Coexistence Analysis Between 5G NR and TVRO in C-Band

L.C. Alexandre, L.O. Veiga, Agostinho Linhares, José R. P. Moreira, M. Abreu and Arismar Cerqueira S. Jr.

Abstract— **This work reports a coexistence analysis between 5G New Radio (5G NR) and Satellite Television Receive Only (TVRO) in C-Band. The coexistence experiments to detect 5G NR interference in TVRO systems are based on the two following approaches: broadcast of analog and digital TV channels, received by a 1.7 meters parabolic antenna pointed to the Star One C2 geostationary satellite from Embratel; 100 MHz-bandwidth 5G NR link at 3.55 GHz with two printed log periodic antennas. The performance analysis has been carried out as a function of the TV channel quality signal, by means of varying the 5G power level at vertical polarization. Measured spectra of either radiofrequency (RF) and intermediate frequency (IF) signals are presented for demonstrating a probable interference problem due to the installation of 5G base stations close to TVRO user homes. For instance, there are still 22 million TVRO users in Brazil and 120 million homes attended by C-Band satellites in United States for radio and TV services. Finally, two efficient technological solutions are proposed and theoretically validated, using SF.1486 ITU-R recommendation, for mitigating 5G NR interference to TVRO and their results are properly compared to other techniques reported in literature.**

Index Terms—**5G, C-Band, coexistence, satellite and TVRO.**

I. INTRODUCTION

The C-Band satellites are typically used for large coverage areas in diverse applications, including broadcasting, telemetry, tracking and command [1]. On the other hand, at higher frequencies, such as Ku- and Ka-Bands, satellite beams are focused on smaller areas to overcome the high signal attenuation due to atmospheric effects [2]. According to the International Telecommunication Union (ITU), the C-Band is vital for many countries, especially for fixed satellite services (FSS) and broadband wireless access (BWA) [3-4]. Home users use geostationary satellites to receive signals from TV broadcasts, using Satellite Television Receive Only (TVRO) systems [5-6]. C-Band satellites are mainly used to simultaneously transmit analog and digital programming from TV head-ends to the local TV broadcasters, which re-transmit the national and local contents to homes, using digital terrestrial transmissions. Those TV broadcast signals are open, thus the home users only need to point their satellite dishes to geostationary satellites. In parallel, many communications systems use TVRO adjacent channels of in C-Band, including 5G New Radio (5G NR), which is the new radio access technology (RAT) developed by the 3rd Generation Partnership Project (3GPP) for the fifth-generation (5G) mobile network. 5G NR is going to operate over two frequency ranges, namely: Frequency range 1 (FR1) from 410 MHz to 7.125 GHz with bandwidth up to 100 MHz; Frequency range 2 (FR2) from 24.25 to 52.6 GHz with bandwidth up to 400 MHz.

Particularly the C-Band region from 3300 to 3600 MHz has been chosen for many countries to cover urban areas, aiming to ensure a trade-off between high data rate and medium coverage [7-8]. 5G NR allows multiple services for different scenarios, such as enhanced mobile broadband (eMBB), a massive number of connected Internet of Things (IoT) devices and Machine-Type Communications (MTC) [9, 10].

Recently, some works on coexistence between telecom (Long Term Evolution (LTE) and 5G) and satellite (TVRO and FSS) systems have been reported in the literature [11-15]. Their importance are due to the interference possibility between these technologies. In 2018, Son et al. [12] presented numerical analyses in a scenario of coexistence between 5G and FSS at 3.8 GHz, resulting in a minimum distance of 15 km to obtain 95% protection against interference. In parallel, Tan et al. [13] presented numerical and experimental analyses of coexistence between 5G and satellite reception systems, operating from 3.4 to 3.6 GHz. The reception system proposed in [13] was composed of commercial filters and low noise blocks (LNBs) based on phased locked loop oscillators (PLL), aiming to

Article submitted on December, 2019. This work was partially supported by RNP, with resources from MCTIC, Grant No. 01250.075413/2018-04, under the Radiocommunication Reference Center (Centro de Referência em Radiocomunicações - CRR) project of the National Institute of Telecommunications (Instituto Nacional de m Telecomunicações - Inatel), Brazil. The authors also thank the technical support of Renato Guadagnini from Venturus, and financial support from CNPq, CAPES, FINEP and FAPEMIG.
(Corresponding author: Arismar Cerqueira Sodré Junior.)

L. C Alexandre, L. O. Veiga and Arismar Cerqueira S. Jr, are with the National Institute of Telecommunications (Inatel), Santa Rita do Sapucai, MG 37-540-000, Brazil (e-mail: luciano.camilo@mtel.inatel.br; veiga@gee.inatel.br; arismar@inatel.br).

Agostinho Linhares is with National Telecommunications Agency (Anatel), Brasilia, DF, 70070-940, Brazil. (e-mail: linhares@anatel.gov.br).

Jose. R. P. Moreira is with Rohde and Schwarz, São Paulo, SP, 05676-120, Brazil. (e-mail: jose.reis@rohde-schwarz.com).

M. Abreu is with Venturus, Campinas, SP, 13086-530, Brazil. (e-mail: marcelo.abreu@venturus.org.br).
Digital Object Identifier: 10.14209/jcis.2020.21

evaluate FSS protection, image quality and the interference origin. By means of a deterministic study, Yuan et al. [14] have analyzed the interference of the 4G / 5G signal in a mobile satellite data reception system, with the purposing of allowing a minimum protection distance between mobile communication system and FSS. Additionally, a spectrum sharing investigation has been carried out between 5G and a FSS operating at 28 GHz in the northern hemisphere [15].

TVRO systems started in the seventies and reached 1.4 million users in 1985 in the United States, mainly due to the deregulation of the telecommunications regulatory agency [16]. Currently, there are about 22 million TVRO users in Brazil [17] and 120 million homes attended by C-Band satellites in United States for radio and TV services [18], making the coexistence between TVRO and 5G a technical and social challenge, as illustrated in Fig. 1. Typically, TVRO downlink is from 3625 to 4200 MHz, which is adjacent to the main FR1 band. Therefore, depending on the power level of the 5G NR access networks and distance from its base station to the TVRO home users, there is a serious risk of interference, making coexistence analysis necessary to maintain high-quality C-band TV and radio services. In parallel, diverse groups have widely applied the ITU-R recommendations to estimate possible interferences from diverse communication systems to FSS, operating in C-Band [4][11-14][19-24]. The ITU-R Recommendations are approved by ITU Member States. Their implementation is not mandatory; however, as they are developed by experts from administrations, operators, the industry and other organizations dealing with radiocommunication matters from all over the world, they enjoy a high reputation and are implemented worldwide.

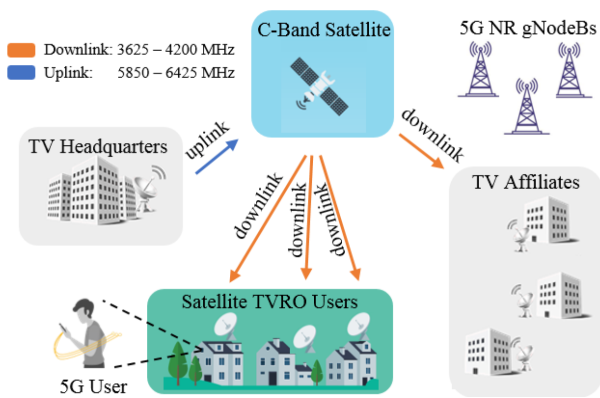


Fig. 1. Coexistence analysis between 5G NR and TVRO in C-Band.

The current work main contributions are the following ones: to the best of our knowledge, our work is the first one in literature on coexistence analysis between 5G New Radio and Satellite TVRO system published in literature; an experimental investigation of the possible 5G impact on approximately 22 million TVRO homes in Brazil, by means of varying the interference received power level and analyzing the TV image quality in analog and digital channels; an analytical analysis on the protection distance, by comparing different commercial low noise block feedhorn (LNBF); the proposal and theoretical validation of two technological solutions based on the use of RF filters and amplifiers with enhanced 1-dB compression point for mitigating the interference and, consequently, enabling a peaceful coexistence between 5G and TVRO systems.

The manuscript is structured in four sections. Section II is concerning the experiment setup, whereas experimental results and the two proposed technological solutions are presented in Section III. Conclusions and final remarks are addressed in Section IV.

II. Experimental Setup

Fig. 2 describes the coexistence experimental setup between TVRO and 5G NR in C-band. Two different vector signal generators from Rohde & Schwarz, SMW 200 and SMBV 100A, have been used to create a 100 MHz-bandwidth 5G NR waveform at 3550 MHz, which was radiated by a Hyperlog 6080 antenna from Aaronia using vertical polarization. All RF signals had been generated following the 3GPP TS 38.141-1 and 3GPP TS 38.141-2 base station conformance testing [25, 26]. The bandwidth and modulation have been chosen in accordance to the 3GPP maximum specifications from the Release 15 for C-Band, aiming to obtain the maximum throughput using FR1 [27]. The 7-meters distance between the 5G signal generator and FSS has been chosen to guarantee a suitable dynamic range for the interference evaluation, as well as for ensuring far-field conditions.

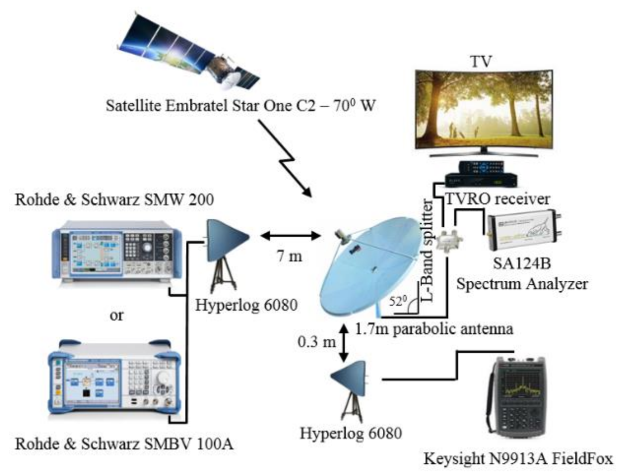


Fig. 2. Experimental setup of the coexistence between 5G NR and TVRO.

At the receiver side, a terrestrial earth station has been installed at -22.2578^0 latitude and -45.6957^0 longitude, in conjunction with a 1.7m C-Band parabolic antenna with a 65 dB-gain LNBF. The TV system has been pointed to the Embratel Star One C2 satellite, located at 70^0 W orbital position to receive the satellite transponder signals. The resultant downconverted signal from LNBF in L-Band has been divided by using 1:2 splitter. One cable was directly connected to the TV receiver and the other one to a spectrum analyzer, to evaluate the performance as a function saturation and distortion in the presence of the 5G NR signal at different power levels. An N9912A FieldFox handheld RF and microwave analyzer from Keysight has been used to monitor the 5G NR power level.

III. Experimental Results

Initially, the intermediate frequency (IF) components in L-Band, after the LNBF down-conversion, have been measured without the 5G NR signal (Fig. 3) for comparison purposes. The transponder signal in C-Band has been mixed with the 5150 MHz local oscillator from LNBF, which is responsible to downconvert the C-Band transponder frequencies to L-Band. One can clearly observe the transponder satellite frequencies without any interference. The marker 1 (Mkr 1) depicts a Globosat channel tuned at the 3720 MHz transponder, implying in IF = 1430 MHz. The frequency shift of 1.5 MHz was due to the LNBF local oscillator instability.

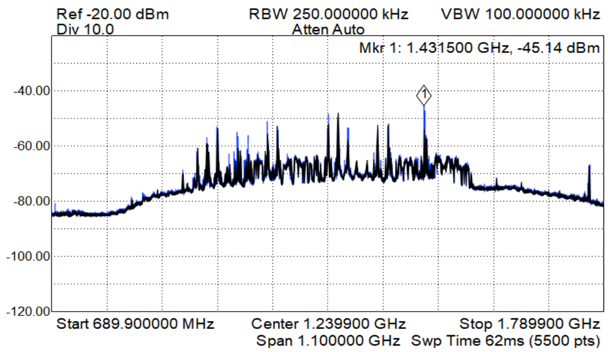


Fig. 3. IF components without the 5G NR signal.

The next step was turning the 5G NR signal generator on for experimentally evaluating its coexistence with TVRO. The 5G transmitted power has been varied from 0 to 18 dBm for obtaining the maximum power level that would not interfere in the TVRO system. The transmitting 5G antenna had been placed at 7.0 m distance to the TVRO receiving antenna, which implied in received channel power from -53 to -37.5 dBm at 3550 MHz. An example of the obtained IF spectrum in the presence of a 5G NR signal is reported in Fig. 4 for -41 dBm received channel power. One can note the impact of the spectrum persistence mode from 5G NR at 1.65 GHz (continuous green line), originally at 3550 MHz before down-conversion, which implied in high-level interference to TVRO. Fig. 5 displays TV images for different power levels, including a good image without any distortion or saturation from Fig. 5a for -48 dBm channel power. The Globosat analog TV channel at 3720 MHz has been interfered by the 5G NR system for power levels higher than –46 dBm, as demonstrated in Fig. 5b. Particularly for -41 dBm, there was no discernible image on the TV screen, as shown in Fig. 5c, due to the IF signal high distortion and saturation, giving rise to a poor-quality image. As expected, this situation has been always noticed for even higher power levels.

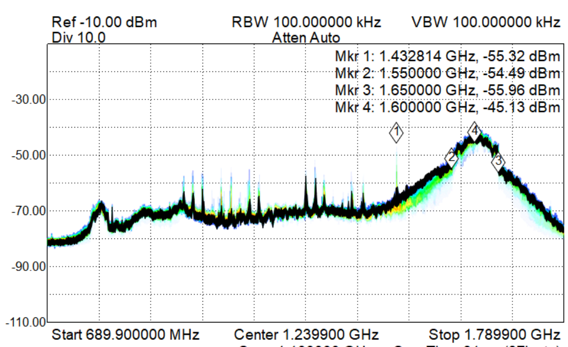
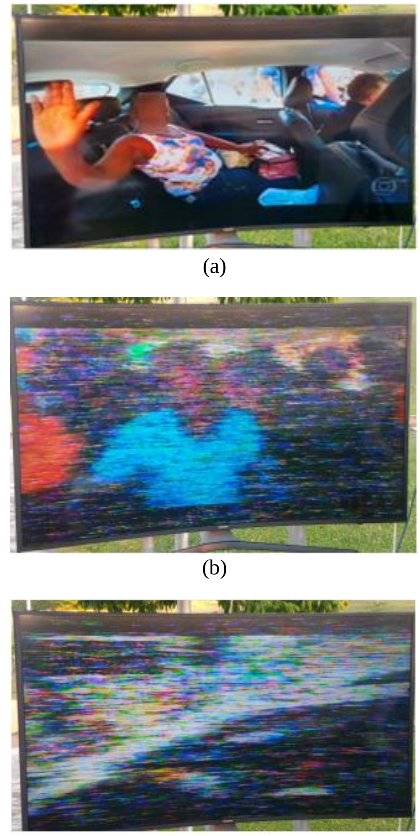


Fig. 4. IF components in the presence of the downconverted 5G NR signal (green continuous line).



(a)

(b)

(c)

Fig. 5. TV images for different 5G signal channel power levels: (a) -48 dBm; (b) -46 dBm; (c) -41 dBm.

The ITU-R SF.1486 methodology for a fixed wireless access (FWA) system in FSS [29] has been applied to sort the TVRO interference problem out due to the 5G NR system. The minimum protection distance is defined as how physically close a new entrant might be in space to an incumbent's receiver. Particularly for the 5G and TVRO coexistence analysis, the minimum protection distance represents the minimum separation between FSS (TVRO user home) and FWA (5G base station) that not results in performance degradation for TVRO users, evidenced by image distortion and blocking in analog and digital channels, respectively. Considering there is no clutter loss in our setup, due to the line-of-sight (LOS) scenario, one can calculate the required protection distance (d) by using the following equations [29]:

$$P_{sat} = EIRP_{FWA} - L + G - R\,, \tag{1}$$

$$L = 92.5 + 20\log(f) + 20\log(d), \tag{2}$$

where G is the reference radiation pattern gain that should be adopted for frequencies from 2 to 31 GHz [28],

$$G = 32 - 25\log\varphi \;\; dBi \text{ for } \varphi_{min} \leq \varphi \leq 48^0 \tag{3}$$

or

$$G = -10\; dBi \qquad \text{for } 48^0 \leq \varphi \leq 180^0, \tag{4}$$

in (3) and (4), φ is the elevation position of the FSS. In (2), f is the frequency (GHz) and d is the protection distance (km). From (1), P_{sat} is the TVRO 1 dB compression point (P1dB), EIRP is the 5G NR effective isotropic radiated power, G = -10 dBi is the TVRO antenna gain [28] for 52^0 of elevation in our scenario, L is the free-space loss and R is the isolation protection, which might be shielding, RF filters or separation distance between stations in decibel.

We propose to use low-cost planar RF filters with low insertion loss before the low noise amplifier (LNA) stage of the LNBF for avoiding interference from 5G NR in TVRO systems. Tab. I summarize the protection distance for $EIRP_{FWA} = 75\ dBm$, L is calculated by (2), for f = 3550 MHz to find the protection distance d, R = 35 dB (RF filter rejection) and P_{sat} varying from – 60 to -45 dBm (P1dB enhancement). As a result, the proposed filter enables to significantly reduce the required separation distance between the 5G NR base station and TVRO users from 12.02 km to 672.6 m. Additionally, the TV signal saturation can be alleviated and, consequently, the protection distance can be further lessened, by improving the LNBF P1dB, which was refereed in Tab. I as the "Proposed solution 2". As a consequence, the calculated enhanced protection distance is only 111 m, which could make the 5G deployment viable in C-band. In this way, the two important systems could coexist without imposing interference with each other.

TABLE I. COMPARISON OF THE PROTECTION DISTANCE INCLUDING AN RF FILTER BEFORE THE LNBF FIRST AMPLIFICATION STAGE.

LNBF	***RF filter***	***LNBF P1dB***	***Protection distance***
Comercial	no	-60 dBm	12.02 km
Proposed solution 1	yes	-60 dBm	672.6 m
Proposed solution 2	yes	-45 dBm	111 m

Finally, a comparison result is reported in Tab. II, illustrating the type of analysis, proposed solution, type of interferer, protection distance and the solution proposed.

TABLE II. COMPARISON AMONG OUR APPROACH WITH THE STATE-FO-THE-ART [11-14].

Ref.	***Interference Signal***	***Analysis Type***	***Proposed solution***	***Obtained result***
[11]	Emulated LTE signal from 3.4 to 3.6 GHz	Analytical	Commercial filter	50 m
[12]	Emulated 5G signal at 3.5 GHz	Analytical	Commercial filter	100 m
[13]	Emulated 5G signal at 3.8 GHz	Analytical	-	15 km
[14]	Emulated 4G/5G in the 2.0 GHz band	Analytical and Experimental	-	-
Current Work	Real 5G NR at 3.55 GHz	Analytical and Experimental	New RF filter and increasing LNBF P1dB	111 m

IV. CONCLUSIONS

A coexistence analysis between the 5G NR and TVRO systems in C-band has been reported and properly discussed for different power levels and as a function of TV quality image of analog and digital channels, transmitted in horizontal polarization. Experimental results demonstrated interference problems and even image cancellation, due to the installation of 5G base stations close to TV user homes, for downconverted 5G channel powers higher than –46 dBm. Two efficient strategies have been proposed for minimizing the saturation and distortion problems and addressing the coexistence between 5G and TVRO systems. The first approach relies on adding low-cost planar RF filters with low insertion loss before the LNBF first amplification stage. Our first idea has been validated by using the ITU-R SF.1486 recommendation, which has also been applied in the references from 11 to 14 and from 19 to 29, enabling to positively reducing the required separation distance between the 5G NR base station and TVRO users from 12.02 km to 672.6 m. Furthermore, increasing the TVRO LNBF 1 dB compression point by 15 dB might further lessen the protection distance to only 111 m. Future works regard the development and implementation of the proposed RF filter, as well as carrying out new experiments based on the M.2101-0 ITU-R recommendation to experimentally validate the current theoretical predictions.

REFERENCES

[1] L. C. Fung, C. K. Tang, K. H. Chan and S. W. Leung, "Assessment of radiated immunity of C-band satellite TV receiving station in Hong Kong local environment due to UWB interference," 2008 Asia-Pacific Microwave Conference, Macau, pp. 1-5, 2008, DOI. 10.1109/APMC.2008.4958437.

[2] K. Johannsen and U. Mathur, "TVRO Antenna Size, Ku Band Versus C Band," in IEEE Transactions on Broadcasting, vol. BC-33, no. 3, pp. 84-88, Sept. 1987, DOI. 10.1109/TBC.1987.266635.

[3] Groups, "Study of Interference From IMT-Advanced Into FSS, And From FSS Into IMT-Advanced In The Band 3 700-4 200 MHz", August 2007, Document 8F/998-E.

[4] F. Z. Widyoseno and Iskandar, "Interference mitigation of FSS earth station and FS station in extended C-Band frequency," 2015 9th International Conference on Telecommunication Systems Services and Applications (TSSA), Bandung, pp. 1-4, 2015, DOI. 10.1109/TSSA.2015.7440460.

[5] J. Chen, Z. Qian, T. Wang and X. Li, "Analysis on the protection distance for spectrum sharing between IMT-2020(5G) and EESS systems in 25.5–27GHz band," 2017 IEEE 2nd Information Technology, Networking, Electronic and Automation Control Conference (ITNEC), Chengdu, pp. 970-975, 2017, DOI. 10.1109/ITNEC.2017.8284880.

[6] ITU-R, "Sharing studies between International Mobile Telecommunication-Advanced systems and geostationary satellite networks in the fixed-satellite service in the 3 400-4 200 MHz and 4 500-4 800 MHz frequency bands in the WRC study cycle leading to WRC-15," Report S.2368-0, Geneva, 2015.

[7] Lin, Xingqin, et al. "5G new radio: Unveiling the essentials of the next generation wireless access technology." arXiv preprint arXiv:1806.06898, 2018, DOI. 10.1109/MCOMSTD.001.1800036.

[8] A. Guidotti et al., "Architectures and Key Technical Challenges for 5G Systems Incorporating Satellites," in IEEE Transactions on Vehicular Technology, vol. 68, no. 3, pp. 2624-2639, March 2019, DOI. 10.1109/TVT.2019.2895263.

[9] S. Lien, S. Shieh, Y. Huang, B. Su, Y. Hsu and H. Wei, "5G New Radio: Waveform, Frame Structure, Multiple Access, and Initial Access," in IEEE Communications Magazine, vol. 55, no. 6, pp. 64-71, June 2017, DOI. 10.1109/MCOM.2017.1601107.

[10] S. Parkvall, E. Dahlman, A. Furuskar and M. Frenne, "NR: The New 5G Radio Access Technology," in IEEE Communications Standards

Magazine, vol. 1, no. 4, pp. 24-30, Dec. 2017, DOI. 10.1109/MCOMSTD.2017.1700042.

[11] Fernandes, L.C. & Linhares, "Coexistence conditions of LTE-advanced at 3400-3600 MHz with TVRO at 3625 – 4200 MHz in Brazil", in Wireless Networks, no. 25 pp. 105-115, 2017, DOI. 10.1007/s11276-017-1544-8.

[12] H. Tan, Y. Liu, Z. Feng and Q. Zhang, "Coexistence analysis between 5G system and fixed-satellite service in 3400–3600 MHz," in China Communications, vol. 15, no. 11, pp. 25-32, Nov. 2018, DOI. 10.1109/CC.2018.8543046.

[13] H. Son and Y. Chong, "Coexistence of 5G system with Fixed satellite service Earth station in the 3.8GHz Band," 2018 International Conference on Information and Communication Technology Convergence (ICTC), Jeju, pp. 1070-1073, 2018, DOI. 10.1109/ICTC.2018.8539462.

[14] J. Yuan, Z. Li, M. Liu, X. Lv and Y. Wang, "A Study on the Coexistence of TD-LTE/5G and Mobile Satellite Service" 2018 24th Asia-Pacific Conference on Communications (APCC), Ningbo, China, pp. 119-124, 2018, DOI. 10.1109/APCC.2018.8633559.

[15] W. A. Hassan, H. Jo, S. Ikki and M. Nekovee, "Spectrum-Sharing Method for Co-Existence Between 5G OFDM-Based System and Fixed Service," in IEEE Access, vol. 7, pp. 77460-77475, 2019, DOI. 10.1109/ACCESS.2019.2921973.

[16] U.S. Government Printing Office, Hearing Before the Committee on Commerce , Science, and Transportation United States Senate "Scrambling of Satellite TV Signals", July, 1986.

[17] Brazil - IBGE, Pesquisa Nacional por Amostra de Domicílios Contínua (PNAD), Retrieved 2019, October 15 from https://biblioteca.ibge.gov.br/visualizacao/livros/liv101631_informativo.pdf.

[18] C-Band Alliance, "FCC Proposal", Retrieved 2019, October 17 from https://c-bandalliance.com/.

[19] Abdulrazak, L. F., Shamsan, Z. A., Aswad, A. K., & Rahman, T. "A Novel computation of expecting interference between FSS and IMT-Advanced for Malaysia," IEEE International RF and Microwave Conference, Malaysia, pp. 367-371, 2008, DOI: 10.1109/RFM.2008.4897367.

[20] Abdulrazak, L. F., & Rahman, T. A. "Review ongoing research of several countries on the interference between FSS and BWA," International Conference on Communication Systems and Applications (ICCSA'08), Hong Kong, 2008.

[21] Mikhaylovich, A. V., & Ivanovich, V. V. "Permissible Interference Power from Earth Station Equipment within 3400–4200 MHz Band," International Seminar on Electron Devices Design and Production (SED), pp. 1-5, 2019, DOI: 10.1109/SED.2019.8798476.

[22] Aijaz, S. "Effects of deploying IMT-Advanced systems on fixed satellite services in the 3 400–3 600 MHZ frequency band in Pakistan".2nd International Conference on Advances in Space Technologies, pp. 1-5, 2008 DOI: 10.1109/ICAST.2008.4747676.

[23] Carciofi, C., Grazioso, P., Petrini, V., Spina, E., Massimi, D., De Sipio, G., Lai, Z. "Co-channel and adjacent-channel coexistence between LTE-TDD and VSAT DVB-S in C-band: experimental campaign on consumer VSAT receivers," IEEE 29th Annual International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC), pp. 1-5, 2018, DOI: 10.1109/PIMRC.2018.8580923.

[24] Höyhtyä, M. " Sharing FSS satellite C band with secondary small cells and D2D communications," IEEE International Conference on Communication Workshop (ICCW), pp. 1606-1611, 2015, DOI: 10.1109/ICCW.2015.7247409.

[25] 3GPP TS 38.141-1, "NR: Base Station (BS) conformance testing, Part 1: conducted conformance testing", 3rd Generation Parnership Project, Technical Specification Group Radio Access Network, December, 2019.

[26] 3GPP TS 38.141-2, "NR: Base Station (BS) conformance testing, Part 2: radiated conformance testing", 3rd Generation Parnership Project, Technical Specification Group Radio Access Network, December, 2019.

[27] European Telecommunications Standards Institute (ETSI) 3rd Generation Partnership Project (3GPP) Technical Specification, "5G; Study on New Radio (NR) access technology", 3GPP TR 138.912 version 15.0.0 Release 15, 2018-09.

[28] ITU-R. "Reference radiation pattern for earth station antennas in the fixed-satellite service for use in coordination and interference assessment in the frequency range from 2 to 31GHz," ITU-R S.465-6, 2010.

[29] ITU-R, "Sharing methodology between Fixed Wireless Access Systems in the Fixed Service and Very Small Aperture Terminals in the Fixed-Satellite Service in the 3400 - 3700 MHz Band," ITU-R SF.1486, May, 2000.

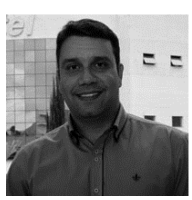
LUCIANO CAMILO ALEXANDRE received his B.Sc. degree in electrical engineering and M.Sc in Telecommunications from Inatel – National Institute of Telecommunications, Brazil, in 2008 and 2020, respectively. In 2007 has founded Fractum (RF & Microwaves) that produced and delivered more than 35.000 microwave radios for the defense market. Also, have experience as an RF engineering instructor since 2006. His field of interest is active and passive microwave devices and wireless systems.

LUCAS DE OLIVEIRA VEIGA is currently a M.Sc. student from the Telecommunication at the National Institute of Telecommunications (Inatel), Brazil. He received B.Sc degree in telecommunications engineering in the same institution in 2012. Currently acts as researcher for the Wireless and Optical Convergent Access (WOCA) Laboratory at Inatel. His fields of interest are antennas, mobile network, and wireless systems.

AGOSTINHO LINHARES DE SOUZA FILHO received his Ph.D. degree in Telecommunications from University of Brasilia in 2015 and M.Sc. degree in Telecommunications from University of Campinas in 2003. He joined Anatel in 2005 and has already worked in the Enforcement Division, Spectrum Engineering Division, Board of Directors Advisory and, currently, is Manager of Spectrum, Orbit and Broadcasting. He is the Coordinator of the Brazilian Communication Commission – Radiocommunication Sector (CBC-2), participates in ITU-R and ITU-T Study Groups, and was Head of Brazilian Delegation in the World Radiocommunication Conference 2015 (WRC-15).

JOSE REIS PINTO MOREIRA received his B.Sc degree in electrical engineering from Faculdade de Engenharia São Paulo – Brazil in 2003 and M.B.A in Business Management in Commerce and Sales from Faculdade Getulio Vargas – Brazil in 2017. He joined Rohde & Schwarz company in 2001, where he is responsible for Automotive, Industry, Components and Research market segments in Brazil.

MARCELO JOSE HERNANDES DE ABREU OLIVEIRA received the B.Sc. degree in computer engineering from the State University of Campinas (Unicamp), Brazil, in 1997. He has been working in the Software Engineering Area since 1997. His is Executive Manager at Venturus and his main responsibilities are Innovation and new business manager, developing a new culture of innovation in the entire organization, helping to build new projects and customers.



ARISMAR CERQUEIRA SODRÉ JUNIOR received the B.Sc. degree in electrical engineering from the Federal University of Bahia, Brazil, in 2001, the M.Sc. degree from the State University of Campinas (Unicamp), Brazil, in 2002, and the Ph.D. degree from Scuola Superiore Sant'Anna, Italy, in 2006. He was an Invited Researcher and Professor from many world-recognized universities, such as the University of Oulu (2017), Scuola Superiore Sant'Anna, Italy (from 2015 to 2019), Danish Technical University, Denmark (2013), Max-Planck Institute, Germany (2010), and University of Bath, U.K. (2004, 2005 and 2007). He was an Associate Professor with the Unicamp from March 2009 to August 2011, when he joined the National Institute of Telecommunications, Brazil, to work in the same position. Since 2009, he has been acting as a Coordinator of R&D Projects on diverse areas of telecommunications, including antennas, 5G networks, radars and microwave photonics. He is a holder of 10 patents, has transferred 24 products to the industry, and has published 246 scientific papers.