – RF modulator; SLS – semiconductor laser source.
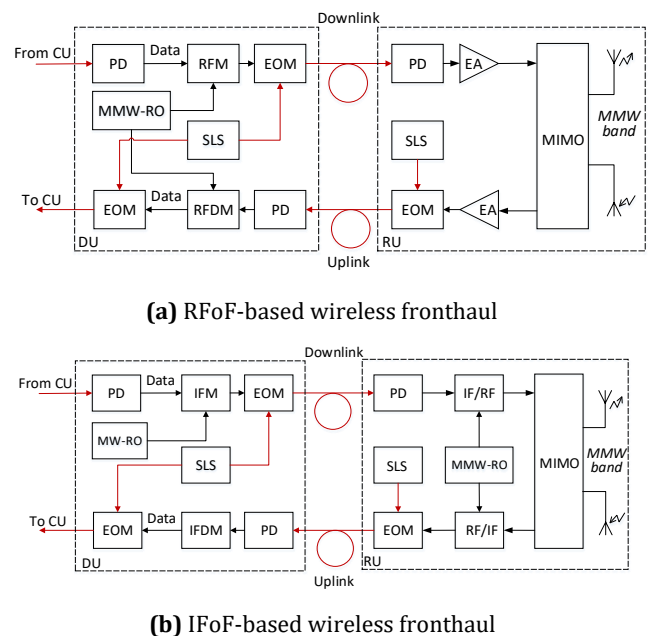

(a) RFoF-based wireless fronthaul

(b) IFoF-based wireless fronthaul

Fig. 1 – Conceptual diagrams of NG-RAN's A-RoF wireless fronthauls (Optical connections are painted in red, electrical connections in black)

The following conclusions can be drawn from the figure:

− The value of the RF subcarrier in the first option is significantly higher in comparison with the second one, which tightens the requirements for the electronic and optoelectronic components of the DU and RU equipment and, as a result, their cost.

− The option with transmission in the RF band is realized with the least number of transformations on the RU, which minimizes its cost, and, consequently, the cost of the fronthaul network equipment.

However, the fiber-optic transmission of the MMW-band signals has a serious limitation due to the dispersion effect of a standard single-mode optical fiber [15]. Namely, according to the conducted modeling experiments, in which the options for the transmission of optical signals with quadrature amplitude modulation (QAM) at RF of 40 GHz and IF of 15 GHz are compared [16, 21, 25] the maximum permissible distance between the DU and RU, even at such a relatively low MMW frequency, decreases by more than 4 times compared to transmission at the IF, reaching units of km, which is not always provided in real C-RAN fronthauls. It is understood that the situation will become much more critical for B5G NG-RANs using RF subcarriers above 100 GHz.

That's why we believe that the optimal approach would be IF-over-Fiber transmission in spite of this option requires an interface at the RU that has to perform RF conversion. Nevertheless, transmission in the IF-band provides flexibility, as there is a simple possibility of RF conversion at a RU, both in the FR1 and in the FR2 (see Introduction).

To effectively implement it in the downlink of Fig. 1 (b), a MMW frequency up-converter is used in the RU scheme, an important element of which is a reference oscillator (RO), the optimal design principle of which will be investigated in Section 4.

3. MICROWAVE PHOTONICS APPROACH TO DESIGN ELECTRONICS APPARATUSES

Microwave photonics is a multidisciplinary scientific branch combining optical, RF, microwave, MMW, and terahertz fields [15, 26, 27 and refs. cited therein]. This field in the last 30 years has attracted immense interest and generated many new R&Ds from both the scientific community and the commercial sector. Emerging applications for a mobile communication network of RoF architecture, sub-terahertz wireless systems, radar, and electronic warfare systems indicate that MWP is a subject of importance. By common opinion, MWP opens the way to super-wide bandwidth characteristics at lower size, weight, and power as compared with traditional means. Fig. 2 depicts typical arrangements of MWP subassembly. As it follows, a photonic processing unit (PPU) is inserted between two optoelectronics modules that are electrical-to-optical (E/O) and optical-to-electrical (O/E) converters. The first one usually includes a semiconductor laser source (SLS) and electro-optic modulator (EOM) as E/O converter. The second one typically contains a pin-photodetector (PD) followed by a low-noise electronic amplifier (EA). Typical functions of the PPU are transmission, switching, distribution, filtration, time-delaying, and up/down frequency conversion of RF signals in an optical domain. An example of the last operation in relation to the RF multiplier circuit including in the reference oscillator of 102 GHz for the NG-RAN RU (see Fig. 1 (b)) will be discussed in Section 4.
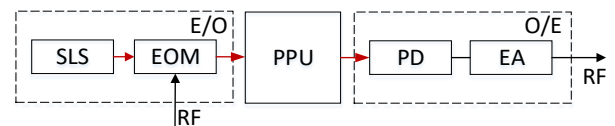

Fig. 2 – Conceptual diagram of MWP subassembly (Optical connections are painted in red, electrical connections in black)

4. COMPARATIVE COMPUTER-AIDED DESIGN OF MMW FREQUENCY MULTIPLIER

In the section, we propose and describe two alternative schemes for implementing a frequency multiplier from 4.25 to 102 GHz using an MWE or MWP approach. The goal of the simulation is to select an optimal design concept for developing a high-order RF multiplier of NG-RAN's reference oscillator using the same input and output powers and frequencies. For both cases, Cadence AWRDE software with an additional introduction of the previously proposed models of optoelectronic devices is implemented. To ensure the practical orientation of the simulation experiments, the parameters of the active and passive schematic elements are selected based on the data sheets of the specific manufactured devices. Table 1 lists the common reference data for the simulation.

4.1 The block diagrams and reference data for simulation

The block diagram of the MWE-assisted RF multiplier under study based on a typical approach to designing high-order MMW multipliers [28] is shown in Fig. 3.

Table 1 – Common reference data

Parameter	Value
Input frequency	4.25 GHz
Output frequency	102 GHz
Multiplication factor	24
Input power	≥5 dBm
Transmission gain	≥-5 dB

As it follows from the figure, due to the fact that a high-order coaxial frequency multiplier is practically impossible to implement in the microwave range [28], the circuit is divided into 3 stages of active multipliers by 2 (MP2-1, MP2-2, and MP2-3), followed by a multiplier by 3 (MP3) in a coaxial-waveguide design. To eliminate the higher harmonics arising in the process of this nonlinear operation, after each multiplication stage the corresponding bandpass filters (BPF1, BPF2, BPF3 and BPF4) are introduced. Reference data for simulating this RF multiplier are given in Table. 2. The parameters of all devices are taken from the websites of the respective manufacturers.

The block diagram of the MWP-assisted RF multiplier under study based on a known MWP approach to designing high-order MMW multiplier [29] is shown in Fig. 4. As it follows from the figure, the circuit is divided into 2 stages based on optical Mach-Zehnder modulators (MZM) pumped by the same semiconductor laser source (SLS). The MZM1 of the first one operates in the maximum transmission bias (MATB) mode implementing 4x multiplication of the input RF signal (4.25 to 17 GHz). Its output intensity-modulated optical spectrum including optical carrier and a set of higher harmonics of the RF subcarrier is converted by a photodetector (PD1) into an RF band, amplified by an electrical amplifier (EA), and the component of 17 GHz is selected using an RF bandpass filter (RF BPF). The output signal of the RF BPF is fed to the input of the second MZM2 that operates in the minimum transmission bias (MITB) mode implementing 6x multiplication (17 to 102 GHz). Its output intensity-modulated optical spectrum including a partly suppressed optical carrier and a set of higher harmonics of the RF subcarrier is filtered by an optical Bragg grating notch filter (OBGF) suppressing an optical carrier and the two nearest harmonics of the RF signal. The remainder is gained by an optical amplifier (OA), converted by a photodetector (PD2) into an RF band, amplified by EA3, and filtered by a waveguide bandpass filter (WG-BPF). Reference data for simulating this RF multiplier is given in Table. 3. The parameters of all devices are taken from the websites of the respective manufacturers.
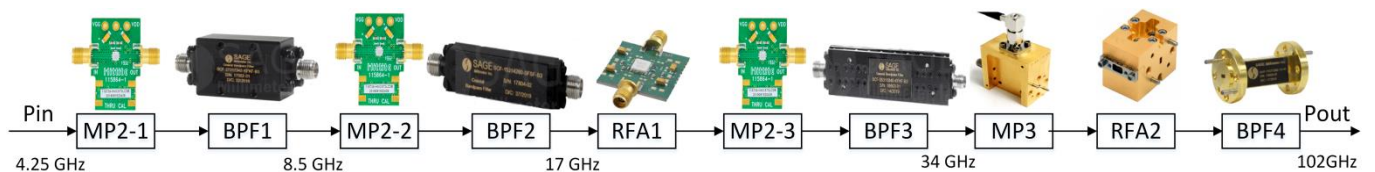

Fig. 3 – Block diagram of the MWE-based frequency multiplier under study
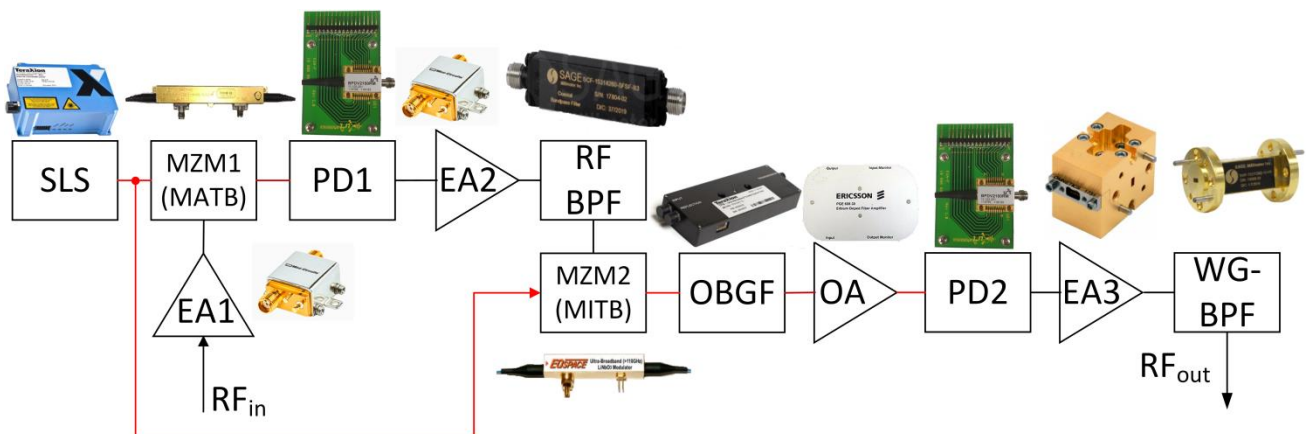

Fig. 4 – Block diagram of the MWP-based frequency multiplier under study (Optical connections are painted in red, electrical connections in black)

Table 2 – Reference data for the simulation experiments referred to MWE approach (Fig. 3)

Element	Manufacturer	Model	Parameter	Value
MP2-1, MP2-2	Analog Devices	HMC573LC3	Input frequency range	4-11GHz
			Output frequency range	8-22GHz
			Typical output power	12dBm
			Typical F_0 isolation	20dBc
BPF1	Eravant (formerly SAGE Millimeter)	SCF-96222270	Bandpass frequencies	8.5-10.7GHz
			Bandpass insertion loss	1dB
			Low side/high side rejection	70/70dB
BPF2	Eravant (formerly SAGE Millimeter)	SCF-17304240	Bandpass frequencies	16.94-17.34GHz
			Bandpass insertion loss	1.5dB
			Low side/high side rejection	40/40dB
RFA	Analog Devices	HMC1082LP4	Frequency response	5.5-18GHz
			Gain	22dB
			OIP3	35dBm
MP2-3	Analog Devices	HMC598	Input frequency range	11-23GHz
			Output frequency range	22-46GHz
			Typical output power	15dBm
			Typical F_0 isolation	20dBc
BPF3	Eravant (formerly SAGE Millimeter)	SCF-35310340	Bandpass frequencies	30-40GHz
			Bandpass insertion loss	1dB
			Low side/high side rejection	40/40dB
MP3	Virginia Diodes	WR8.0x3	Input frequency range	30-46GHz

Element	Manufacturer	Model	Parameter	Value
			Output frequency range	90-140GHz
			Input power	20-240mW
			Harmonics	-20dBc
RFA2	Eravant (formerly SAGE Millimeter)	SBL-6531243550	Frequency range	65-120GHz
			Gain	35dB
			Noise figure	5dB
BPF4	Eravant (formerly SAGE Millimeter)	SWF-10404340-10-B1	Bandpass frequencies	98-102GHz
			Bandpass insertion loss	2dB
			Low side/high side rejection	40/40dB

Table 3 – Reference data for the simulation experiments referred to MWP approach (Fig. 4)

Element	Manufacturer	Model	Parameter	Value
SLS	Teraxion	NLL	Wavelength range	1525-1565nm
			Output power	80mW
			Linewidth	10kHz
			Frequency noise (1-100kHz)	$<2\times10^4$ Hz^2/Hz
MZM1	ThorLabs	LN05S-FG	Wavelength range	1525-1605nm
			Insertion loss	5dB
			Optical extinction ratio	20dB
			Bandwidth	35GHz
			Maximum RF power	24dBm
EA1	Analog Devices	HMC637	Frequency range	0.1-6GHz
			Gain	13dB
			P1dB output power	29dBm
			Noise figure	5dB
PD1	II-VI (formerly Finisar)	BPDV2150	Wavelength range	1525-1575nm
			Bandwidth,	0-43 GHz
			Responsivity	0.6A/W
			Maximum Optical Input Power	16dBm
EA2	Analog Devices	HMC1082LP4	Frequency response	5.5-18GHz
			Gain	22dB
			OIP3	35dBm

Element	Manufacturer	Model	Parameter	Value
RF BPF	Eravant (formerly SAGE Millimeter)	SCF-17304240	Bandpass frequencies	16.94-17.34GHz
			Bandpass insertion loss	1.5dB
			Low side/high side rejection	40/40dB
MZM2	EOspace	Custom	Wavelength range	1525-1565nm
			Insertion loss	7dB
			Optical extinction ratio	20dB
			Bandwidth	110GHz
			Maximum RF power	18dBm
OBGF	Teraxion	TFN	Wavelength range	1525-1565nm
			Bandwidth	2-50GHz
			Insertion loss	≤3.5dB
			SMSR	>20dB
			Maximum input power	500mW
OA	Ericsson	PGE 60830	Wavelength range	1540-1560nm
			Gain	20dB
			Maximum output power	13dBm
			Noise ratio	5 dB
PD2	II-VI (formerly Finisar)	XPDV4121R	Wavelength range	1525-1575nm
			Bandwidth,	0-105GHz
			Responsivity	0.6A/W
			Maximum Optical Input Power	10dBm
EA3	Eravant (formerly SAGE Millimeter)	SBL-6531243550	Frequency range	65-120GHz
			Gain	35dB
			Noise figure	5dB
WG-BPF	Eravant (formerly SAGE Millimeter)	SWF-10404340-10-B1	Bandpass frequencies	98-102GHz
			Bandpass insertion loss	2dB
			Low side/high side rejection	40/40dB

4.2 AWRDE models and setups

Fig. 5 depicts the AWRDE model of a 24-order frequency multiplier based on an MWE approach. The model under study includes a chain of frequency multipliers in the form of subcircuits (SUBCKT), bandpass filters (BPFD), and amplifier (LIN_S) library models in accordance with Fig. 3. For running a simulation experiment, two instrumental library models of RF oscillator (TONE) and RF spectrum analyzer (TP) are introduced on its input and output, correspondingly. The parameters of each element of the model are taken from Table 2. In the bottom of the figure, the output power values for each stage are marked.

It should be noted that each of the first three selected frequency multipliers is an integrated circuit containing the multiplying stage itself, located between the input and output amplifiers (Fig. 6).
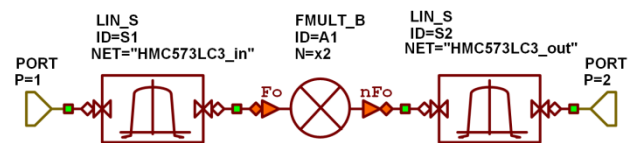

Fig. 6 – The schematic of each of the first three frequency multipliers

In addition, Fig. 7 depicts the AWRDE model of a 24-order frequency multiplier based on an MWP approach. The model under study includes a chain of subcircuits (SUBCKT) in accordance with Fig. 4 and Table 3. Namely, it contains the models of RF devices ("EA1", "EA2-1", "EA2-2", "RF BPF", "EA3", "WG BPF"), which are the same for Fig. 5, early proposed models of active optoelectronic devices [23, 24] such as semiconductor laser source ("Laser"), Mach-Zehnder modulators ("MZM1", "MZM2"), photodetectors ("PD1", "PD2"), and optical Bragg grating filter ("OBGF"), as well as equivalent optical elements such as splitter ("SPLIT2"), isolators ("ISOL8R"), amplifier ("OA"), and coaxial-to-waveguide adapter ("WG1"). The calculation of the elements of the last group, due to the work of AWRDE at the symbolic level (see Introduction), is performed in the same way as their microwave counterparts. The parameters of each element of the model are taken from Table 3.
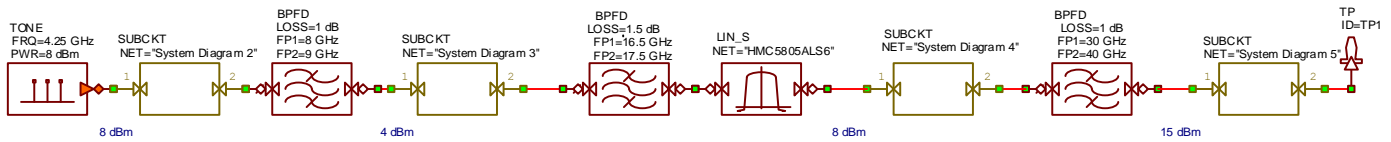
Fig. 5 – AWRDE setup of MWE approach-based frequency multiplier
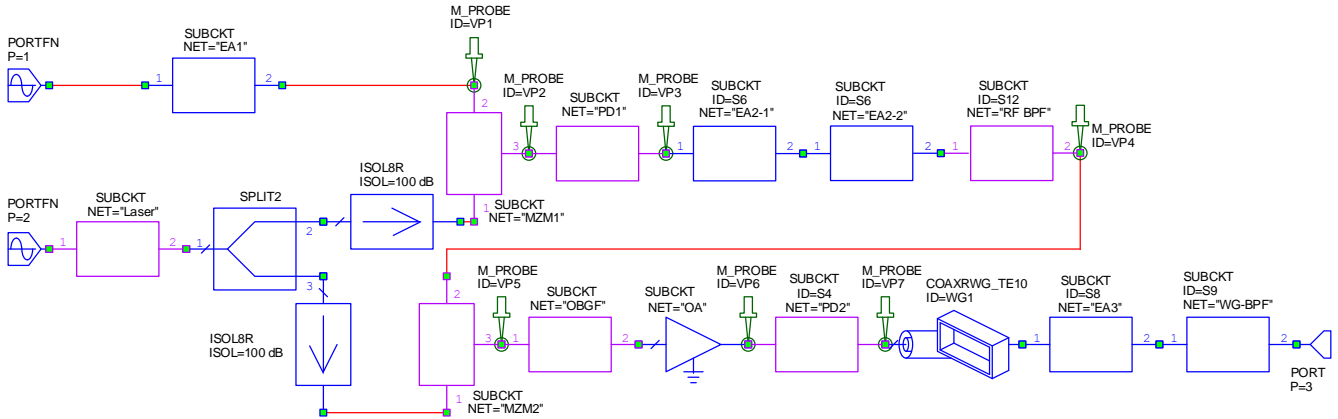

Fig. 7 – AWRDE setup of MWP approach-based frequency multiplier

Currently, the operating principles and features of the above optoelectronic devices are described in a large number of publications (see, for example, [15]). Nevertheless, for a better understanding, we believe it necessary to explain the operation of the Mach-Zehnder electro-optic intensity modulator in the modes of MATB and MITB used in this model. The basic circuit of MZM, is shown in Fig. 8.
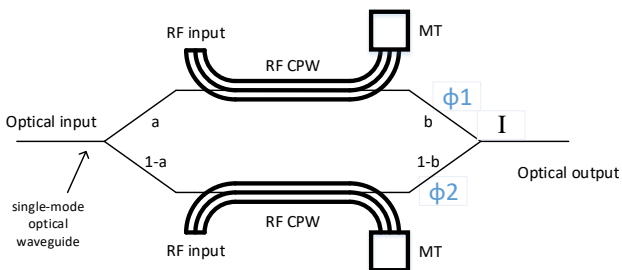

Fig. 8 – Basic circuit of MZMs used in MWP approach-based frequency multiplier

In the figure unmodulated laser emission is introduced through the input optical waveguide. In accordance with the principle of designing a widely-known Mach-Zehner interferometer (MZI), the optical circuit contains two planar single-mode waveguides formed in lithium niobate connected by input and output Y-couplers with branching coefficients "a" and "b". Depending on the phase difference between optical fields, φ_1- φ_2, the light can constructively or destructively interfere. An interaction with propagating an optical signal is performed by the coplanar waveguides (CPW) including the matched terminations (MT) on their ends. Assuming no loss in waveguides, the equality

of dividing coefficients of both splitters, and ideal linear electro-optic effect, the transfer function of MZM will correspond to formula (1), where V is applied voltage, Vπ is a so-called half-wave voltage related to control bias at which the phase difference in the two MZI arms reaches 180º.

$$T_{MZM}\left(V\right) = \frac{1}{2}\left\{1 + \cos\left[\varphi_0 + \frac{\pi V}{V_\pi}\right]\right\} \qquad (1)$$

Calculated by (1) taking into account the data in Table 3, the transfer characteristic of the MZM with the marked areas of MATB and MITB modes is shown in Fig. 9.
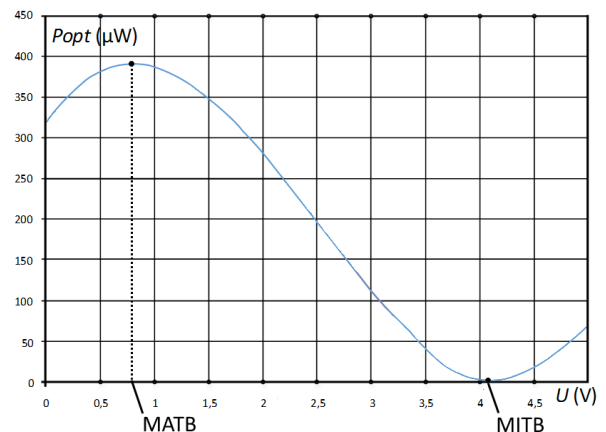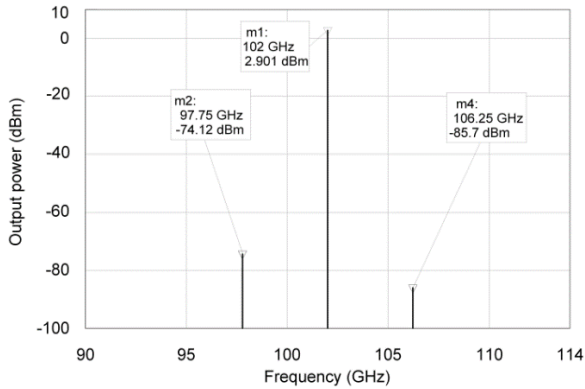

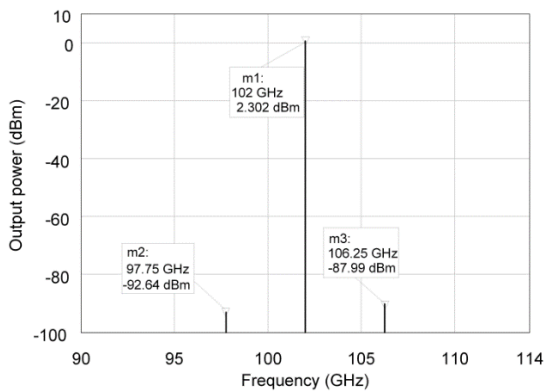**Fig. 9** – The transfer characteristic of the MZM

4.3   Simulation results

In the course of the simulation experiment, first, the spectra at the output of the frequency multiplier for the circuits in Fig. 3 and Fig. 4 were

under study. The measurement results are shown in Fig. 10 (a) for an MWE approach and in Fig. 10 (b) for an MWP approach.

(a) For MWE model

(b) For MWP model

Fig. 10 – Simulated output spectra for the frequency multiplier under study

In addition, their amplitude characteristics were investigated. The measurement results of output power vs input power are shown in Fig. 11.
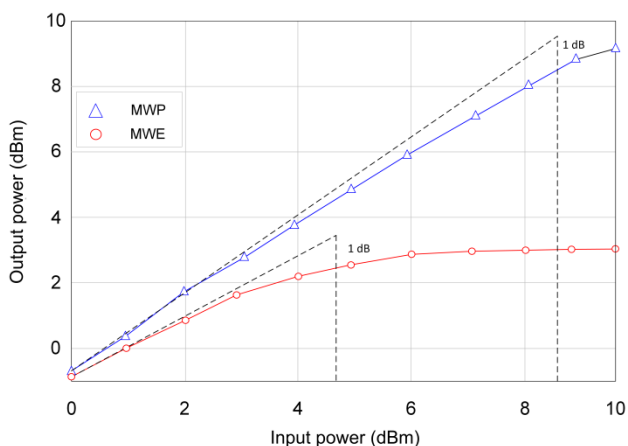

Fig. 11 – Amplitude characteristics for the frequency multiplier under study

The following outcomes can be drawn from these figures.

− The output spectra of both schemes under study have a high-side mode suppression ratio. Nevertheless, due to the higher linearity of the characteristics of the used optoelectronic devices, its minimum value for the MWP approach turned out to be 13 dB higher (90 dB vs 77 dB) than for the MWE approach.
− Measurement of the amplitude characteristics showed that the input power level of the MWP-based scheme according to the standard criterion, which is a 1-dB deviation from linear, is almost 5 dB higher than that of the MWE-based scheme. Consequently, its dynamic band is significantly better.

5. CONCLUSION

To choose the optimal principle for designing B5G NG-RAN's radio unit circuitry using a microwave-electronics (MWE) or microwave-photonics (MWP) approach, in this paper we performed a comparative simulation for a specific example of developing such an obligatory RU's node as a reference oscillator with an output frequency of more than 100 GHz, which was typically implemented by means of a circuit that includes a relatively low-frequency RF oscillator followed by a high-order frequency multiplier. In particular, we proposed and described two alternative schemes for implementing a frequency multiplier from 4.25 to 102 GHz using an MWE or MWP approach. The goal of the simulation was to select an optimal design concept for developing a high-order RF multiplier of NG-RAN's reference oscillator using the same input and output powers and operating frequencies. For both cases, Cadence AWRDE software with an additional introduction of the previously proposed models of optoelectronic devices was implemented. To ensure the practical orientation of the simulation experiments, the parameters of the included active and passive schematic elements were selected based on the the specifications of commercially available discrete components.

As a result, a comparison of the investigated variants showed the potential advantage of the MWP approach from the point of view of the simplicity of the scheme, since even at the current level of optoelectronic device production, the

multiplication of a higher order is essentially provided. This advantage will significantly increase as promising optoelectronic devices [30] are put into production and the operating frequencies of the B5G systems move into the submillimeter range. Another advantage is the significally wider dynamic range that cannot be achieved with the traditional MWE approach.

Our further research will focus on a detailed comparative study of the rest of the crucial features of the high-order frequency multipliers for 5G's fronthaul, in particular, on the phase noise characteristic that is one of the main limitations of frequency-multiplying chain in millimeter and sub-millimeter wavelength ranges, as well as on experimental verification of the simulated results.

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