An Integrated Photonic Remote Access Unit for 60 GHz Wireless Connections

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We present the design of a Remote Access Unit (RAU) that integrates Radio-Over-Fiber (RoF) with 60 GHz wireless (10-20 GHz on-chip) and Fiber to the Home (FTTH) services. The device integrates several tunable radio frequency transmitters and optical receivers on a single Indium phosphide chip. It can simultaneously operate in four bands within the 1500-1570 nm wavelength range. The chip was designed within a Multi Project Wafer run and benefits from the generic integration technology and use of standardized building blocks, available through dedicated software tools and Process Design Kits (PDKs).

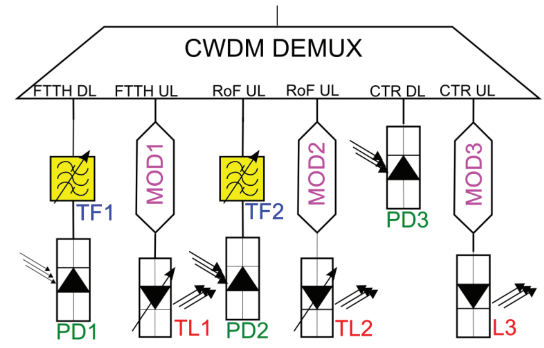
1 Introduction

Rapidly increasing demand for network capacity and efficiency observed during the past decades enforced changes in telecommunication technologies. Providers are seeking for the alternative infrastructures that would lower their costs, improve user safety and allow supporting multiple services [1]. It seems the design of the cutting-edge and cost-efficient Next-Generation access Networks (NGN) [2] is only possible by merging the currently distinct optical and wireless infrastructures [3]. Such an amalgamated network would be capable of offering the best part of both worlds: the stability, ultra-high capacity and long transmission distances of optical fiber networks with the agility and flexibility of the wireless networks. To achieve this goal the COMANDER project [4] proposed a novel design of the Access Point Unit (APM) which builds upon the Radio-over-Fiber paradigm and provides a large flexibility since it can coexist with all the systems already deployed on the same physical configuration. Moreover, a 60 GHz band is introduced in order to deliver unforeseen multi-gigabit speeds to the wireless user. Described combination of subcarrier modulation techniques and the tools to isolate and select wavelengths "on demand" enables prospective operators to dynamically allocate the bandwidth to the particular subscribers.

2 Access Point Module specification

The APM employs a Coarse Wavelength Division Multiplexing (CWDM) multi/de-multiplexer that separates an optical signal into the six bands as specified in Fig.1.

All the down link signals are generated at the Central Office (CO) and carry dual side band (DSB) or single side band (SSB) modulated traffic at an intermediate frequency between 10 to 15 GHz subcarrier. 60 GHz mm-wave carrier is subsequently generated at the APM output with the aid of electronic up-converter or optical delayed interferometer for the wireless transmission of the data. The uplink channels are in turn generated at the APM by externally modulated continuous wave (CW) lasers.



FTTH DL: Fiber To The Home down link, **FTTH UL:** Fiber To The Home uplink, **RoF DL:** Radio over Fiber down link that carries data signals from the CO to the APM, **RoF UL:** Radio over Fiber uplink that carries data signals from the APM to the CO,
CTR DL: Control down link that carries control signals from CO to APM, **CTR UL:** Control uplink that carries control signals from the wireless antenna to the CO.

Figure 1: Scheme of the proposed chip design.

The control signals are used for bandwidth allocation processes, wavelength tuning of the RoF DL filter and the RoF UL tunable laser tuning prior to the initiation of the next scheduled data session. After Optical-to-Electrical conversion at the photodiode, the control signals generated at subcarrier frequency of 59.8 GHz, are broadcasted by the microwave antenna. At the same time, the UL control wavelength carries signaling pulses from the wireless antenna to the CO which notify the latter about the pending uplink traffic requests from the wireless users.
The target transmission speed of UL and DL FTTH signals is 10 Gbps whereas for the respective RoF signals 2.5 Gbps is foreseen. The control signals require sub-gigabit speeds to ensure communication between the APM and CO.

3 Circuit design

The optical subunit of the APM was designed as a photonic integrated circuit (PIC) on the Indium Phosphide platforms following the generic integration concept [5]. Two proposed chips will be fabricated in cooperation with foundry partners Oclaro and FhG HHI [6, 7] in a multi-project wafer (MPW) run [8] offered by the PARADIGM project [9]. The size of the chip is in both cases is 4 × 6 mm^2 and it combines several passive and active devices: multiplexer, fixed and tunable transmitters and tunable receivers as schematically shown on Fig.1.
It is worth noticing that both chips were designed with the use of OptoDesigner – a dedicated software [10] which significantly reduced time for translating the functional specification into a final mask layout by offering direct access to the PDK of the chosen foundry. Moreover, the information about technology and parameters of the building blocks provided by the foundries in their Design Manuals allowed compatibility check at the early stage of the design process and prevented additional problems that might have been potentially introduced during circuit compilation. Once all the building blocks were placed and the interconnections were made, the Design Rule Check (DRC) functions built into the software enabled fast an accurate verification whether the design is foundry compliant.

3.1 Multiplexer/Demultiplexer

The CWDM multiplexer/demultiplexer was realized as an Arrayed Waveguide Grating (AWG). The original design assumed cascading AWGs in order to obtain the targeted multi/demultiplexer response. However, due to the complexity of the whole circuit and the use of multiple building blocks the available space on the die was significantly reduced, therefore authors decided to use a single multiplexer for all 6 channels. The AWG of a reasonably smaller footprint was specifically designed to have a non-constant channel spacing and was optimized for both foundries. Due to the waveguide resolution it was not possible to obtain large bandwidth difference per channel without introducing additional losses or increasing the footprint. The figure below shows the comparison between AWG responses for the target specification and the final design.

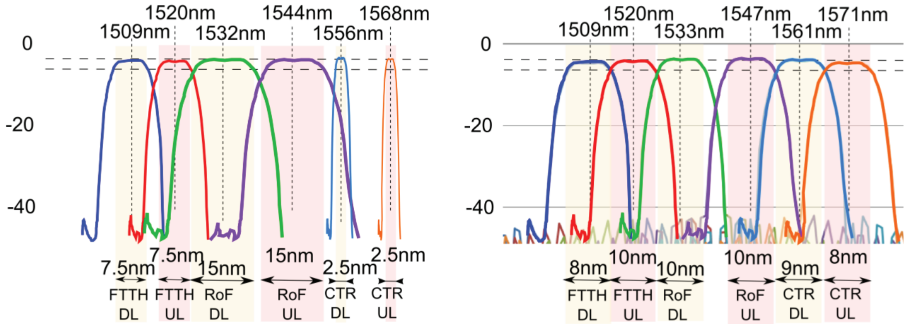


Figure 2: Comparison of the target and designed spectral response of the multi/demultiplexer

3.2 Tuneable Transmitters

The circuit of Fig.1 contains two tuneable Distributed Bragg Reflector (DBR) lasers of the structure presented in figure 3.

In case of FhG/HHI the DBR laser is offered as a smart building block, while on the Oclaro platform the corresponding structure has to be built from the basic building blocks.

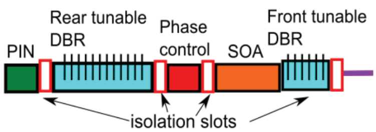


Figure 3: Tuneable laser structure with isolation slots.

Regardless of the approach, each laser structure was optimized to meet the targeted specification – central wavelength and tuning range while obeying the foundry rules.

Bragg reflectors create the resonant cavity while a Semiconductor Optical Amplifier (SOA) section provides gain. The short front grating determines both the position of the reflectivity peak and the level of optical power being coupled out. The long rear tunable grating is tuned to the same peak position but has to provide much higher reflectivity. As the reflectivity depends on both grating's length L and its strength κ it might be impossible to obtain exactly 100% in the fabrication process. Therefore a PIN photodiode is placed behind the rear DBR as an optical termination element. Both foundries offer tunability of their gratings in the 4 nm range towards shorter wavelengths. The main parameters of the DBR laser for both foundries are compared in the table below.

Table 2: Comparison of the tuneable laser parameters designed at HHI and Oclaro platforms.

Parameter name	Kappa [cm^{-1}]	L RDBR [µm]	L FDBR [µm]	L SOA [µm]	L PM [µm]
HHI	90	300	50	500	50
Oclaro	35	500	60	450	130

Amplitude modulation with speeds over 10 Gbps as defined in section 2 can be obtained on Oclaro platform which benefits from the fast electro-optic phase modulators

(EOPMs). Mach Zehnder Interferometers (MZI) with 500 μm long EOPMs in their arms working in push-pull configuration were employed for modulation of FTTH UL, RoF UL and CTR UL signals.
Since the thermal and current injection phase modulators on the HHI platform offer much lower modulation speeds another approach was used. Additional SOA section was placed in front of the DBR laser as an optical switch, performing on-off keying.

3.2 Tuneable Receivers

Tuneable receivers are designed as a cascade of a tuneable filter and an RF PIN photodiode. Since tunable filters are not available in the foundry design kit two approaches were proposed to realize them. The first approach involves a continuous filter based on the asymmetric Michelson interferometer [11] with Bragg gratings in its both arms. The simulations carried out in a circuit simulator [10] allowed to optimize the filter structure for 1 nm of 3-dB bandwidth (BW) and the extinction ratio (ER) of 15 dB. The tunability range, limited by the tunability of thee gratings, equals to 4 nm. When it comes to the Oclaro platform a discrete filter was designed i.e. a SOA-based wavelength selector [12], with a simulated 3dB bandwidth of 0.75 nm of and estimated extinction ratio of 20 dB.

Conclusions and acknowledgments

We have designed an optical subunit of the Access Point Module on a 4 x6 mm^2 PIC. Using a CWDM multiplexing scheme, the device contains three transmitter and three receivers channels for FTTH, RoF and control functionality. The PIC will be fabricated via the OCLARO and HHI MPW runs of the PARADIGM project. Despite the unavoidable difference of the designs on the building block level we expect to be able to operate the APM units in a single system as we demonstrated that they have been designed towards a single circuit functionality.

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