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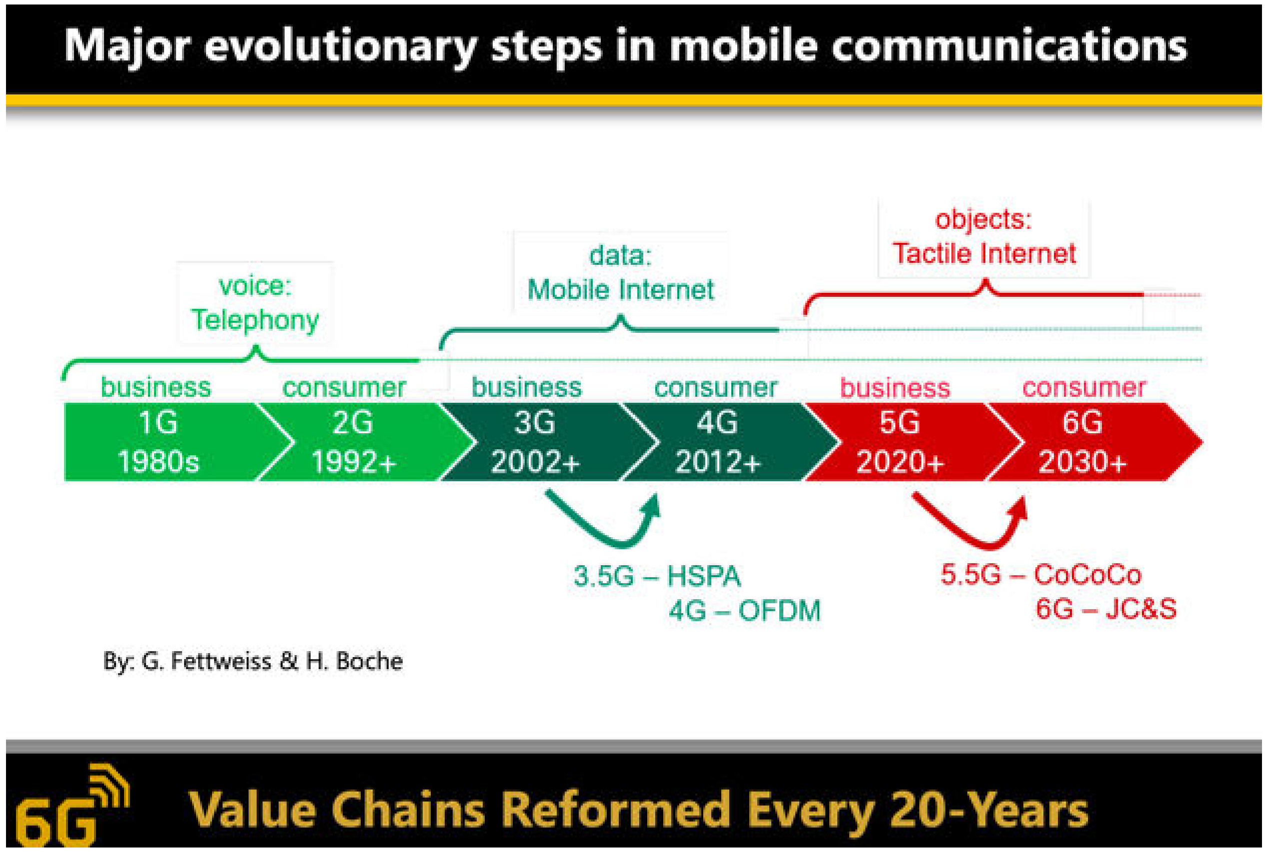
Instituto Nacional de Telecomunicações - Inatel

5G Highlights on Antennas and Optical/Wireless Towards 6G

Prof. Dr. Arismar Cerqueira S. Jr.
E-mail: arismar@inatel.br

Motivation



Courtesy of Prof. Matti Latva-aho
(6G Flagship Director)

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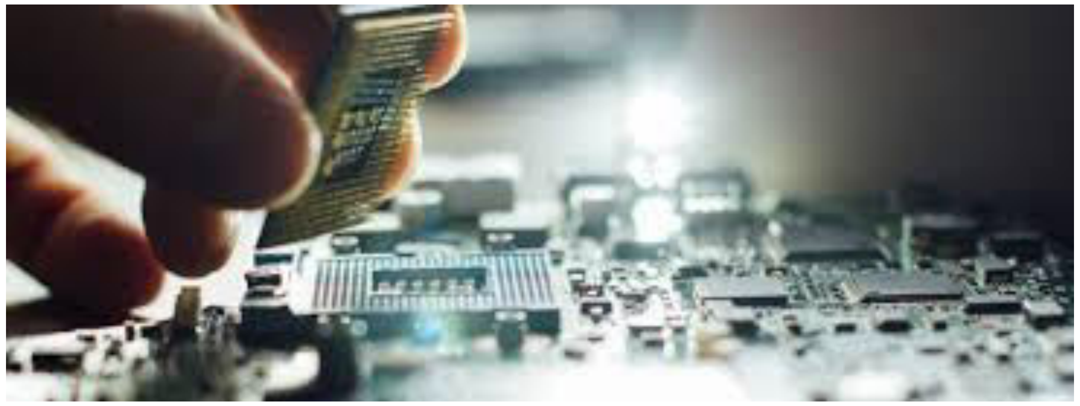
5G


6G

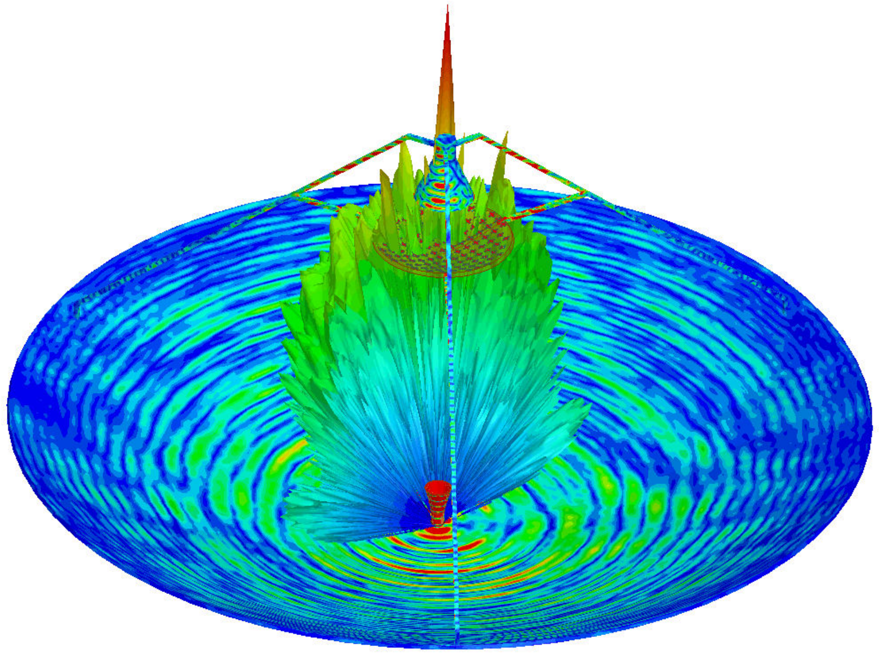

INDUSTRY 4.0



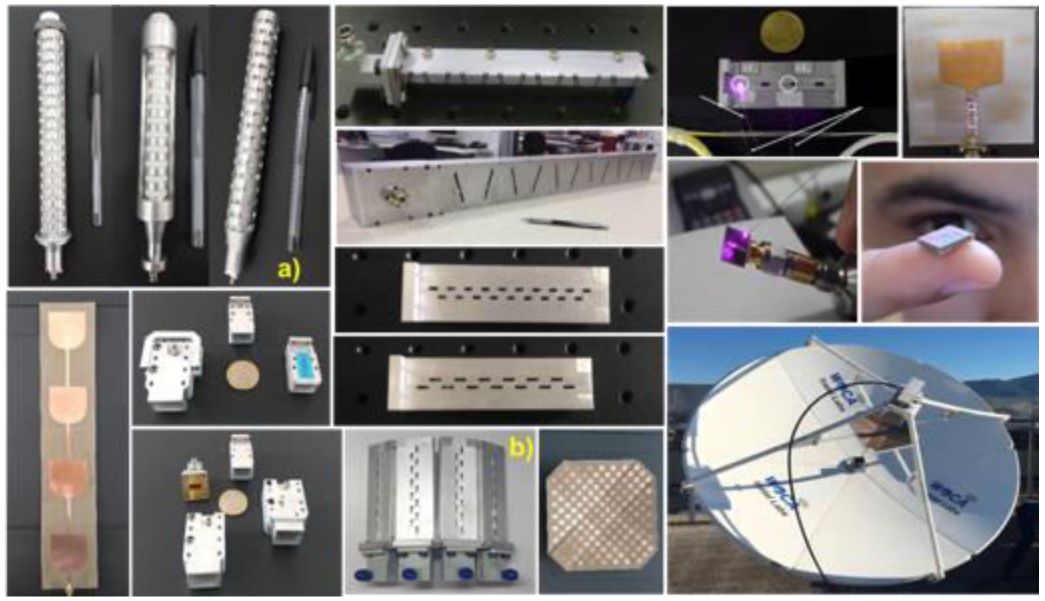

BRADAR


BRADAR
EMBRAER DEFESA & SEGURANÇA

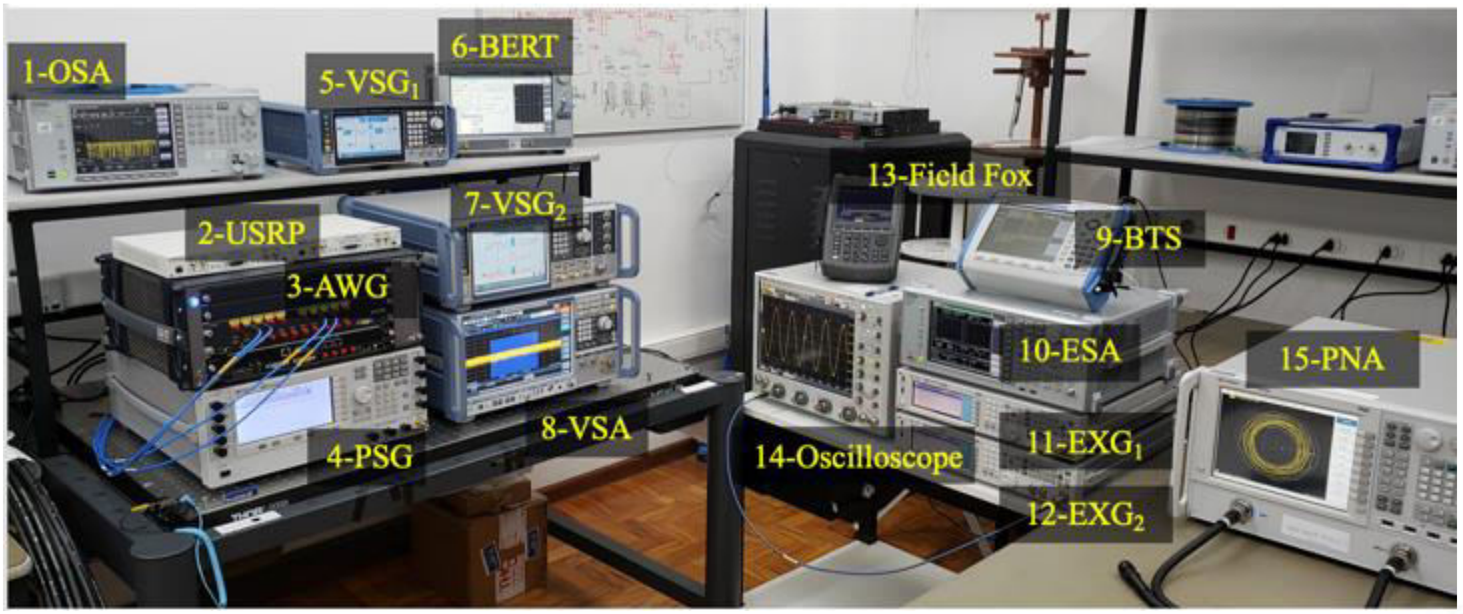
???




WOCA


a)
b)

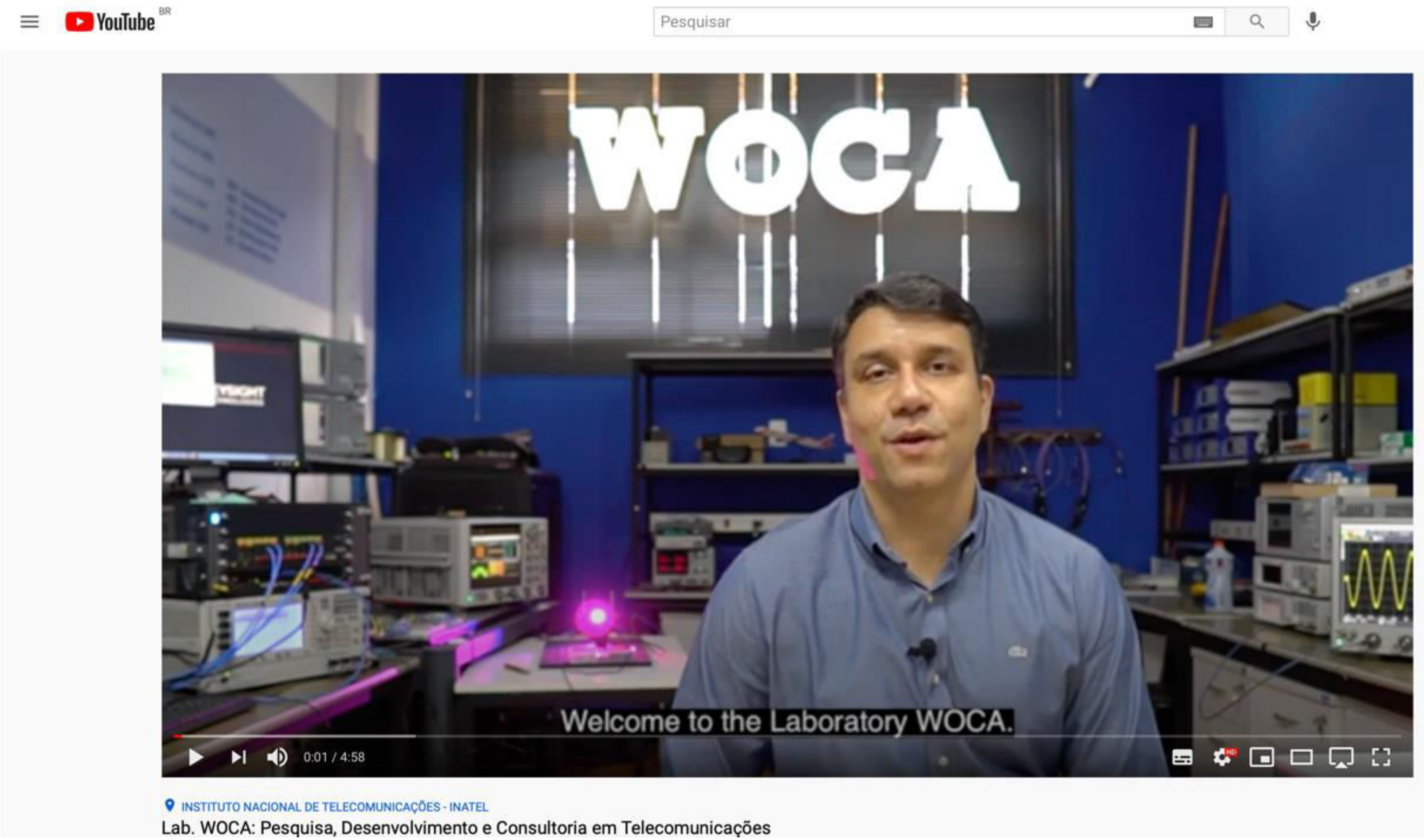
Lab. WOCA (Wireless and Optical Convergent Access)



21 Researchers, including Prof. Arismar Cerqueira, 10 PhD. Students, 07 Master Students and 03 Undergrad Students

https://www.youtube.com/watch?v=RcRHJknqIaM

Lab. WOCA (Wireless and Optical Convergent Access)



WOCA Inatel Labs

https://www.youtube.com/watch?v=RcRHJknqIaM

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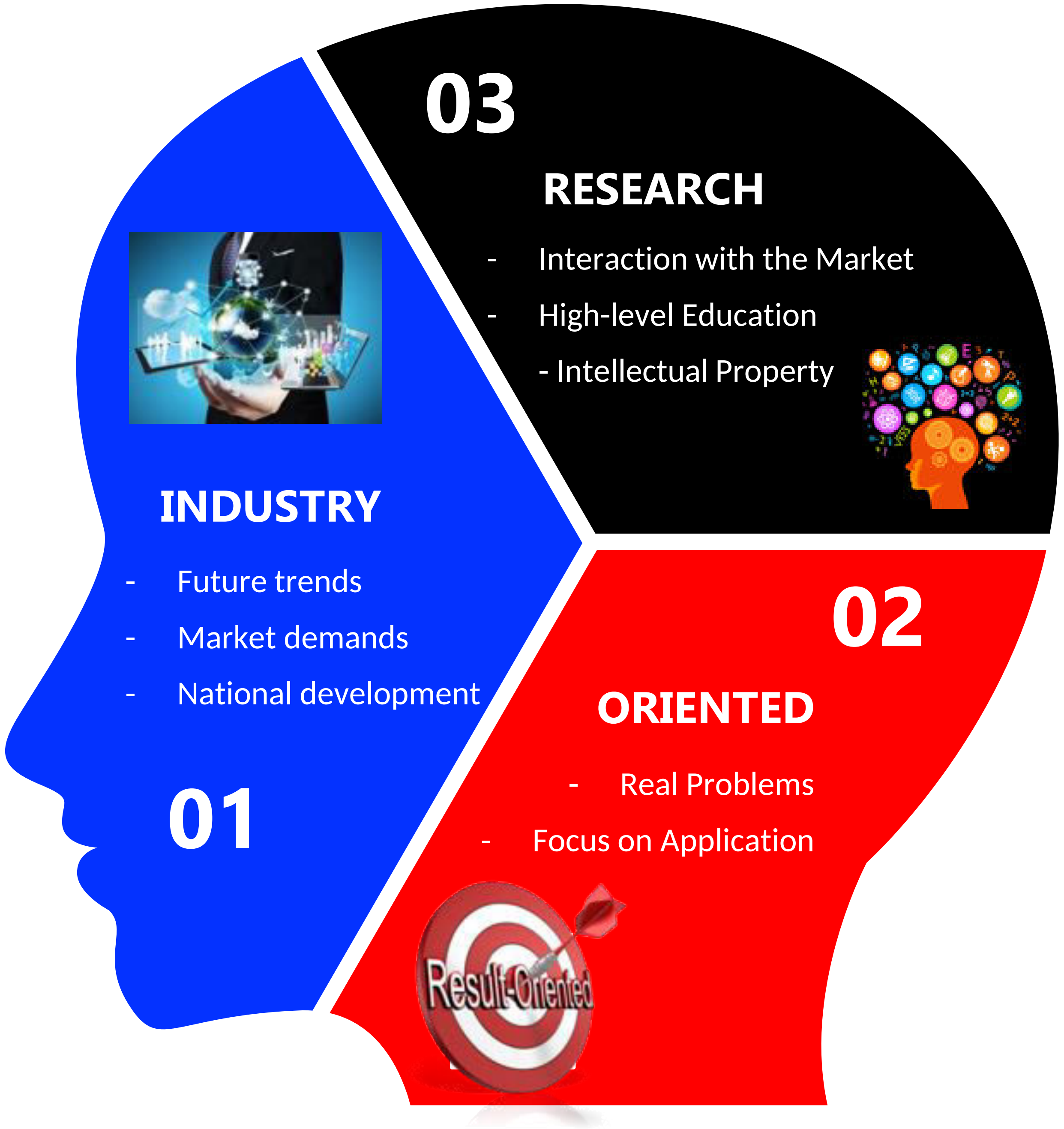
Lab. WOCA: IoR – Industry Oriented Research



IoR:
Industry
Oriented
Research

WOCA
Inatel Labs

Development of Antennas for Radars from the Brazilian Army

Surveillance Radar Saber M60: 1° Brazilian Genuine Radar
(Brazilian Army)

Radar S200 IFF (Identification Friend)

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Antenna Development for 5G Applications

Inumerous applications from RFID (13.5 MHz) to 5G, including mm-waves (> 30 GHz)!

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Dual-polarized 64-elements Antenna Array for TDD-based Massive MIMO Systems

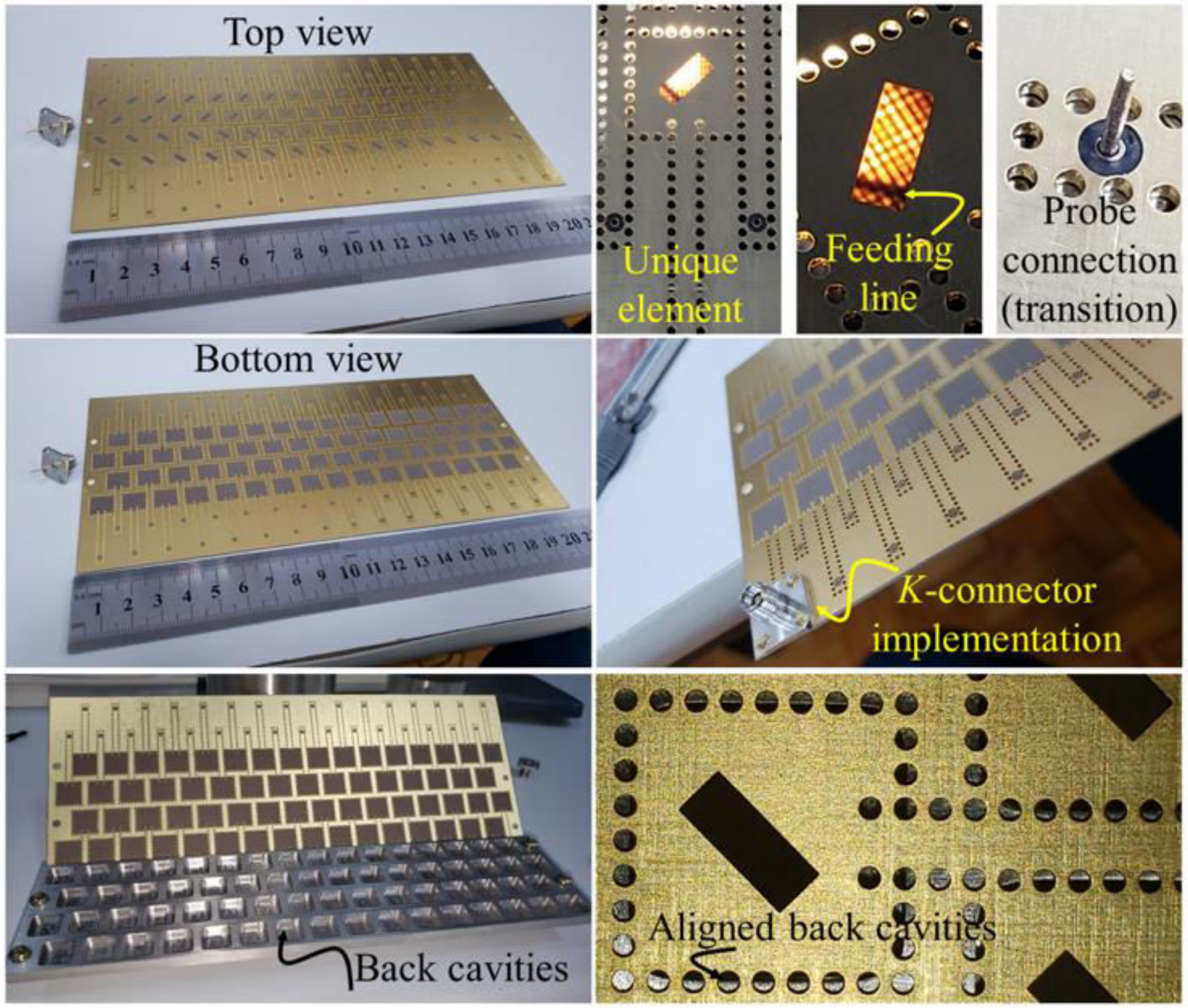
A 64-element and Dual-Polarized SICL-based Slot Antenna Array Development Applied to TDD Massive MIMO

H.R.D. Filgueiras and Arismar Cerqueira S. Jr.

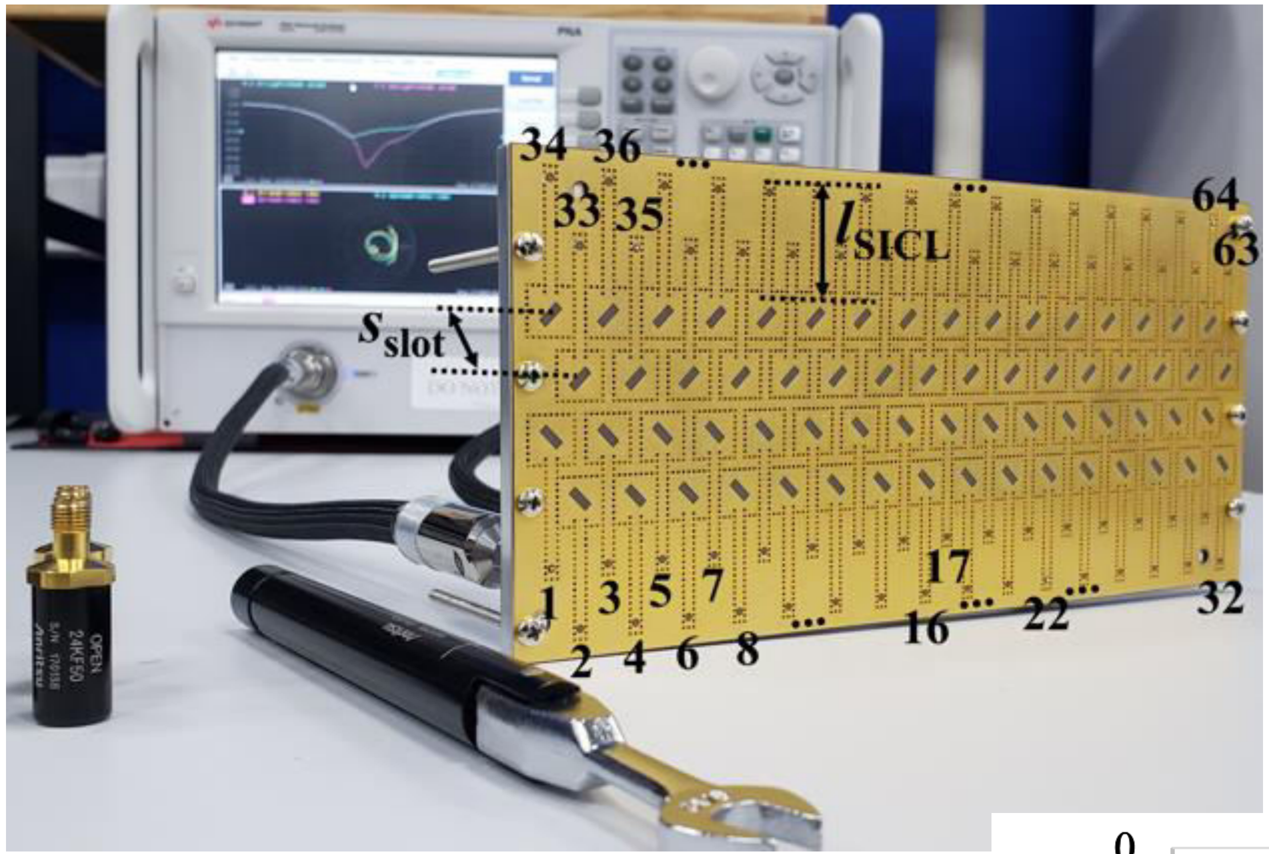
***Abstract*— This letter reports the concept, design, fabrication and characterization of a novel 64-element, slot-based and substrate-integrated coaxial line (SICL)-fed dual-polarized antenna array (SICL-SAA) for fully-digital massive multiple-input multiple-output (mMIMO) applications. The proposed array is composed of ±45° polarized elements based on half-wavelength slots. Each slot has its own back cavity, acting as an individual reflector for enabling boresight radiation. The slot is fed using a SICL feeding line for shielding the propagating mode in the feeding network, aiming at low mutual coupling levels. Experimental results in excellent agreement with full-wave numerical simulations demonstrate up to 2 GHz bandwidth from 24.5 to 26.5 GHz for all array elements. Furthermore, the mutual coupling between adjacent elements is kept lower than -23 dB for the entire bandwidth, the radiating elements provide an 85° beamwidth in both planes (φ = 0° and φ = 90°) and 7.4-dBi gain.**

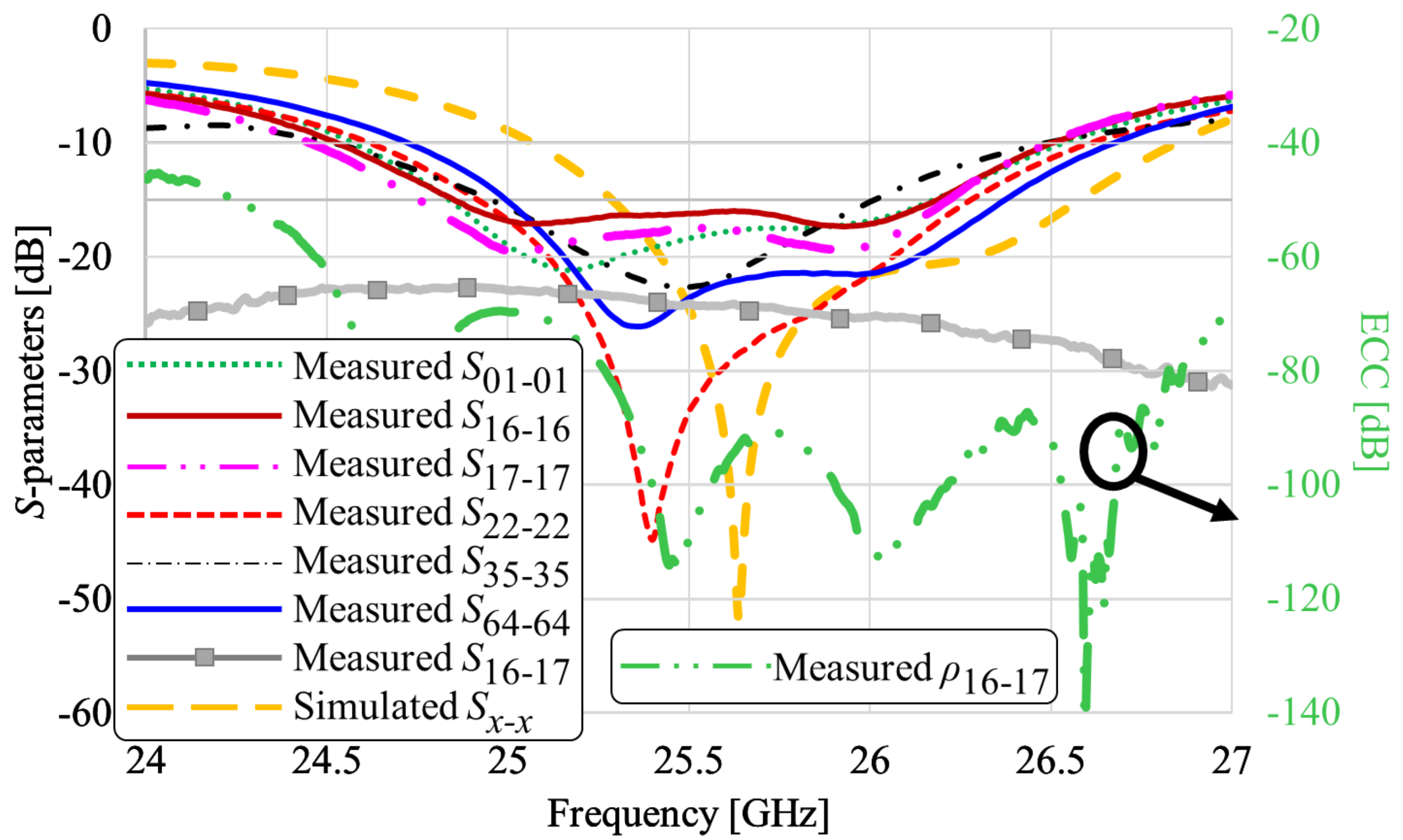
of mobile communication (5G) proposes operation in sub-millimeter and millimeter waves above 20 GHz. As a matter of fact, its first Release from 3GPPP (Release 15) has standardized two distinct frequency ranges (FR), namely [10][11]: FR1 from 410 to 7,125 MHz; FR2 from 24.25 to 52.6 GHz. Such a feature enables flexibility for providing multiple applications and fulfilling the tough and different requirements from the expected 5G scenarios, including ultra-reliable and low-latency communication (URLL), massive machine-type communication (mMTC) and enhanced mobile broadband communication (eMBB) [10-14].

The 3GPP Release 15 proposed a system channel modeling considering a mMIMO application up to 100 GHz [15]. A feature to be taken into account is that each path between transmitter and receiver considers a singular antenna radiation



Dual-polarized 64-elements Antenna Array for TDD-based Massive MIMO Systems





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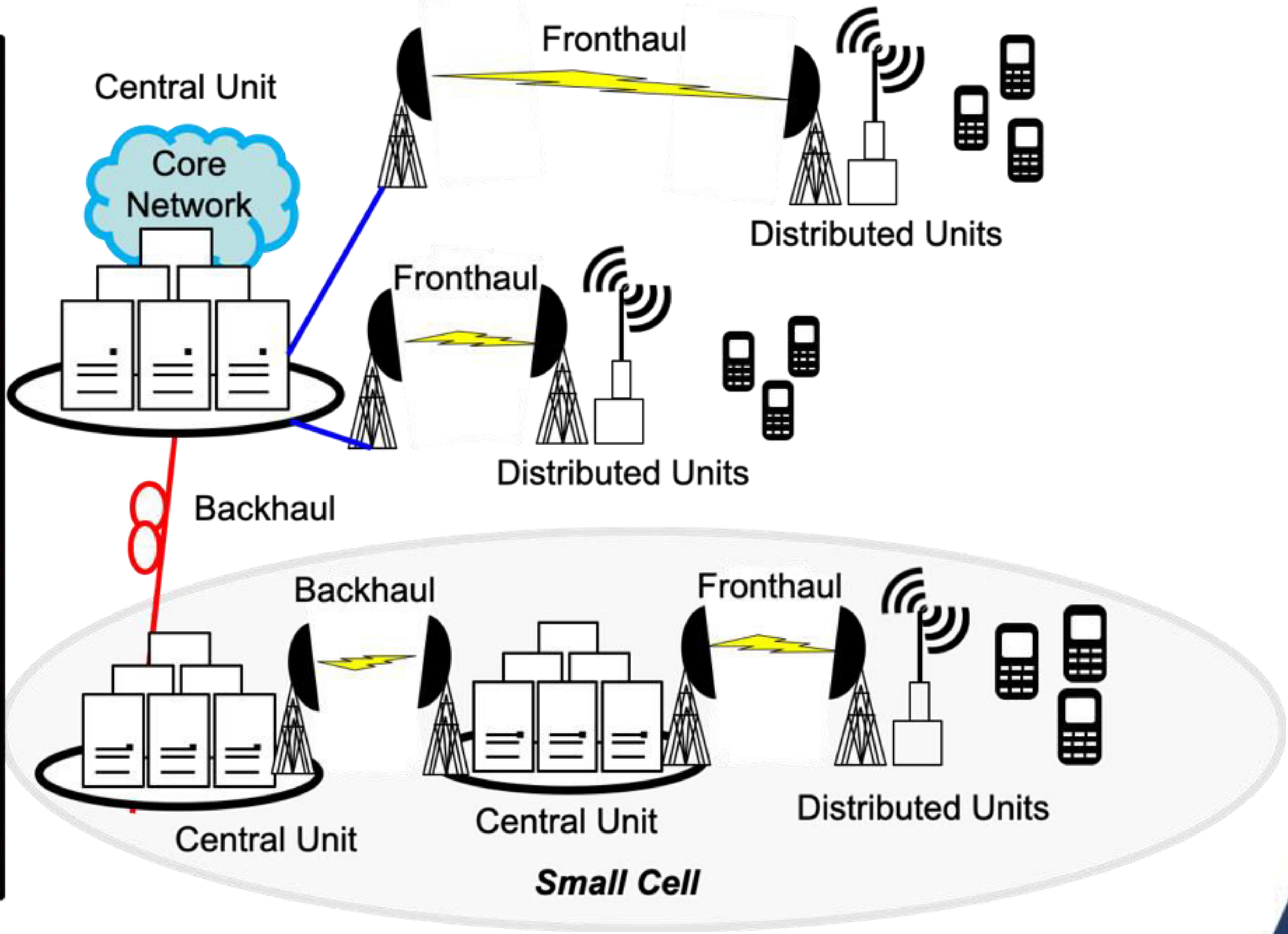
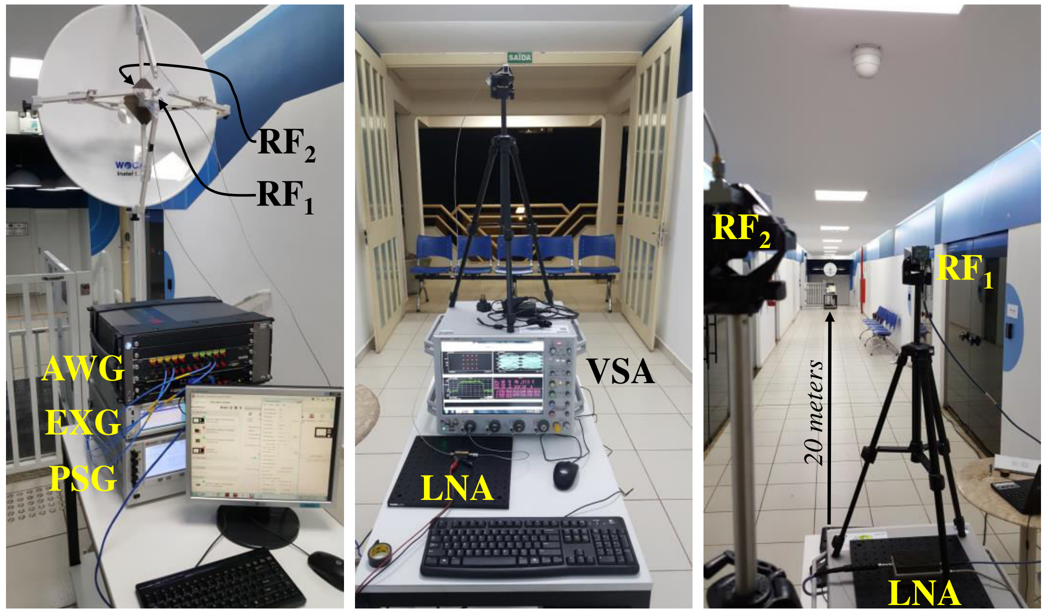
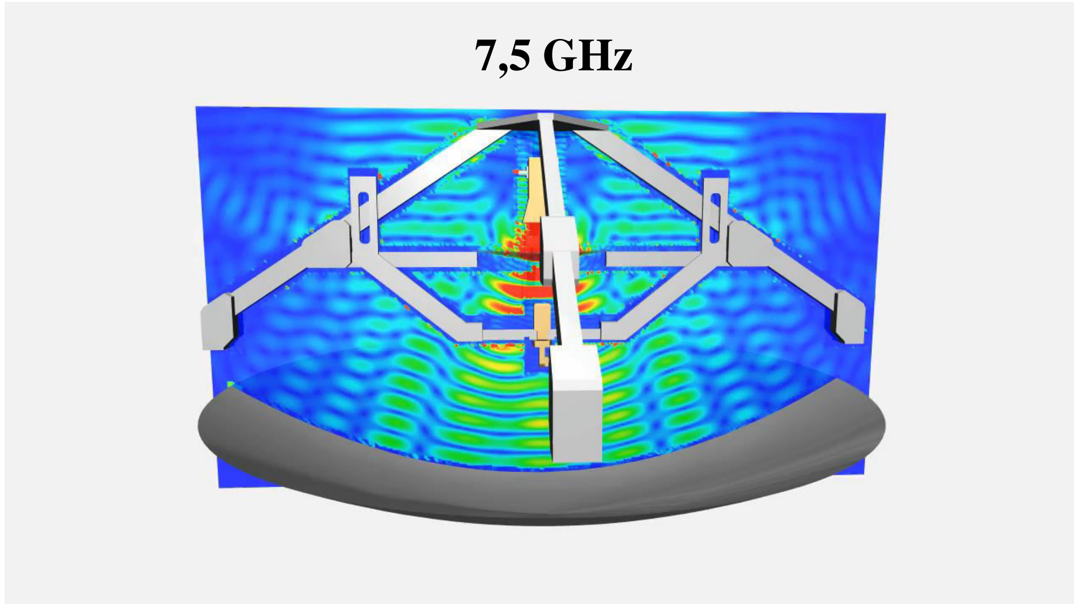
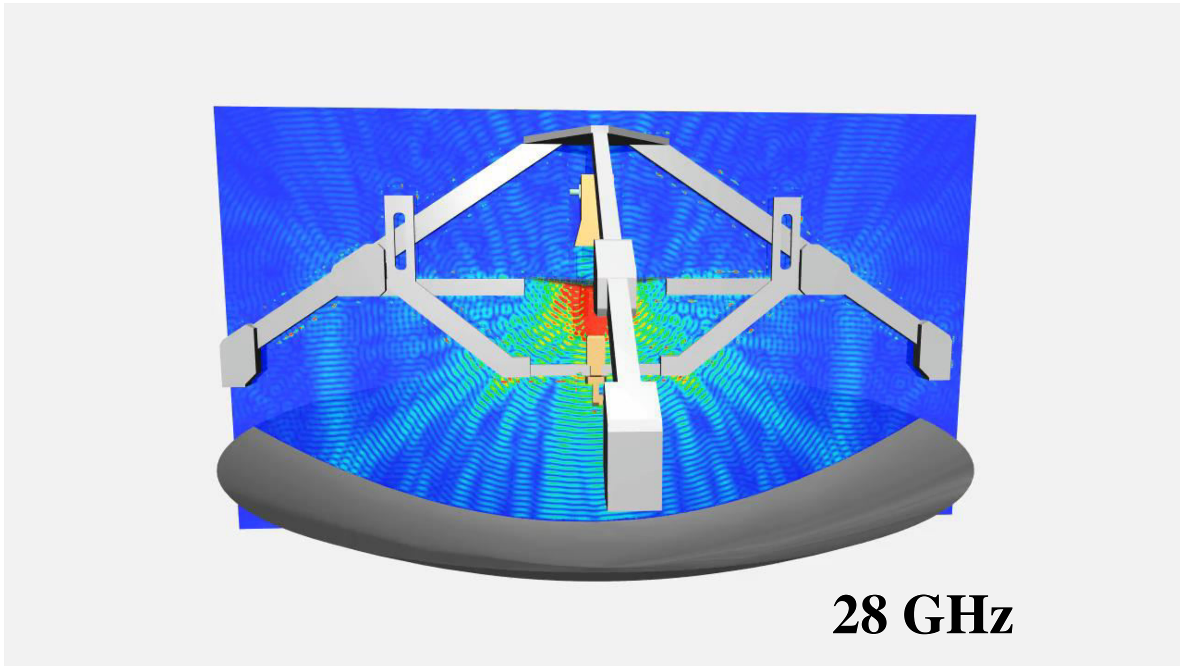
FSS-based Dual-Band Focal-Point/Cassegrain Parabolic Antenna
5G Implementation



FSS-based Dual-Band Focal-Point/Cassegrain Parabolic Antenna
5G Implementation







5G

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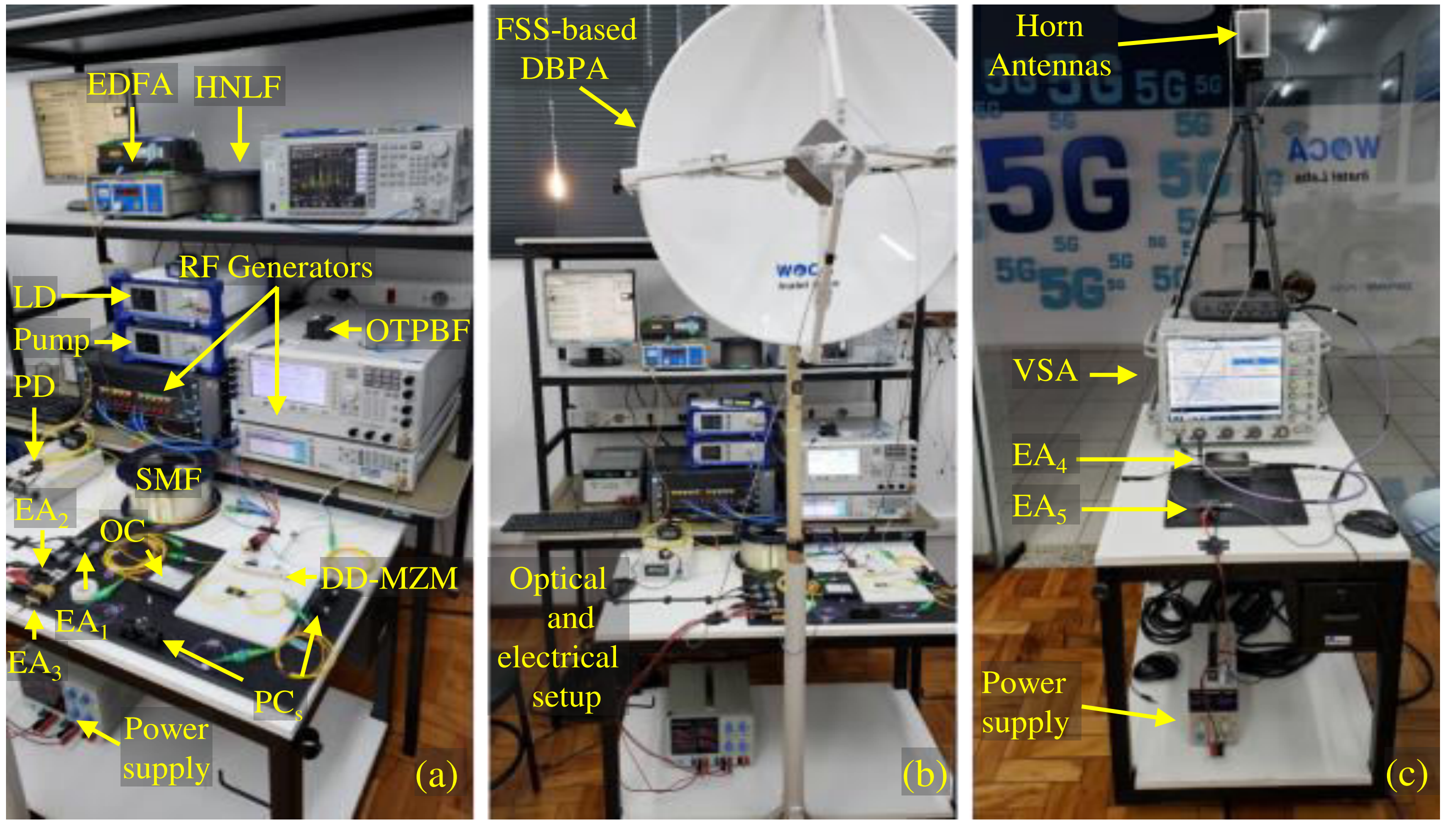
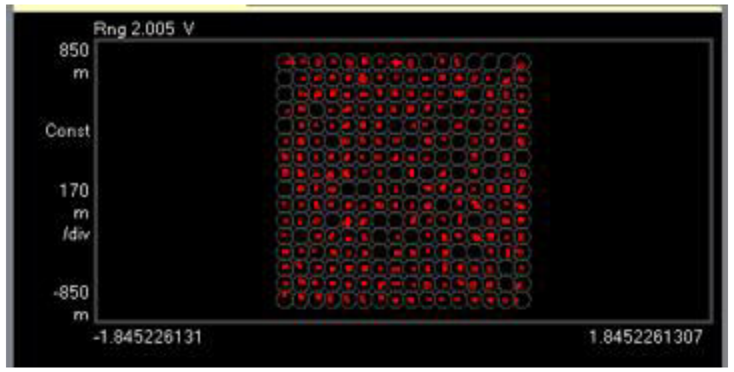
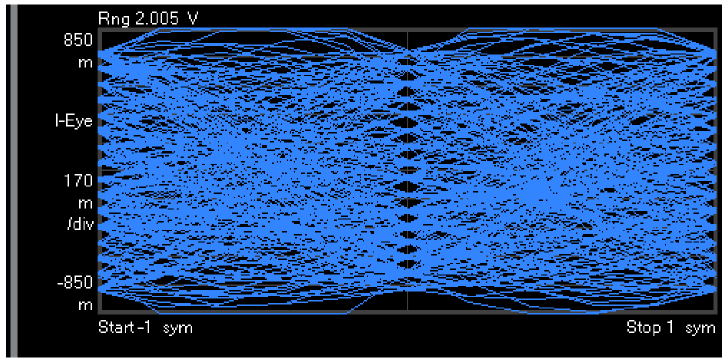
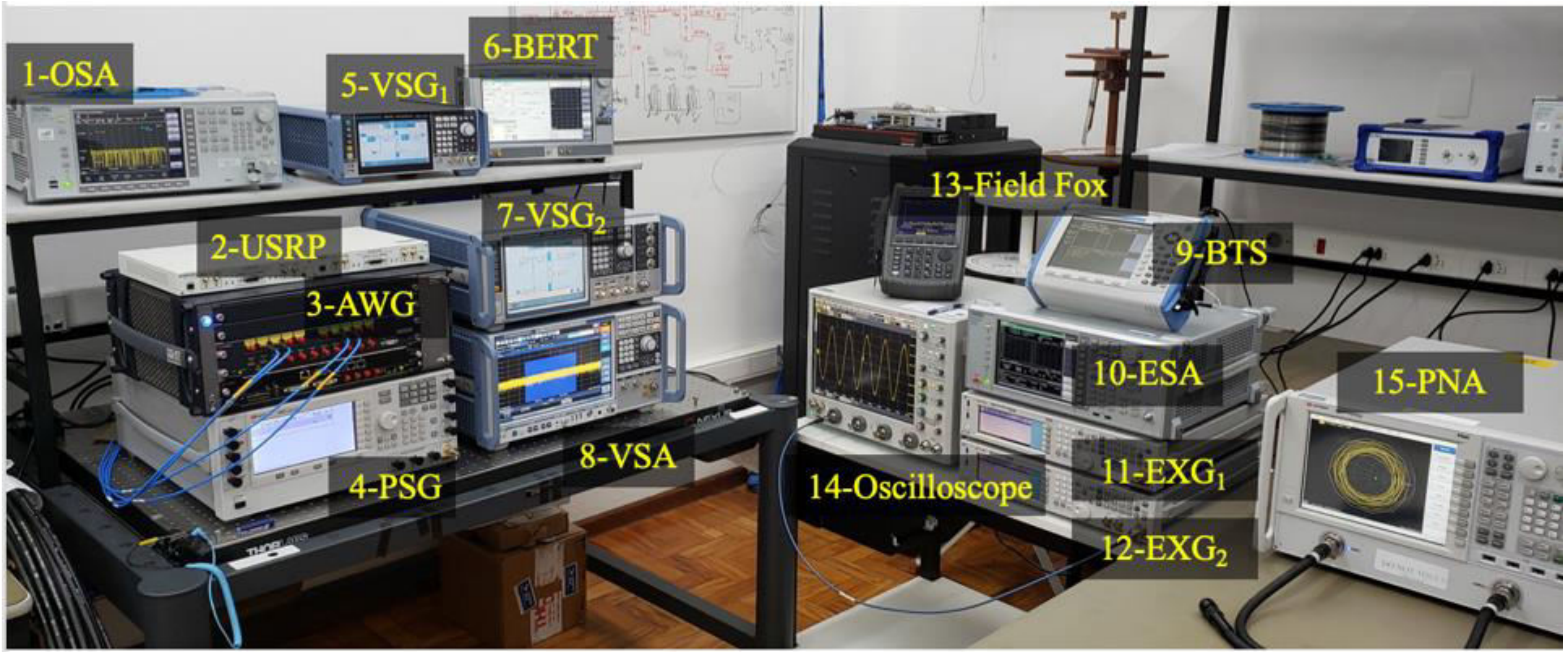
FSS-based Dual-Band Focal-Point/Cassegrain Parabolic Antenna 5G Implementation



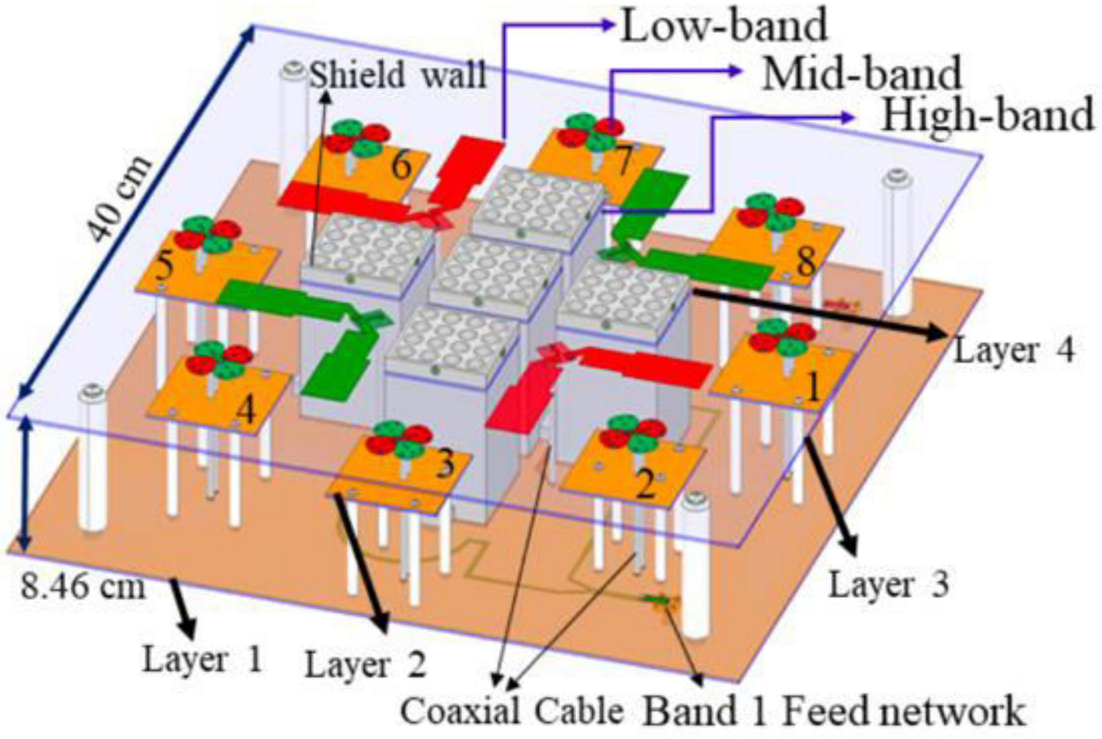


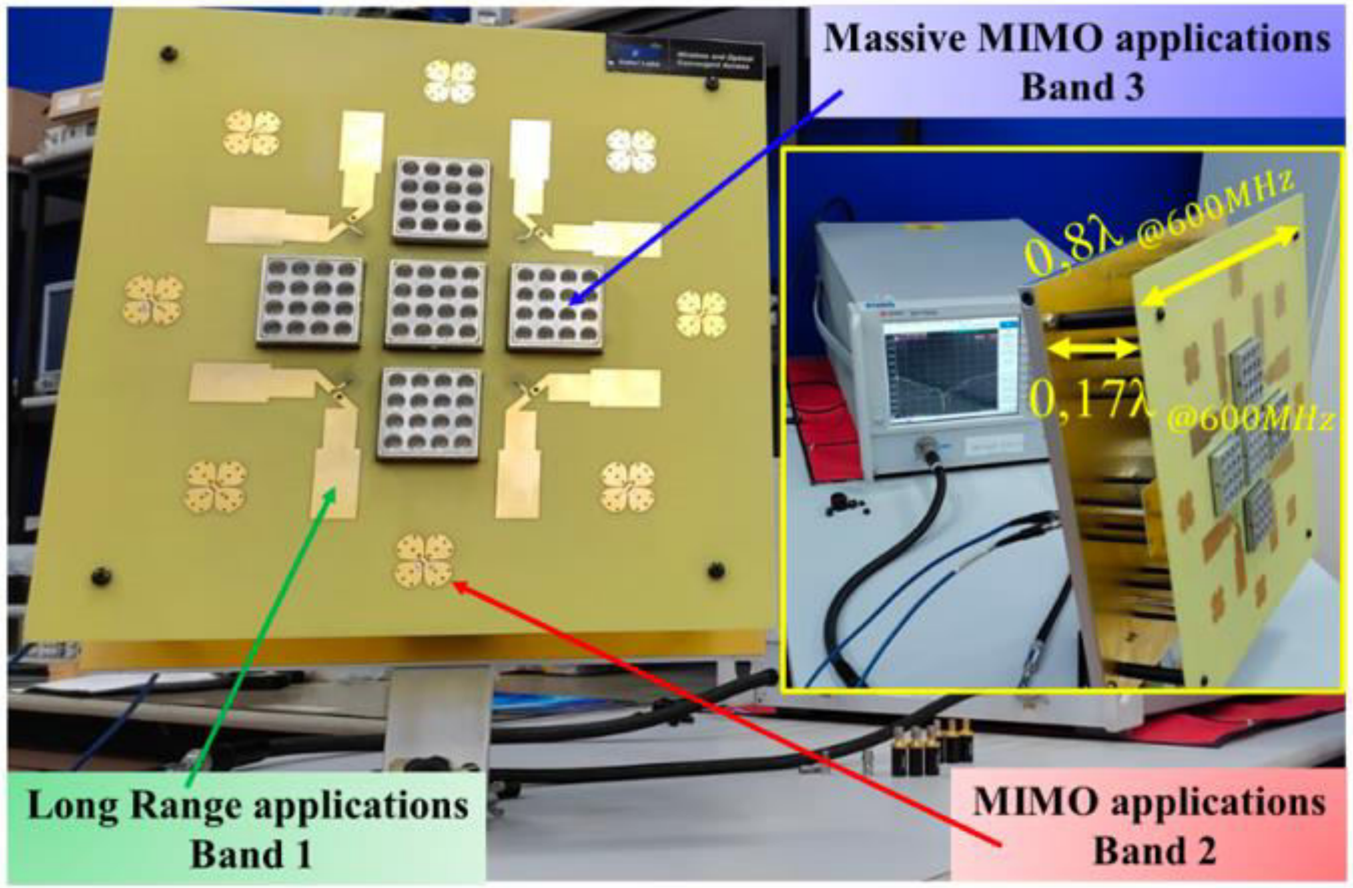


30 Gbps!



Tri-band and Dual-polarized Antenna Array Development Applied to 5G NR Base Stations





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High-Altitude Platform Stations as IMT Base Stations: Connectivity from the Stratosphere

DIGITAL DIVIDE: CLOSING THE GAP

High-Altitude Platform Stations as IMT Base Stations: Connectivity from the Stratosphere

Luciano Camilo Alexandre, Agostinho Linhares, Geraldo Neto, and Arismar Cerqueira Sodre Jr.

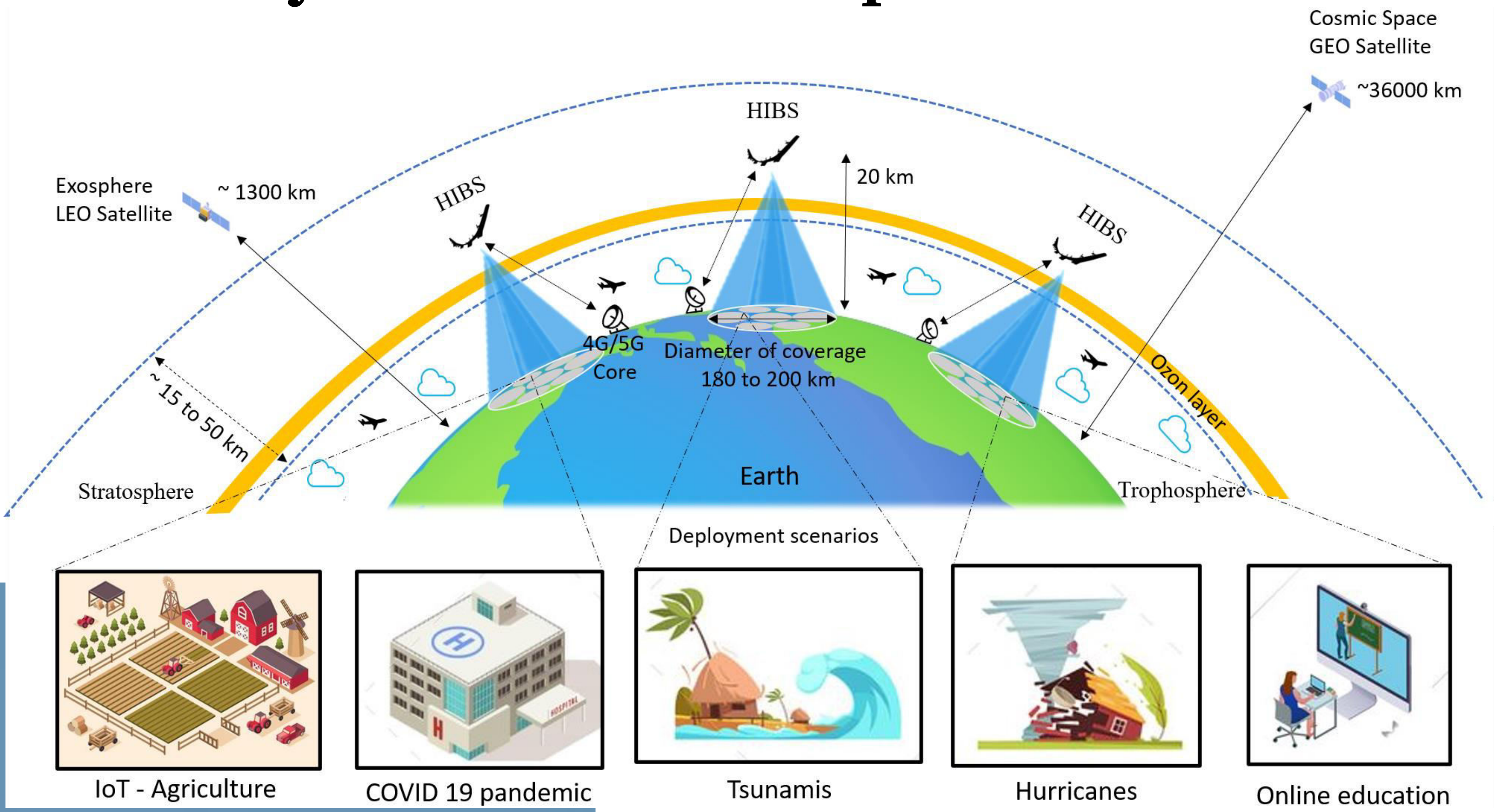
The authors describe the fundamentals of HIBS, as well as its deployment scenarios and regulatory aspects. Furthermore, it is reported, for the first time in the literature, a coexistence analysis between HIBS and fixed services point-to-point (FS-PP), as an International Telecommunication

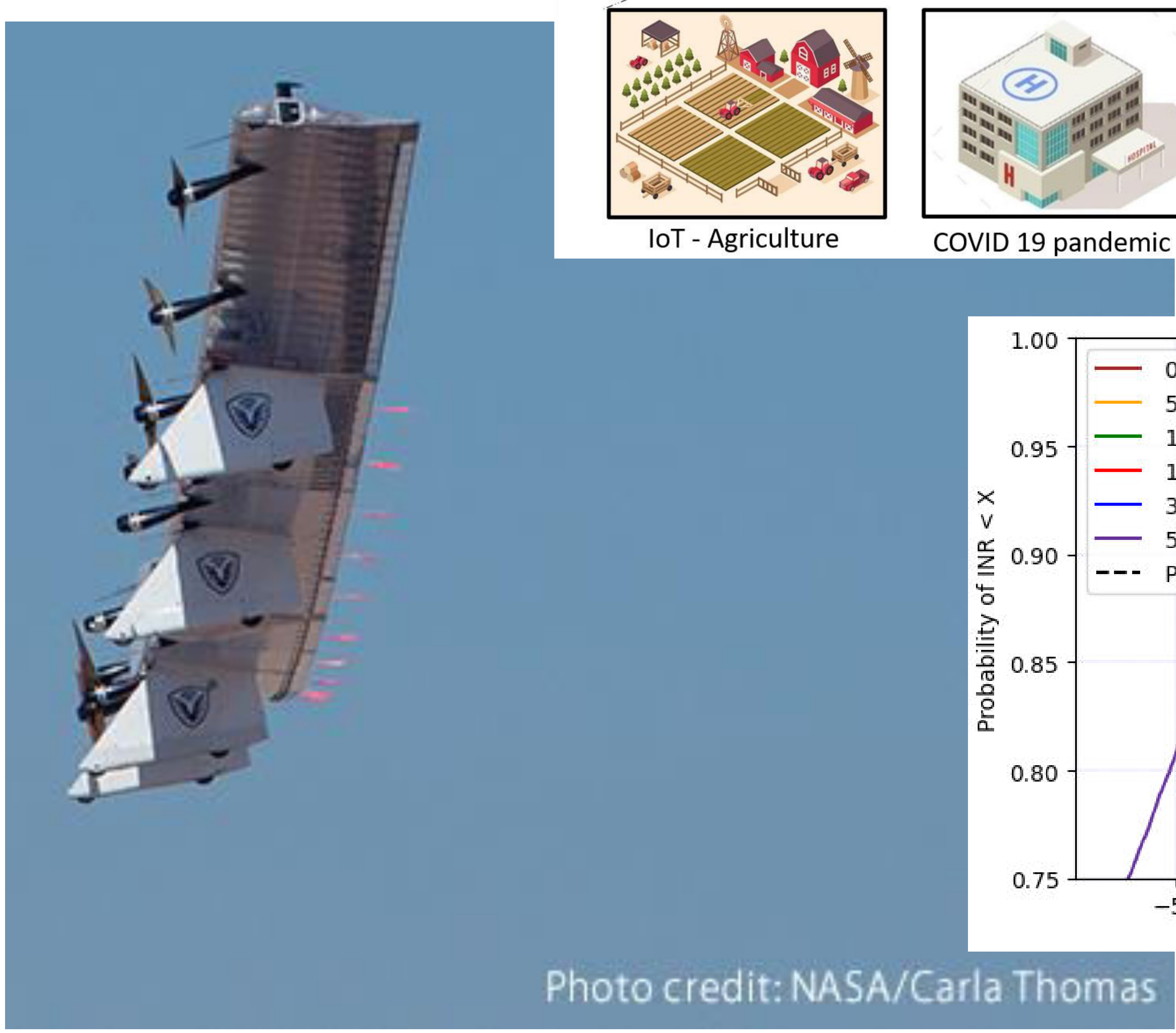
Abstract

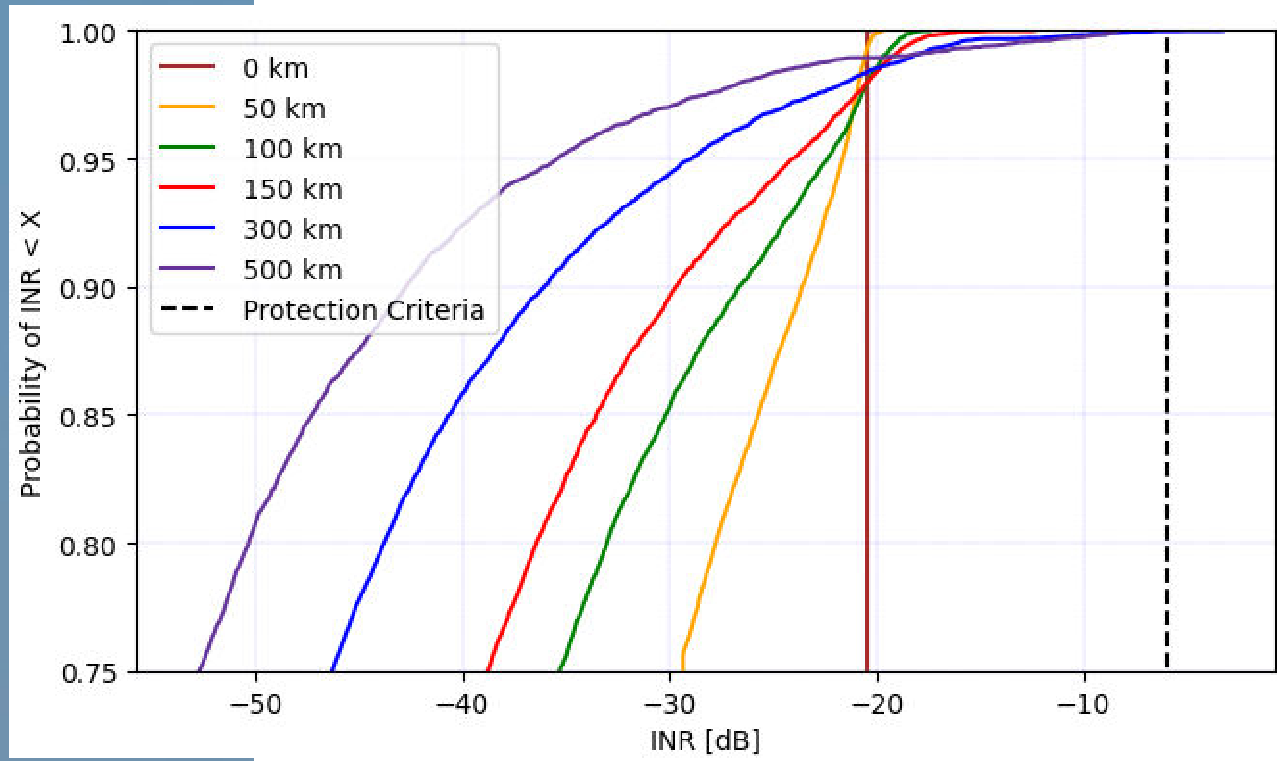
High-altitude platform station (HAPS) as International Mobile Telecommunications (IMT) base station (HIBS) has been attracting the attention of aerospace and telecommunication companies from many countries in recent years. The HIBS' remarkable differential feature is the possibility of using HAPS to complement the IMT terrestrial coverage, benefiting from the platforms being located in the stratosphere, enabling much wider coverage when compared to conventional terrestrial solutions. In

According to the Teacher Task Force (TFF), an international alliance coordinated by the United Nations Educational, Scientific, and Cultural Organization (UNESCO), 190 countries have closed all their schools, and the COVID-19 pandemic has interrupted classroom learning of 9 out of 10 students worldwide [2]. This situation is very hard for low-income countries, such as those from Sub-Saharan Africa, in which 89 percent of learners do not have Internet access to household computers, and 82 percent do not have any kind of Internet access. Mobile phones could enable children to

High-Altitude Platform Stations as IMT Base Stations: Connectivity from the Stratosphere

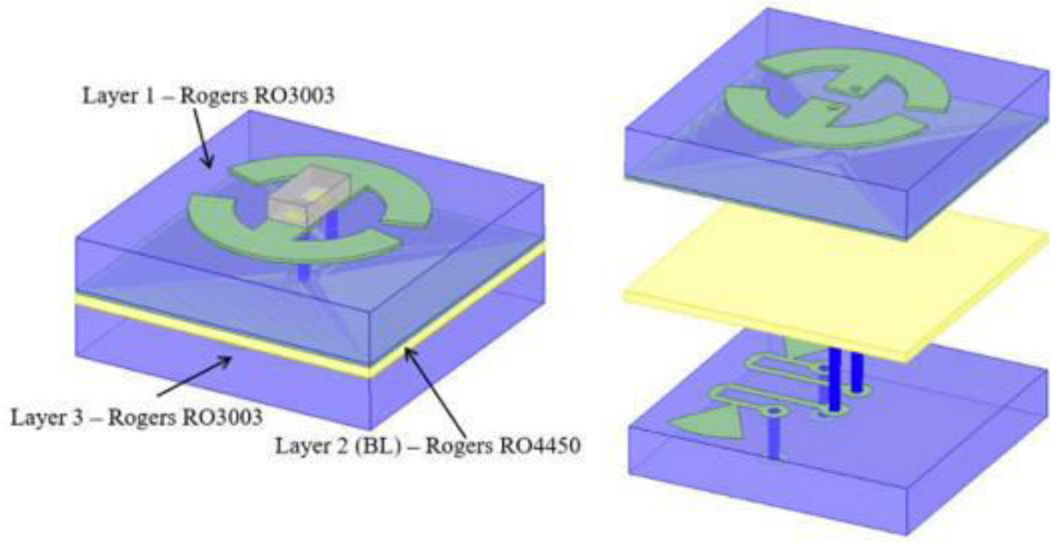






A 2-bit Tunable Unit Cell for 6G Reconfigurable Intelligent Surface Application

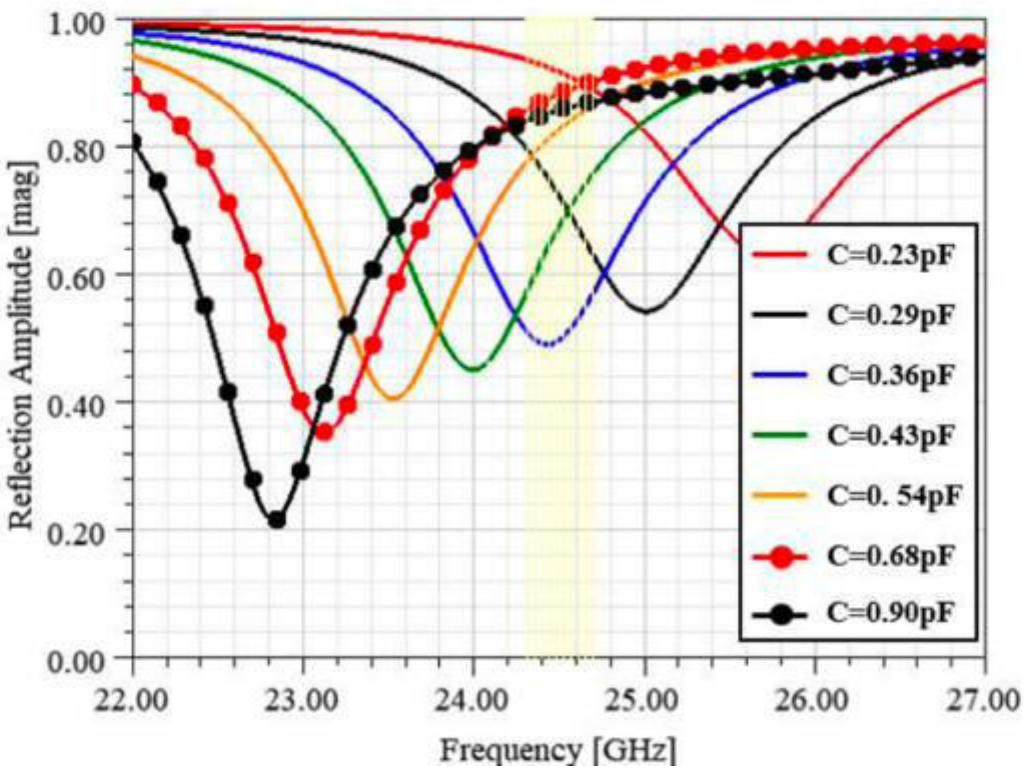
Luis G. da Silva[1], Pei Xiao[2], and Arismar Cerqueira S. Jr.[1]
[1]Laboratory WOCA (Wireless and Optical Convergent Access), National Institute of Telecommunication (Inatel), Santa Rita do Sapucaí-MG, Brazil, luis.gustavo@inatel.br, arismar@inatel.br
[2]ICS/5GIC, The University of Surrey, Stag Hill Campus, Guildford, GU2 7XH, UK, p.xiao@surrey.ac.uk

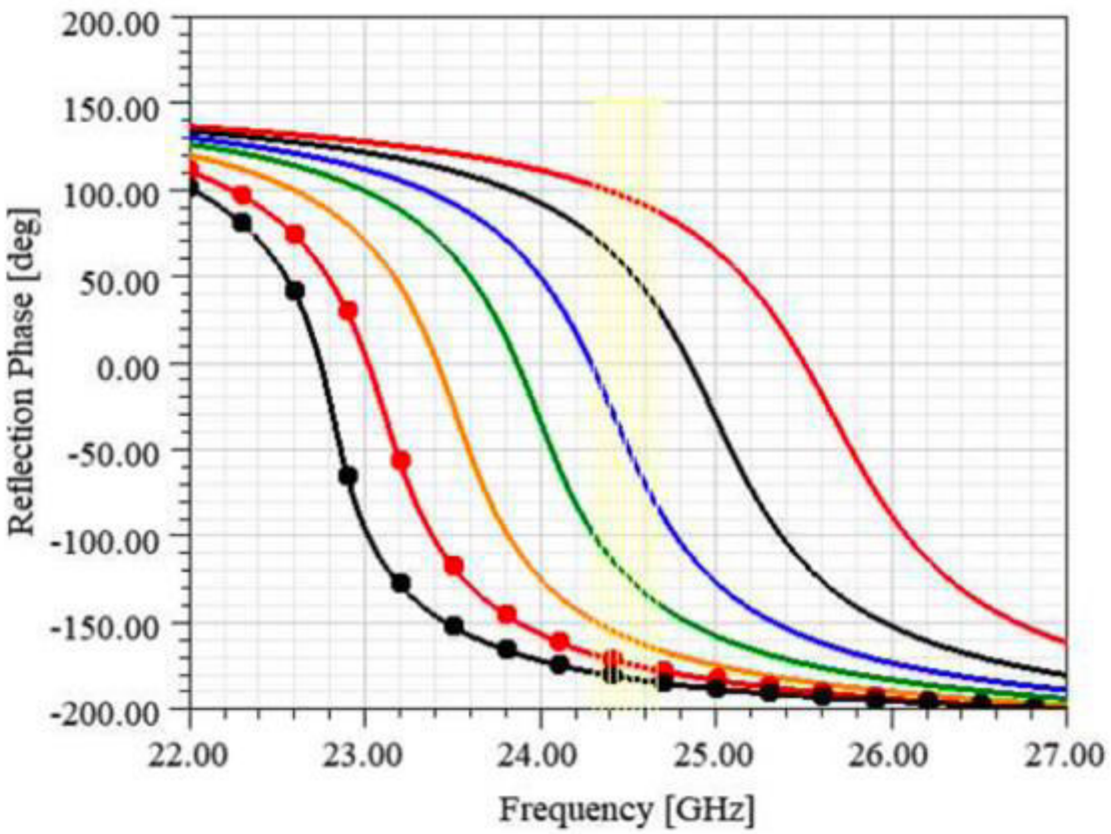


***Abstract*—This paper presents a 2-bit unit cell for reconfigurable intelligent surface (RIS) applications of beamforming and beam-steering in the frequency range 2 (FR2) from the fifth generation of mobile communications (5G). The proposed RIS unit cell is based on a printed split-ring resonator (SRR) loaded with a varactor diode, which connects two circular loops at the top and a ground plane at the bottom, resulting in a 0.245x0.245λ_0 total area. The entire unit cell element encompasses four conducting layers, in which the first two ones form the SRR, whereas RF chokes are printed at the middle layer to isolate the DC circuit and the bias lines are routed at the fourth layer. The RIS unit cell design has been conceived using the full-wave electromagnetic solver ANSYS HFSS. Its numerical results demonstrate reflection phase shift up to 270° and reflection magnitude higher than 0.5 at 24.5 GHz. The proposed reconfigurable intelligent surface might be applied to future wireless communication systems, planar antenna reflectors, and vortex beam generation.**

passive structures, with no power amplifiers, and represent an alternative for relay systems.

Early works on the concept of RISs can be found in [9][10] starting from late 2003. Posteriorly, in 2010 L. Subrt *et al.* introduced the idea of intelligent walls to control the propagation of electromagnetic waves in indoor scenarios [11]. The presented concept was based on deploying walls inside buildings equipped with an active frequency selective surface (FSS) and monitoring sensors for controlling the propagation environment according to the traffic demand. After that, authors from [12] proposed ideas of FSS and simulations of smart environments performed using 3-D propagation models. Additionally, an electronically tunable metasurface based on reflector patch resonators and controlled by PIN diodes was utilized to implement spatial microwave modulators [13]. It was shown that spatial microwave modulators with 0° and 180° phase shift states





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applied sciences

MDPI

Article

Integrating Optical and Wireless Techniques towards Novel Fronthaul and Access Architectures in a 5G NR Framework

Ramon Maia Borges [1,2], Celso Henrique de Souza Lopes [1], Eduardo Saia Lima [1], Marco Aurélio de Oliveira [1], Matheus Sêda Borsato Cunha [1,2], Luciano Camilo Alexandre [1], Luis Gustavo da Silva [1], Luiz Augusto Melo Pereira [1], Danilo Henrique Spadoti [2], Murilo Araujo Romero [3] and Arismar Cerqueira Sodré Junior [1,*]

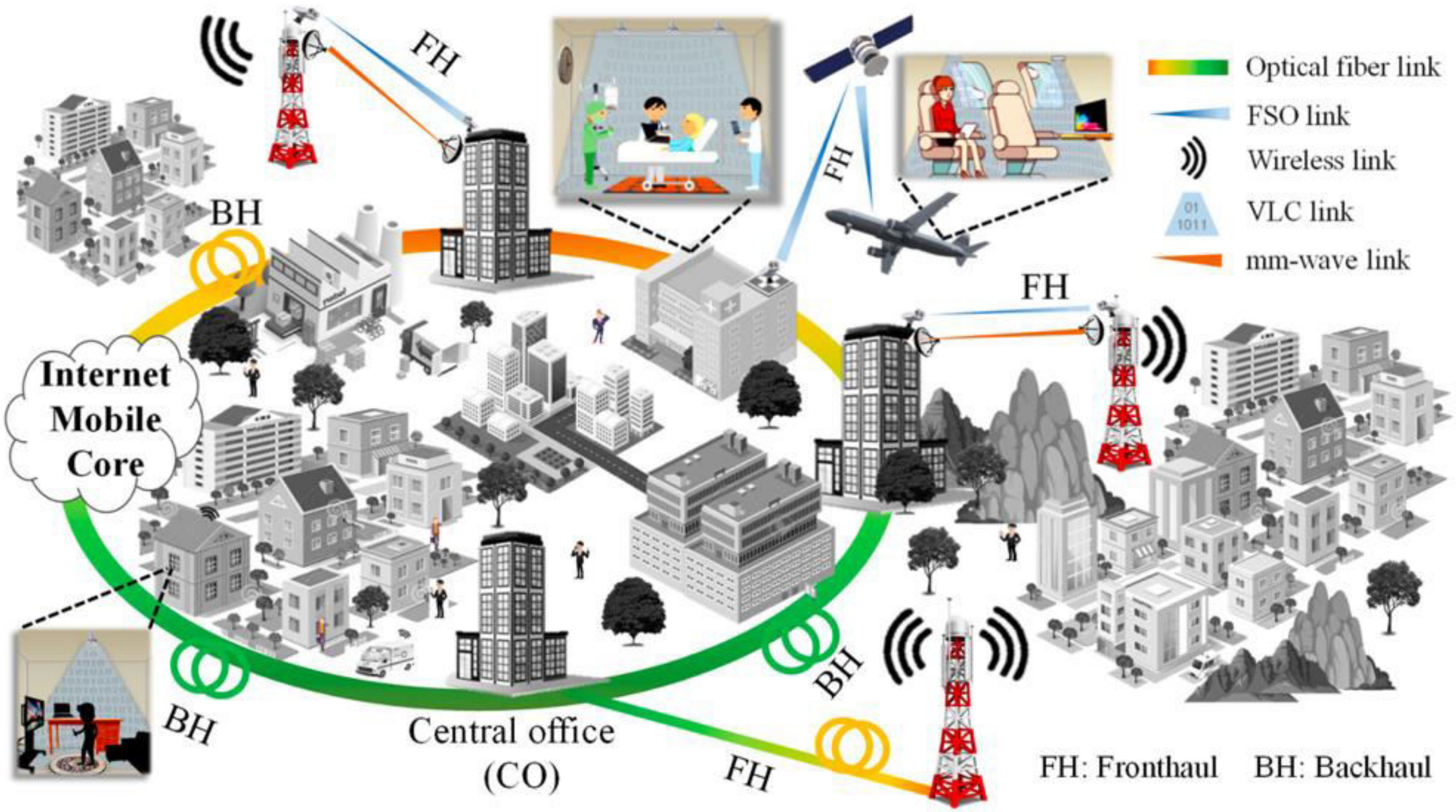


Figure 1. Optical-wireless communication system based on RoF/FSO/wireless fronthaul configurations combined to VLC/wireless access for 5G and beyond.

Integration of a GFDM-Based 5G Transceiver in a GPON Using Radio Over Fiber Technology

Ramon Maia Borges, Tiago Reis Rufino Marins, Matheus Sêda Borsato Cunha, Hugo Rodrigues Dias Filgueiras, Igor Feliciano da Costa, Regivan N. da Silva, Danilo Henrique Spadoti, Luciano Leonel Mendes, and Arismar Cerqueira Sodré, Jr.

***Abstract*—This paper reports the integration and experimental performance analysis of a GFDM-based 5G transceiver in a gigabit passive optical network (GPON), using radio over fiber technology. The proposed architecture enables to simultaneously transport two 5G candidates RF signals through an active GPON under real channel conditions. One signal is generated by a GFDM-based 5G prototype transceiver at 735 MHz, whereas the second one is synthetized by a vector signal generator at 26 GHz. A dual-drive Mach–Zehnder modulator has been utilized in the optical line terminal to modulate both signals, with the purpose of mitigating the interference between them. Particularly for the GFDM-based 735 MHz signal, a modulation error ratio (MER) of 40 dB has been obtained at RF-driven signal up to –9 dBm. Furthermore, the use of a digital predistortion scheme has been efficiently employed to reduce the impact of the nonlinear distortions and enhance MER. The 26-GHz RF signal, aimed for the 5G millimeter wave band, has been investigated as a function of error vector magnitude (EVM) for bitrates up to 1 Gbit/s. EVM_{RMS} of 2.18% and 5.70% have been obtained for 100 Mbit/s and 1 Gbit/s, respectively. Finally, the latency and throughput measurements of the baseband signal originally running over GPON have shown no significant penalties.**

services cover enhanced mobile broadband (eMBB), ultra-reliable low latency (URLL), massive machine type communication (mMTC) and long range for remote area applications. Additionally, remote areas applications must cover 50 km radius, with the aim of providing high quality broadband access in rural and remote areas [1]. Summarily, 5G wireless networks will support 1,000-fold gains in capacity, connections for at least 100 billion devices and multi-Gbit/s individual user experience capable of extremely low latency and short response times. As a consequence, 5G networks must have a flexible physical layer (5G PHY) to address different requirements for a multi-service system [2]. Multiple waveforms have been studied in the past few years and the generalized frequency division multiplexing (GFDM) have shown as a promising solution in terms of bit error rate (BER), out-of-band (OOB) emission and complexity [3].

The 5G networks are likely to operate in the millimeter wave frequency bands [4], [5], in which there is a lot of unexploited

DSP-Based Flexible-Waveform and Multi-Application 5G Fiber-Wireless System

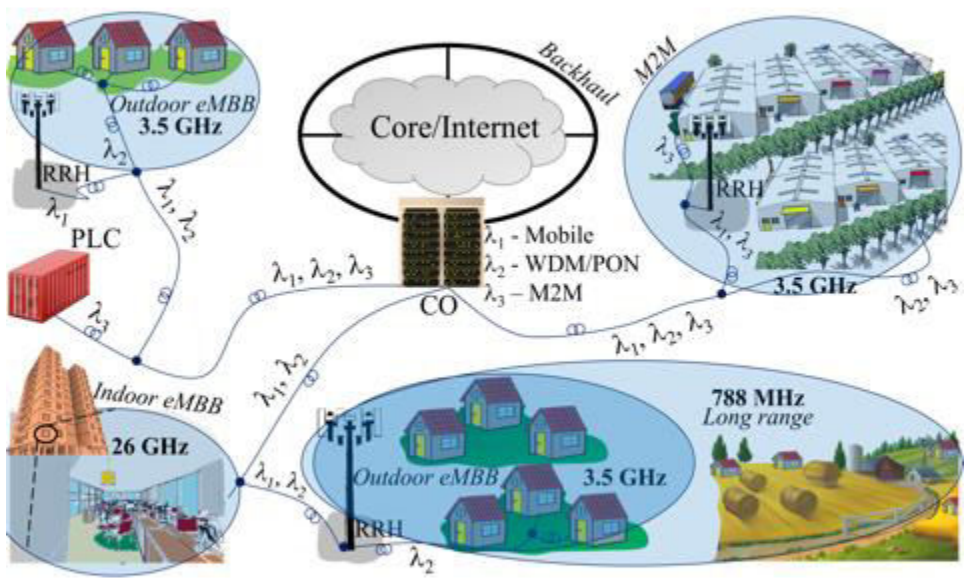
Ramon Maia Borges, Luiz Augusto Melo Pereira, Hugo Rodrigues Dias Filgueiras, Alexandre Carvalho Ferreira, Matheus Seda Borsato Cunha, Egidio Raimundo Neto, Danilo Henrique Spadoti, Luciano Leonel Mendes, and Arismar Cerqueira S. Jr

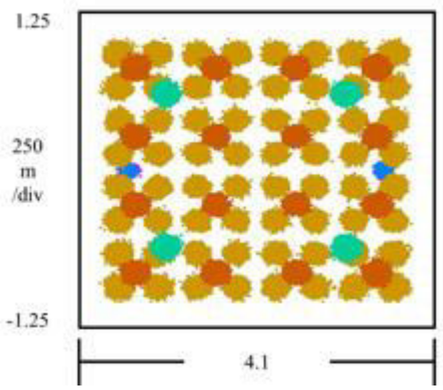
***Abstract*—This article reports the implementation and experimental performance investigation of a DSP-based flexible-waveform fiber-wireless (FiWi) system for 5G enhanced mobile broadband (eMBB) and new vertical applications. Our radio over fiber-based fronthaul solution uses a wavelength-division-multiplexing passive optical network (WDM-PON) infrastructure, from a commercial Internet service provider, to enable 5G operation over multiple frequency bands, including: a DSP and flexible waveform-based signal at 788 MHz, which can be set as generalized frequency division multiplexing (GFDM) or filtered orthogonal frequency division multiplexing (F-OFDM); 5G new radio (NR) signals at 3.5 or 26 GHz in accordance to 3GPP Release 15; an additional vector 26 GHz signal with bandwidth of up to 800 MHz. The DSP-based functionality provides digital pre-distortion (DPD), besides the real-time waveform generation. Experimental results demonstrate 4.41 Gbit/s total throughput in the air in accordance to the 3GPP requirements, as well as an innovative low-latency M2M application based on PROFINET standard.**

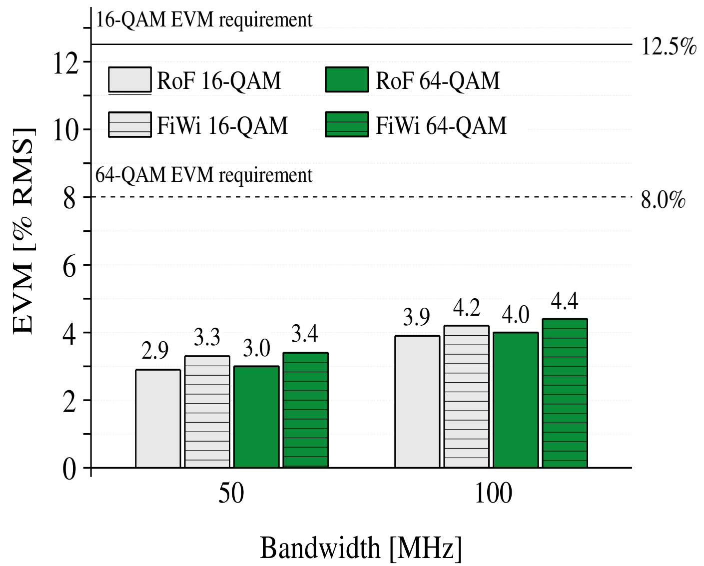
***Index Terms*—DSP, fiber-wireless system, 5G NR, F-OFDM, microwave photonics.**

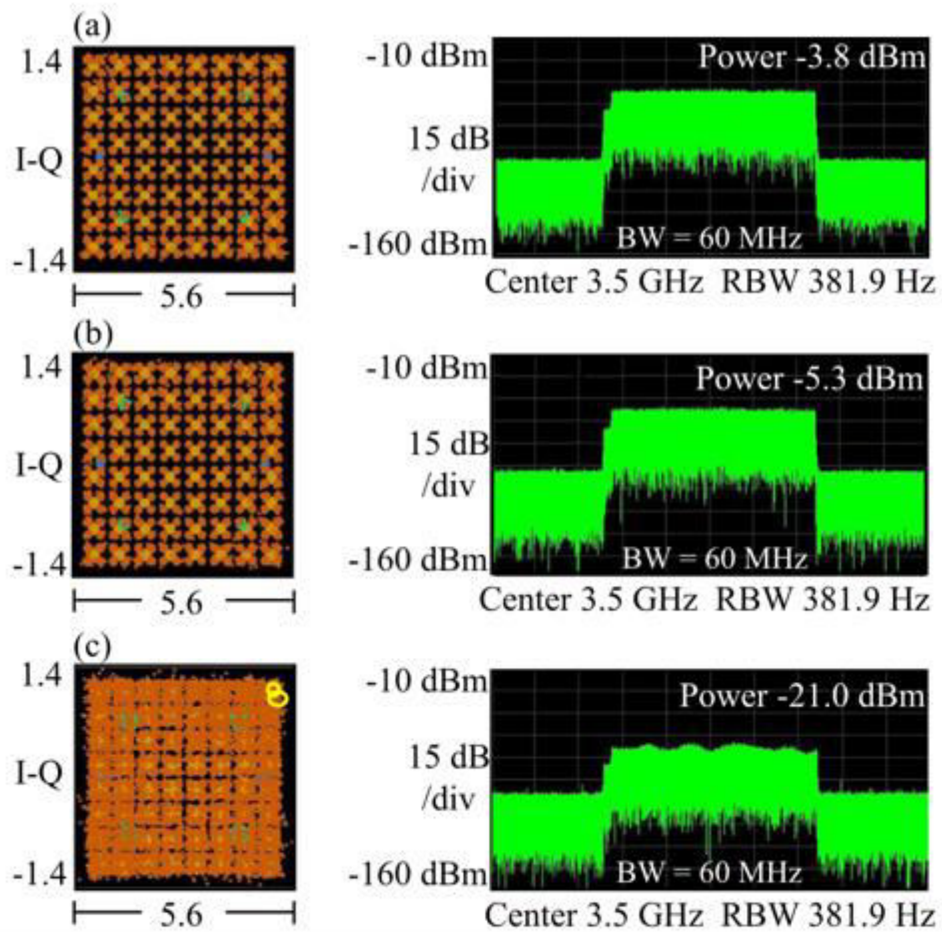
emerges as an enabler of a fully-connected society and should create an open ecosystem for innovation due to the new value-added services and applications. Key usage scenarios include enhanced mobile broadband (eMBB), massive machine type communications (mMTC) and ultra-reliable and low latency communications (URLLC). Extreme long-range coverage and high-speed mobility usage cases have also been targeted with particular interest [2], [3]. Hence, 5G must address multi-service systems based on diverse capabilities, by using innovative technical solutions, such as new radio (NR) and additional spectrum bands [4], [5].

One of the 5G NR most important innovation challenges refers to the applied multiplexing technique since it impacts in the resulting transmit spectrum and, consequently, in the coexistence with other communication systems. Diverse waveforms based on multicarrier transmission and spectral confinement techniques have been studied in the past few years [6]–[8]. Particularly,









406 JOURNAL OF LIGHTWAVE TECHNOLOGY, VOL. 39, NO. 2, JANUARY 15, 2021

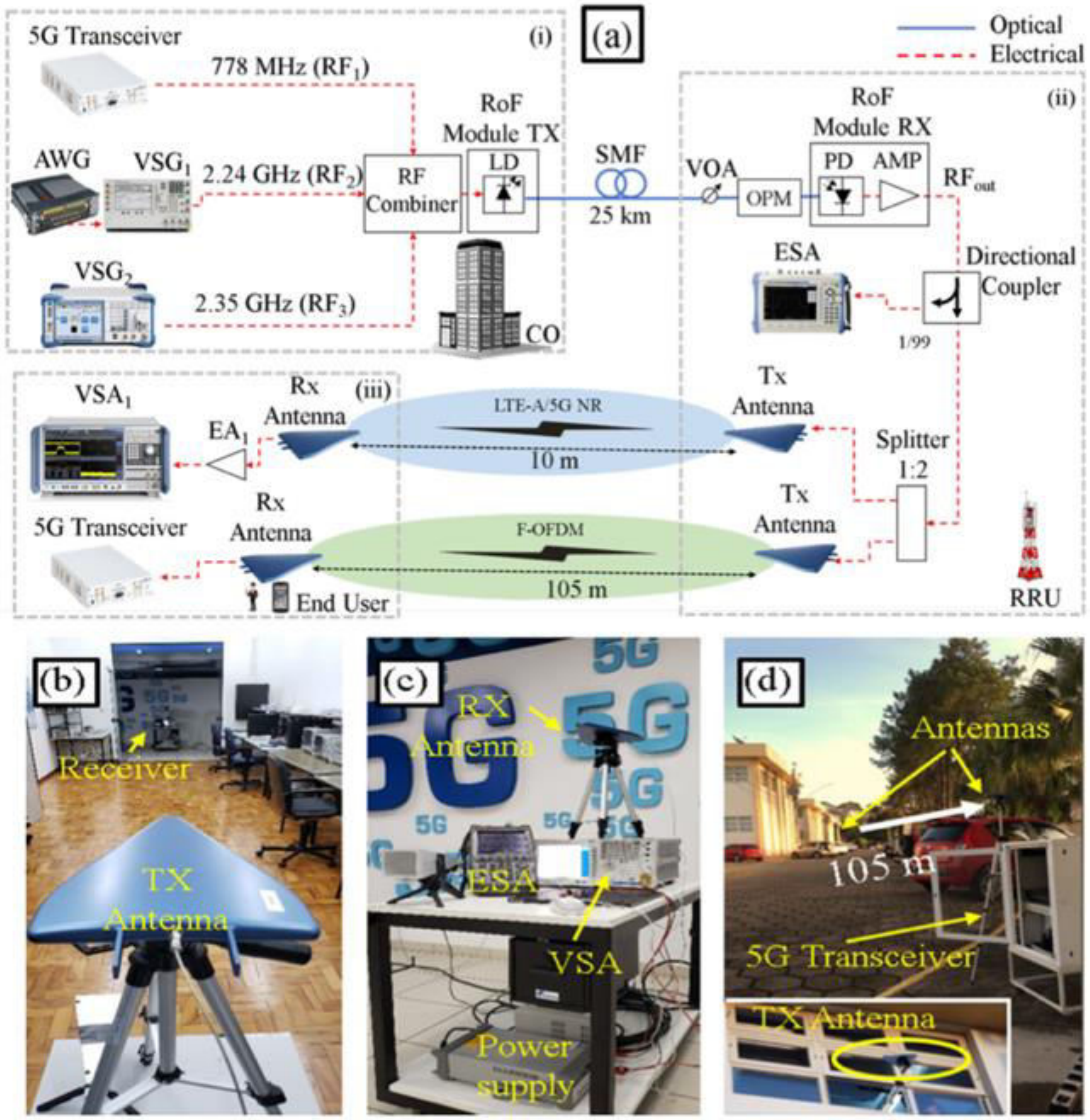
Non-Standalone 5G NR Fiber-Wireless System Using FSO and Fiber-Optics Fronthauls

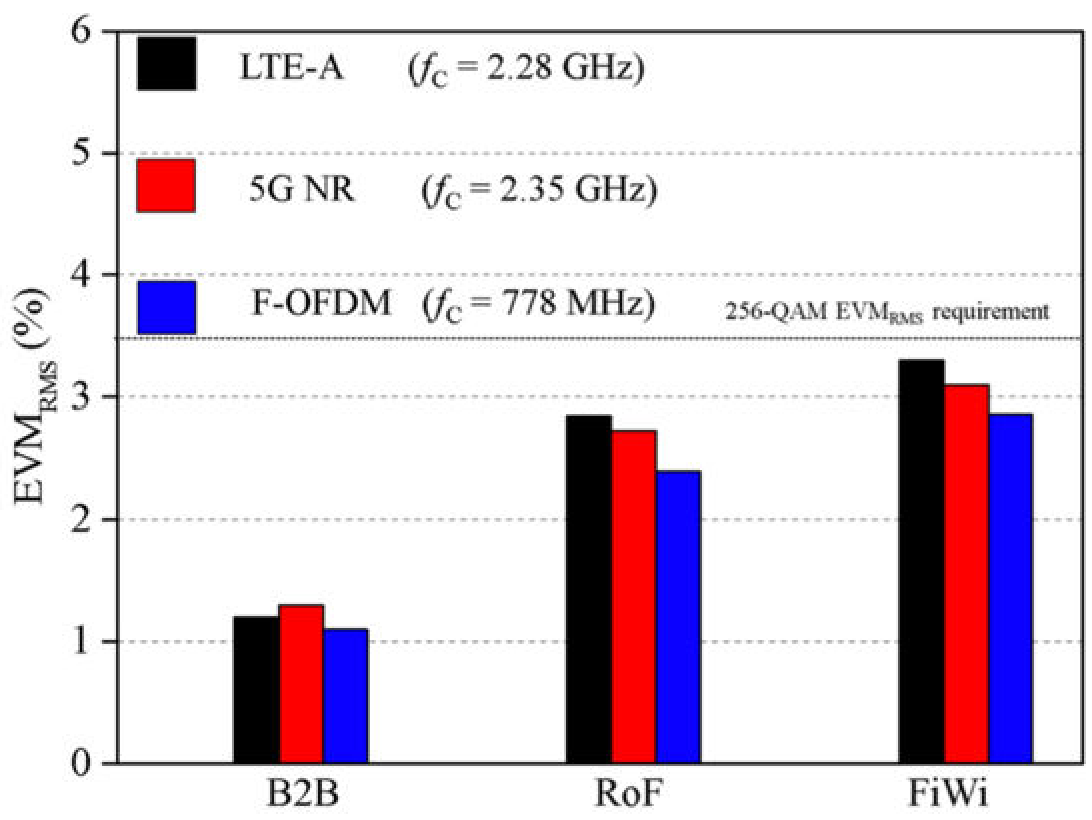
Celso Henrique de Souza Lopes, Eduardo Saia Lima, Luiz Augusto Melo Pereira, Ramon Maia Borges, Alexandre Carvalho Ferreira, Marcelo Abreu, Whebert Damascena Dias, Danilo Henrique Spadoti, Luciano Leonel Mendes, and Arismar Cerqueira Sodre Junior

***Abstract*—The fifth-generation of mobile networks (5G) claims for a radio access network (RAN) update in order to support the enormous incoming wireless data traffic. In this context, we experimentally evaluate two distinct hybrid architectures applied to 5G New Radio (NR) FiWi systems based on different optical fronthaul approaches. The first architecture operates in non-standalone (NSA) mode, defined by the 3rd generation partnership project (3GPP), for simultaneously transmitting 4G and 5G technologies through an unique FiWi system. The three considered waveforms are as follows: a filtered orthogonal frequency division multiplexing (F-OFDM) signal at 778 MHz with 10 MHz bandwidth from our 5G flexible-waveform transceiver; a long-term evolution-advanced (LTE-A) signal with five 20 MHz sub-bands centralized at 2.24 GHz; a 5G NR signal at 2.35 GHz with 100 MHz bandwidth. On the other side, the second architecture employs radio over fiber (RoF), free space optics (FSO), and wireless technologies converged into a heterogeneous network (HetNet). The additional multi-standard and multiband optical-wireless network is based on a 10-MHz bandwidth F-OFDM signal at 788 MHz, a 100-MHz bandwidth 5G NR signal at 3.5 GHz, and a 400-MHz bandwidth *M*-QAM signal at 26 GHz. Throughput up to 3 and 1.4 Gbps are demonstrated for RoF/FSO and RoF/FSO/Wireless transmission, respectively.**

I. Introduction

The fifth-generation of mobile network fifth-generation of mobile networks (5G) has already started to be commercially implemented worldwide. The main application scenarios that 5G aims to serve are basically defined as: enhanced mobile broadband (eMBB); massive machine type communication (mMTC) and ultra-reliable low-latency communication (URLLC) [1]. In addition, the enhanced remote area communications (eRAC) scenario, aimed for long-range communications up to 50 km, has also be considered potential to be included in the next 3GPP release versions. [1]. Due to the 5G plurality of applications, it becomes necessary to use innovative technical solutions, including: 5G new radio (5G NR) standard; additional spectral bands; software-defined network (SDN); massive multiple-input multiple-output (mMIMO). The 3GPP Release 15 establishes the phase 1 for the 5G standardization, called the New Radio Phase 1. At this initial stage of implementation, 5G networks operate in NSA, hence leveraging the fourth-generation of mobile networks (4G) architecture for deploying





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IEEE JOURNAL OF SELECTED TOPICS IN QUANTUM ELECTRONICS, VOL. 27, NO. 2, MARCH/APRIL 2021 6100308

5G NR RoF System Based on a Monolithically Integrated Multi-Wavelength Transmitter

Matheus Sêda Borsato Cunha, Eduardo Saia Lima, Nicola Andriolli, Danilo Henrique Spadoti, Giampiero Contestabile, and Arismar Cerqueira S. Jr.

Abstract—**We propose and demonstrate the use of a monolithically integrated multi-wavelength transmitter for multiband 5G new radio (NR) radio-over-fiber (RoF) systems, simultaneously operating in the standalone (SA) and non-standalone (NSA) modes. The novel integrated photonic circuit, integrating eight tunable and directly modulated distributed feedback lasers, aims to reduce the transmitter complexity and footprint, enabling compact, high-performance and low-cost 5G solutions for frequencies up to 10 GHz. We report the implementation of a 4G/5G shared optical mobile fronthaul using two 5G NR and a LTE-A signals, evaluated in two distinct scenarios, as a function of root mean square error vector magnitude (EVM_{RMS}) and in accordance to the 3GPP Release 15 requirements. In the first phase, three optical carriers in C-band are independently modulated with three mentioned RF signals, whereas subcarrier multiplexing (SCM) is applied to the second scenario for jointly modulating an optical carrier at 1554 nm. Gbit/s throughput is demonstrated for validating the applicability of our monolithically integrated multi-wavelength transmitter either for enabling multiapplication and/or diverse RF standards, using a single wavelength or multiservice exploiting different wavelengths from an unique optical source.**

concerning the evolution of communications systems. In thi framework, it has been observed a focus on the development o the fifth-generation of mobile networks (5G), which promote a significant progress to the information and communication field areas. Furthermore, high-definition services, multimedi applications and game services, beyond the thousands of device composing the Internet of Things (IoT), have been caused a exponential growth in the demand for wireless communication [1], [2]. Particularly, 5G includes multiple services and specifi requirements for each application. To attend this plurality, 5(networks are going to take advantage of new techniques, suc as: the 5G new radio (NR) standard; flexible waveforms; mas sive multiple-input multiple-output (mMIMO) techniques; an additional frequency bands, including millimeter-waves [3], [4]

The 5G frequency spectrum has been divided into two distinc bands. The frequency range 2 (FR2) considers frequencies abov 6 GHz, with carrier frequencies around 30 GHz and bandwidt (BW) up to 1 GHz, aiming enhanced mobile broadband (eMBB

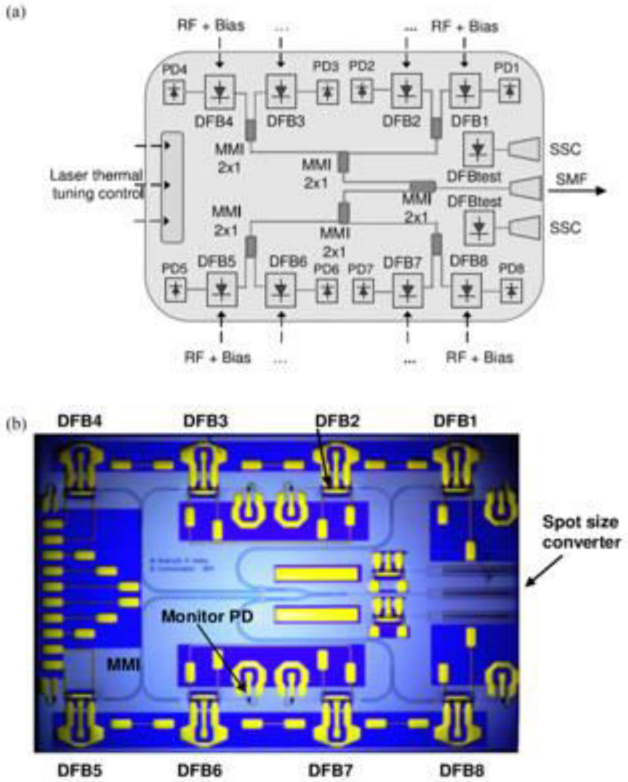


Fig. 1. (a) PIC Schematic. (b) PIC microscope photography.

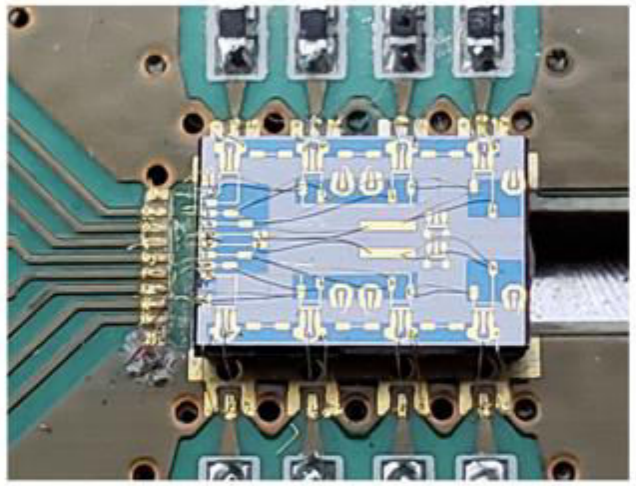
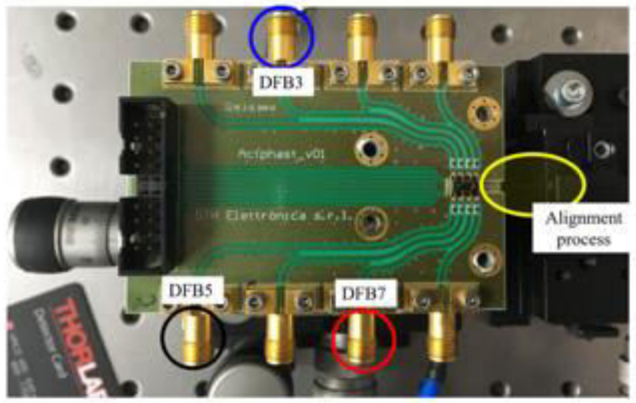


Fig. 2. Photonic integrated circuit photography.



the output facet is anti-reflection coated to minimize reflections, since SSC is orthogonal to the facet.

Each wavelength (λ) is ensured by a complex-coupled distributed feedback laser incorporating a twin waveguide formed

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Non-Standalone 5G NR FiWi System Based on a Photonic Integrated Multi-Wavelength Transmitter

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Abstract—**This letter presents a non-standalone 5G new radio (NR) multiband fiber-wireless (FiWi) system implemented using an integrated multi-wavelength transmitter with direct modulation. In this system, three 4G/5G RF signals are simultaneously transported over a 12.5-km long radio over fiber (RoF) link, before being amplified and radiated: a 20-MHz 5G NR signal at 788 MHz; five 20-MHz LTE subcarriers at 2.6 GHz; a 100-MHz 5G NR signal at 3.5 GHz. Wireless transmissions through a 10-m long indoor picocell-like link and a 115-m long realistic outdoor wireless link are demonstrated. All 4G and 5G received signals comply with the 3GPP Release 15 requirements, in terms of EVM_{RMS}, except for 16 QAM at 3.5 GHz on the 115-m link. Experimental results demonstrate a total throughput of 1.36 Gbit/s and 230 Mbit/s on the 10-m and 115-m scenarios, respectively.**

Index Terms—**5G mobile communication, fronthaul, multi-wavelength transmitter, RoF and wireless networks.**

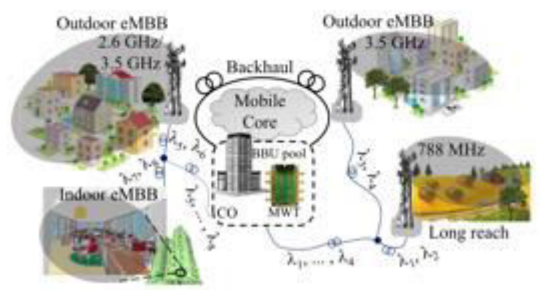
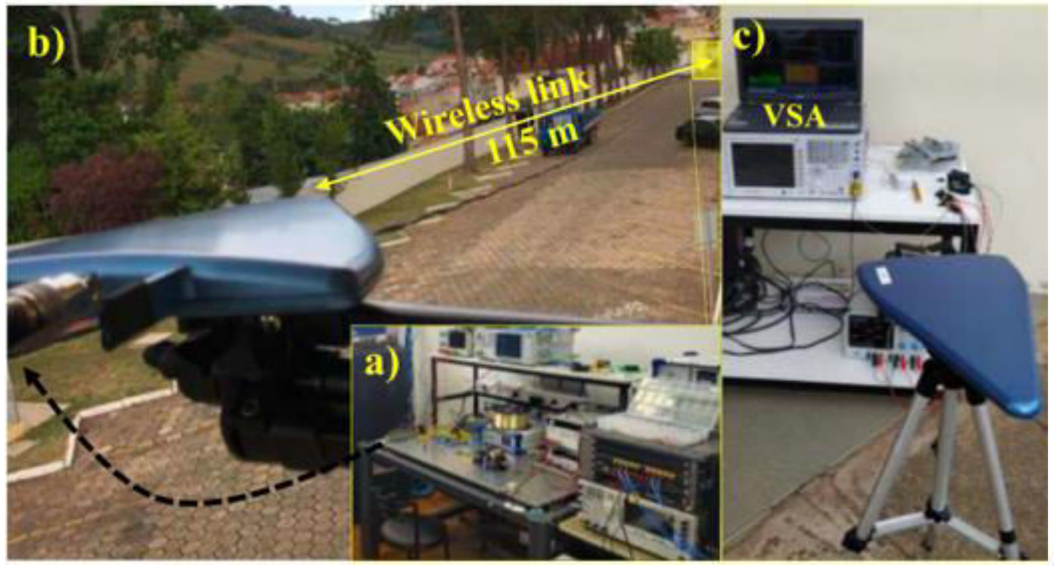


Fig. 1. Non-standalone 5G NR fiber wireless system based on a monolithically integrated multi-wavelength transmitter.

networks and centralized RAN (C-RAN) [2]. The latter consists of keeping the remote radio unit (RRU) at the antenna site



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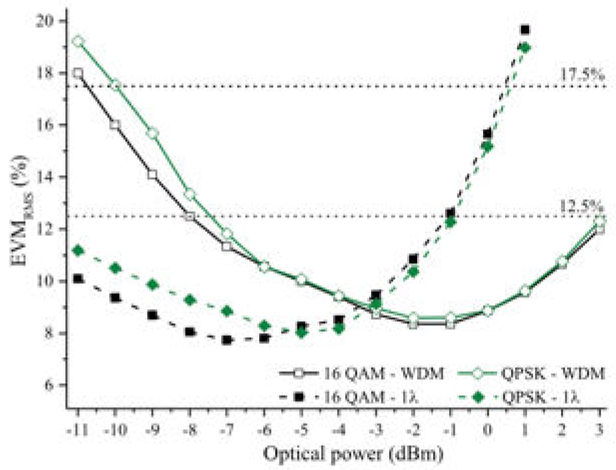
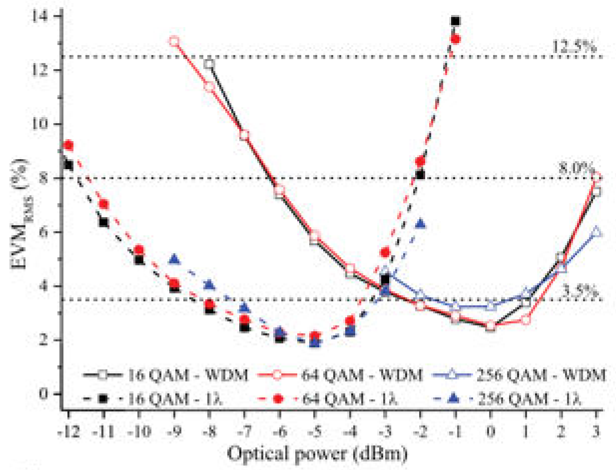
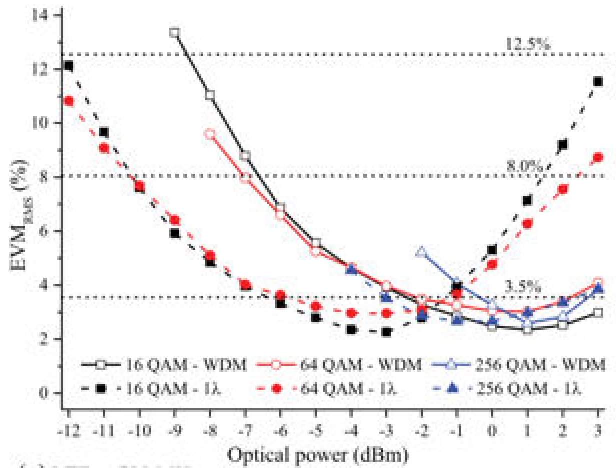


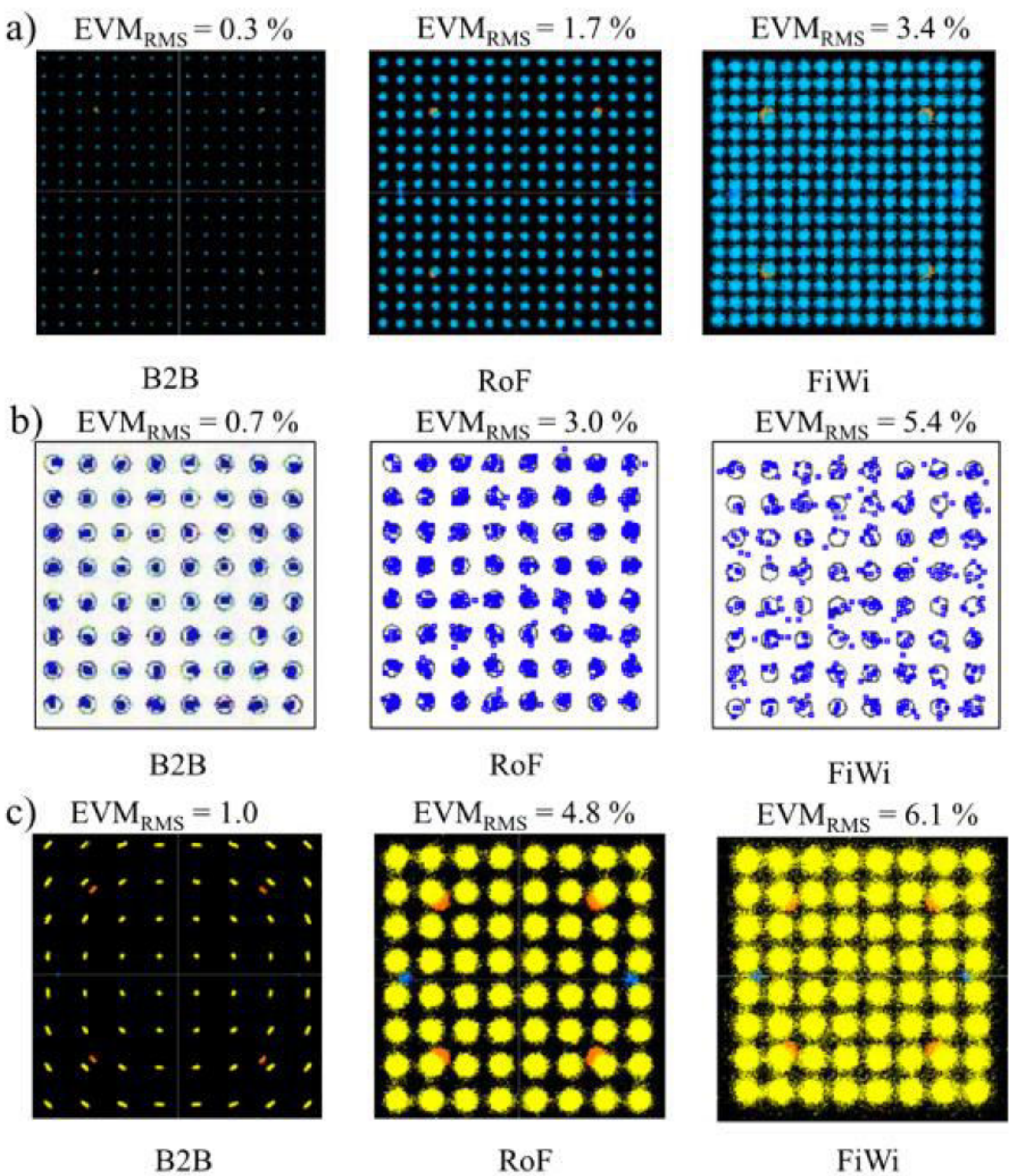
(a) 5G NR at 10 GHz

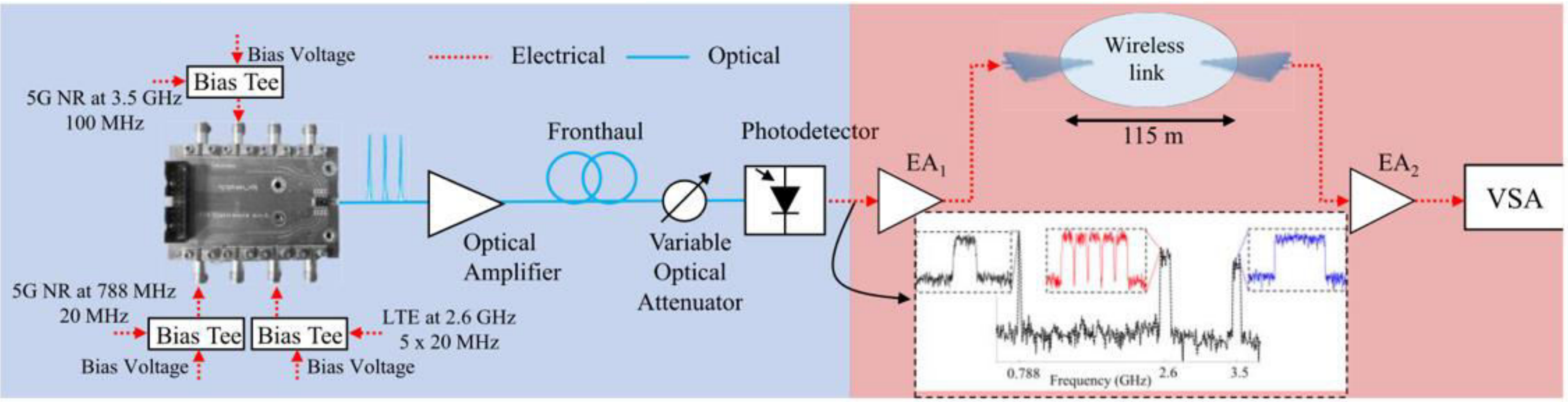


(b) 5G NR at 738 MHz.

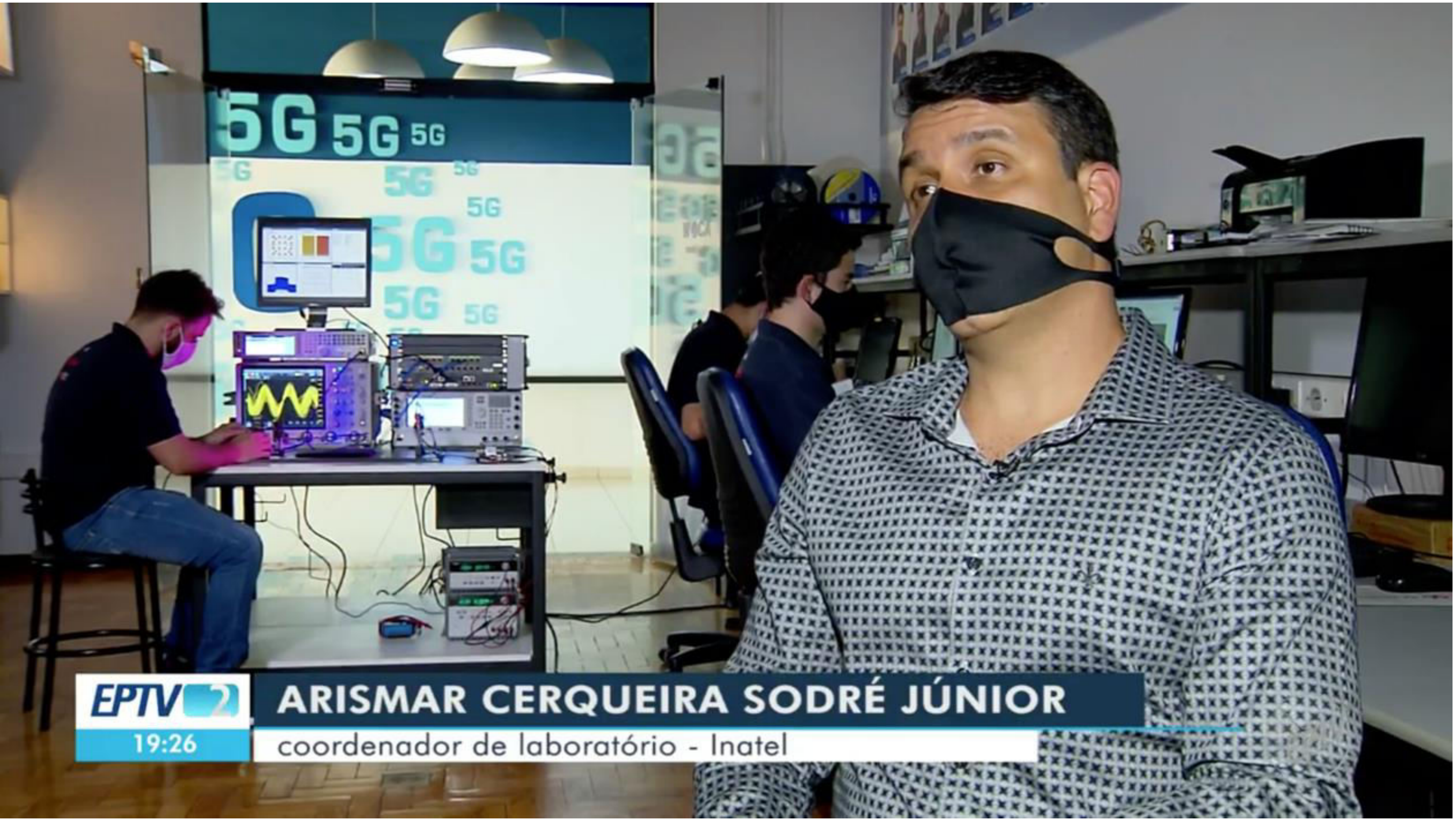


(c) LTE at 790 MHz.





Demo of a VLC Systems Towards 6G



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