Horizon 2020 Grant Agreement no: 814523

Tera**h**ertz end-to-end wireless systems supp**o**rting ultra-high data **R**ate applications

ThoR

D5.3

Analysis of the Consequences of the Results of WRC 2019

Coordinator (EU): Thomas Kürner
Organisation: Technische Universität Braunschweig

Coordinator (Japan): Tetsuya Kawansihi
Organisation: Waseda University

Start date of project: 01-Jul-2018

Date of issue: 26-03-2020
Due date: 29-02-2020
Ref: ThoR_CIT_200212_D_WP5_D5_3

Leader in charge of deliverable: Akihiko Hirata
Chiba Institute of Technology

Project co-funded by the European Commission within the Horizon 2020 programme and the National Institute of Information and Communications Technology in Japan (NICT)		
Dissemination level		
PU	**Public**	**X**
PP	**Restricted to other programme participants (including the Commission Services)**	
RE	**Restricted to a group specified by the consortium (including the Commission Services)**	
CO	**Confidential, only for members of the consortium (including the Commission Services)**	

Contents

Change register

Version	Date	Author	Organisation	Changes
A	20-02-2020	Akihiko Hirata	Chiba Institute of Technology	Initial
B	23-02-2020	Thomas Kürner	TU Braunschweig	Adding text and references
C	25-02-2020	Akihiko Hirata	Chiba Institute of Technology	Version ready for review
D	09-03-2020	Eisaku Sasaki	NEC	Revision by reviewer

Reviewed by Eisaku Sasaki (NEC) Version C

1. Statement of independence

The work described in this document is genuinely a result of efforts pertaining to the ThoR project. Any external source is properly referenced.

Confirmation by Authors: Akihiko Hirata, Chiba Institute of Technology
Thomas Kürner, TU Braunschweig

2. ABBREVIATIONS

AI	Agenda Item
EESS	Earth Exploration-Satellite Service (passive)
ETSI	European Telecommunications Standards Institute
FS	Fixed Service
IEEE	Institute of Electrical and Electronics Engineers
IF	Intermediate Frequency
ITU-R	International Telecommunication Union - Radiocommunication Sector
LMS	Land-Mobile Service
PLO	Phase Locked Oscillator
RAS	Radio Astronomy Service
RF	Radio Frequency
RR	Radio Regulations
THz	Terahertz
WRC	World Radiocommunication Conference

3. Executive summary

This deliverable describes the outcome of World Radiocommunications Conference (WRC) 2019 with reference toTerahertz (THz) communications and makes an assessment of the results both in general and specifically for the ThoR project. WRC 2019 has included a new footnote to the radio regulations, which describes the conditions for the use of the spectrum between 275 and 450 GHz by land mobile and fixed service. Totally, 160 GHz of spectrum are now available for THz communications, where no specific conditions are necessary to protect Earth exploration-satellite service (EESS), which provides a sound basis for the future implementation of THz communications. Although a large of the spectrum has been identified for use for the implementation of land mobile and fixed service, where no specific conditions are necessary to protect Earth exploration satellite service, this is not the case for parts of the while planned spectrum within the ThoR project. Hence, this document also includes the corresponding mitigation methods to deal with this situation. Furthermore, the deliverable also identifies a couple of future regulatory and standardisation activities.

4. Introduction

Over the past few years, there has been an increasing interest to study the use of frequency bands above 275 GHz for active services such as THz communications. For example, in 2017 IEEE 802 has published the first wireless standard for fixed point-to-point links operating at carrier frequencies between 252 and 321 GHz [1]. The development of this standard has been based on the 2016 version of the Radio Regulations (RR) [2].

While the RR already include an allocation to Fixed Service (FS) and Land Mobile Service (LMS) on a co-primary in the frequency band 252-275 GHz, the bands above 275 GHz do not foresee the allocation to any radio services. However, footnote No. 5.565 of the RR contains identifications for radio astronomy service (RAS), Earth exploration-satellite service (EESS) (passive) and space research (passive) services and defines dedicated frequency bands, which need to be protected from harmful interference from any other services. A closer look at these bands reveals, almost all of bands above 275 GHz are in potential use for either EESS or RAS

Hence, any use of spectrum beyond 275 GHz for THz communications with bandwidths of up to several tens of GHz is possible only if the spectrum is shared with at least one of the above-mentioned passive services. Footnote 5.565 concretely states that "administrations wishing to make frequencies in the 275-1,000 GHz range available for active service applications are urged to take all practicable steps to protect these passive services from harmful interference". In the worst-case scenario, this could lead to different decisions in different countries [3].

In order to address the above-mentioned problem, the WRC 2015 has invited ITU-R to perform "Studies towards an identification for use by administrations for LMS and FS applications operating in the frequency range 275-450 GHz" [4], with the goal to define more detailed rules at the WRC 2019 under its agenda item AI 1.15. WRC are held about every three to four years. It is the task of WRC to review, and, if necessary, revise the RR, the international treaty governing the use of the radio-frequency spectrum and the geostationary-satellite and non-geostationary-satellite orbits. Revisions are made on the basis of an agenda determined by the ITU Council, which takes into account recommendations made by previous WRC.

WRC 2019 agenda item 1.15 has called for studies to identify frequency bands for use by administrations for the LMS and FS applications operating in the frequency range 275-450 GHz, in accordance with Resolution 767 (WRC-15). Resolution 767 (WRC-15) invites ITU-R to conduct sharing and compatibility studies between LMS and FS applications and passive services applications planned to operate in the frequency range 275-450 GHz and to identify candidate frequency bands for use by systems in LMS and FS applications, while maintaining protection of the passive services applications identified in RR No. 5.565 [4].

Following this invitation, a couple of studies have been performed investigating sharing scenarios between FS and LMS on one side, and RAS and EESS on the other side. The studies are summarized in ITU-R, Report SM.2450-0, "Sharing and compatibility studies between land-mobile, fixed and passive services in the frequency range 275-450 GHz," 2019 [5]. Here it has to be mentioned, that within the ThoR project sharing studies between FS and EESS have been performed [3] and fed into the WRC preparation process through the German Administration.

The focus on these sharing studies in terms of passive services has been on EESS [3, 6, 7, 8], since earlier studies [9, 10] have already identified EESS as the more critical service due to its operational characteristics, whereas RA with its large antennas typically located in very remote area and pointing up the sky can be protected by simple measures like a minimum distance of the THz communication device to the RA antenna. Most of the studies concluded that in the bands 275-296 GHz, 306-313

GHz, 318-333 GHz and 356-450 GHz only, no specific conditions to protect EESS are necessary, for systems operating within the parameters given in the referenced ITU-R Reports. The atmospheric attenuation independent of free-space losses at 275 to 450 GHz is not sufficient to provide compatibility between FS and RAS operations in the absence of other considerations. Separation distances and/or avoidance angles between RAS stations and FS stations should be considered depending on the deployment environment of FS stations.

Based on these studies, the outcome of AI 1.15 in WRC 2019 is the introduction of a new footnote 5.X115 [11]. The content of this footnote has some implications both for THz communications in general and the ThoR project specifically. These implications are described in the following chapters. The remaining part of the deliverable is structured as follows: Chapter 5 contains the summary of the outcome of WRC 2019. The following chapter 6 list the now available spectrum for THz communications and chapter 7 discusses the implications. Conclusions are provided in chapter 8.

Parts of the content of this deliverable has been submitted to the International Workshop on mobile THz systems [12].

5. Summary of the outcome of WRC 2019 wrt Agenda Item 1.15

Based on these studies, the outcome of AI 1.15 in WRC 2019 is the introduction of a new footnote 5.X115, which provides more clear conditions for the operation of fixed and land mobile service applications in frequency bands in the range 275-450 GHz [11]:

- The frequency bands 275-296 GHz, 306-313 GHz, 318-333 GHz and 356-450 GHz are identified for use by administrations for the implementation of LMS and FS applications, where no specific conditions are necessary to protect EESS (passive) applications.
- The frequency bands 296-306 GHz, 313-318 GHz and 333-356 GHz may only be used by FS and LMS applications when specific conditions to ensure the protection of EESS (passive) applications are determined in accordance with Resolution 731 (Rev.WRC 2019).
- In those portions of the frequency range 275-450 GHz where radio astronomy applications are used, specific conditions (e.g. minimum separation distances and/or avoidance angles) may be necessary to ensure protection of radio astronomy sites from LMS and/or FS applications, on a case-by-case basis in accordance with Resolution 731 (Rev.WRC 2019).
- The use of the above-mentioned frequency bands by LMS and FS applications does not preclude use by, and does not establish priority over, any other applications of radio services in the range of 275-450 GHz. Such services are for example radar or imaging applications. With its resolution, COM6/19 (WRC 2019) has defined a preliminary agenda for the WRC 2027, on the identification of spectrum for radio location applications in frequency bands in the range 275-700 GHz for millimetre and sub-millimetre wave imaging systems.

The frequency bands identified for use by administrations for the implementation of LMS and FS applications in the frequency band 275-450 GHz are shown in Fig. 5.1. Figure 5.2 shows the atmospheric attenuation computed over horizontal paths of 1 km at five different heights above sea level [5]. This figure shows that the large attenuation is observed at around 325 GHz and 380 GHz. The large atmospheric attenuation enables the compatibility between FS and RAS at these frequency ranges.

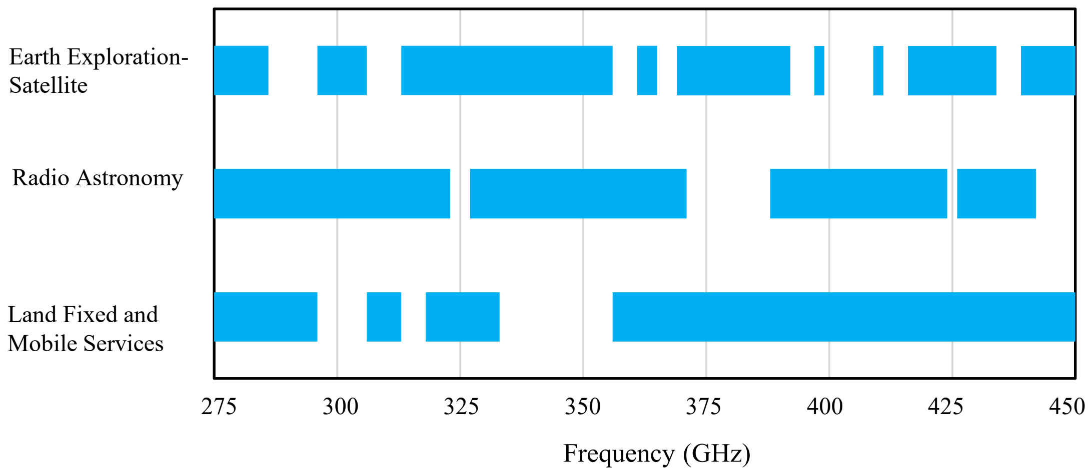

Fig. 5.1 The frequency bands identified for use by administrations for the implementation of LMS and FS applications.

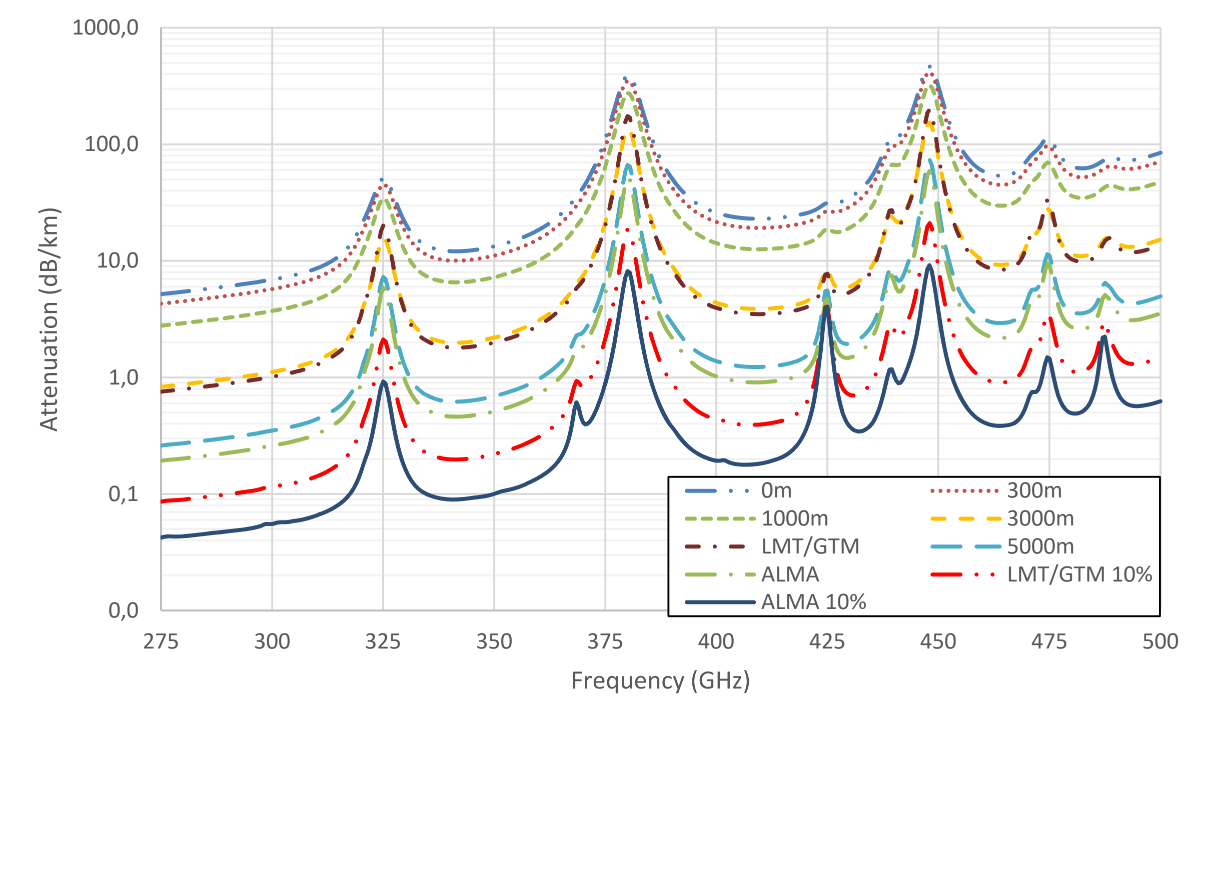

Fig. 5.2 Atmospheric attenuation computed over horizontal paths of 1 km at five different heights above sea level [5].

6. Total available Spectrum for THz Communications

Together with the already allocated spectrum between 252 and 275 GHz, totally 160 GHz of spectrum are available for THz communications in the whole frequency band between 275 and 450 GHz with no specific conditions necessary to protect EESS. All details are provided in Table 6.1.

Table 6.1 Overview of available Spectrum for THz Communications

<table>
<tr><td>Frequency in GHz</td><td>Status in Radio Regulations</td></tr>
<tr><td>252-275</td><td>Allocation for land mobile and fixed service on a co-primary basis [1]</td></tr>
<tr><td>275-296</td><td rowspan="4">Identification for use for the implementation of land mobile and fixed service according to FN 5.X115;

no specific conditions are necessary to protect Earth exploration-satellite service (passive) applications [10].</td></tr>
<tr><td>306-313</td></tr>
<tr><td>318-333</td></tr>
<tr><td>356-450</td></tr>
<tr><td>296-306</td><td>may only be used by fixed and land mobile service applications when specific conditions to ensure the protection of Earth exploration-satellite service (passive) applications are determined in accordance with Resolution 731 (Rev.WRC 2019) [10].</td></tr>
</table>

7. Practical Impact in THz wireless communication

As described in Section 5, WRC 2019 identified frequency bands 275-296 GHz, 306-313 GHz, 318-333 GHz and 356-450 GHz for use by administrations for the implementation of LMS and FS applications, and some limitation of FS and LMS are necessary in the frequency bands of 296-306 GHz, 313-318 GHz and 333-356 GHz. Therefore, THz wireless communication systems to be developed in the future will need to adapt the frequency bands identified in WRC 2019.

In this chapter, we discuss the practical impact of WRC 2019 results in THz wireless communication. Firstly, the impact of WRC 2019 results in ThoR project will be described in the section 7.1 Secondly, we discuss the effect of WRC 2019 results on the standard of IEEE 802.15.3d in the section7.2. Finally, we discuss the potential regulatory steps towards future WRCs in section 7.3

7.1. ThoR Project

Within ThoR two different outdoor experiments are planned. Frist within WP5 we are planning to build a transmitter and a receiver for the outdoor transmission experiments in order to measure the accurate radiation pattern of the high gain antenna, and to measure the dependence of the transmission characteristics on the weather conditions for evaluating the reliability of 300 GHz-band fronthaul/backhaul links. For the corresponding outdoor transmission experiment, which will take place in Japan, we need to obtain an experimental radio station license from the Japanese government. The experiment and the corresponding measures are described section sub-section 7.1.1. One of the main goals of ThoR is the demonstration to transmit real data in an outdoor environment. This experiment requires a trial license in Germany. The boundary conditions of this experiment are briefly described section sub-section 7.1.2.

7.1.1. Outdoor Transmission Experiment in Japan

We have designed the transmitter using commercial THz components. Figure 7.1 shows the diagram of the transmitter. A phase locked oscillator (PLO) generates a 16.66 GHz signal, and the 6-multiplier outputs a 99.96 GHz signal with a power of 15.6 dBm. The multiplier by three generates a 299.88 GHz signal with a power of 1.4 dBm. However, the 299.88 GHz was not identified for FS and LMS in WRC 2019. In order to obtain experimental radio station licence from Japan government, we need to change the carrier frequency of the 300 GHz-band wireless transmitter. We changed the frequency of PLO from 16.66 GHz to 16.30 GHz in order to meet the frequency band identified in WRC 2019. The frequency of the output signal becomes 293.4 GHz, which corresponds to the frequency band identified in WRC 2019. In order to suppress the spurious of out band, we applied for a bandpass filter. The frequency characteristics of the 300 GHz-band bandpass filter with a center frequency of 293.4 GHz is shown in Fig. 7.2. Figure 7.3 shows the photograph of the 300 GHz-band transmitter.

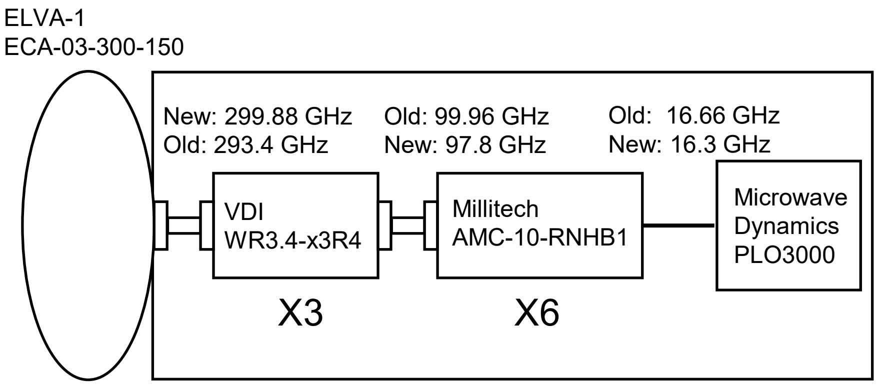

Fig. 7.1: Diagram of 300 GHz-band transmitter.

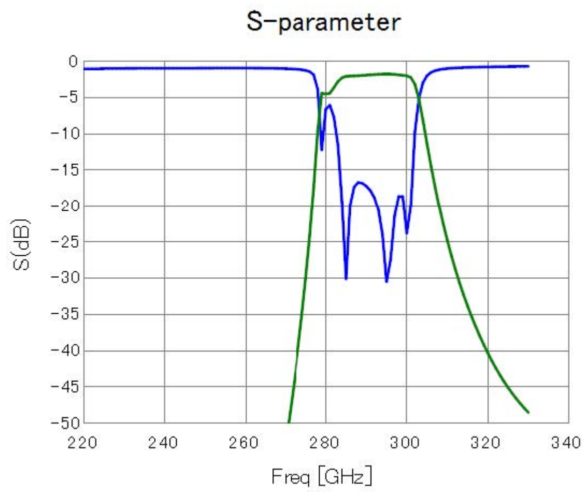

Fig. 7.2: Frequency characteristics of 300 GHz-band bandpass filter.

Fig. 7.3: Photograph of 300 GHz-band transmitter.

7.1.2. ***Outdoor Transmission Experiment in EU***

The ThoR approach to demonstrate real data transmission is based on the use of modems operating according to IEEE 802.15.3e-2017 (60 GHz within the V-band) and ETSI EN 302 217 (70/80 GHz within the E-band) standards [13]. The output of these modems represents the intermediate frequency (IF) which is the input for the 300 GHz Radio Frequency (RF) transmit/receive modules. Each modem can provide data streams with a bandwidth of 2 GHz. By utilizing multiple aggregated IF carriers form a wider RF channel, so that the ThoR system can reach very high data rates in a real-life environment. The ThoR design, which is described in ThoR D2.3 [14], foresees to use the 287-308 GHz frequency range in DEMO-3 and hence, is overlapping with the frequency band between 296 and 306 GHz, which requires to comply with specific conditions towards EESS. On the other hand, key components for the RF part have been already fabricated and characterised [14]. While a complete redesign of these components is in principle possible, this is not the case to be realized within the limited remaining project duration.

Therefore, the following mitigation strategies will be followed in ThoR:

1. Wrt to its planned DEMO-3 ThoR will ask for a trial license for the year 2021 covering also the frequency range 296-306 GHz. It is quite likely, that such a trial license can be obtained, since EESS operating in this frequency range is currently not operational [5, p. 34]. Furthermore, the ThoR link will be a single link, whereas the sharing studies in [3, 5] have revealed interference issues taking into account multiple links.
2. Independent from the measures taken in 1. ThoR will explore to use the band 306-313 instead of the band 296-306 GHz. Based on the measurement results from [14] this seems to be a valid option although a lower performance cannot be excluded.

7.2. IEEE 802.15.3d

The channel plan defined IEEE Std. 802.15.3d-2017 [1] covers also the bands 296-306 GHz and 318-321 GHz, where specific conditions to ensure protection of EESS. The frequency band 356 to 450 GHz is not covered by the above-mentioned standard.

Based on this situation the following potential activities in IEEE 802 might be considered:

1. To comply with the situation in the bands 296-306 GHz and 318-321 GHz an amendment might be necessary in order to exclude those channels covering these bands. The current IEEE Std. 802.15.3d-2017 covers the frequency bands 252 to 321 GHz. On the other hand, the continuing use of the frequency bands 296-306 GHz and 313-318 GHz by this standard will be possible, if additional sharing studies in accordance with Resolution 731 (Rev.WRC 2019) show that no harmful interference to EESS occurs. This may trigger a potential regulatory activity towards WRC 2023.
2. In order to make use of the large chunk of spectrum between 356 GHz and 450 GHz, an amendment to IEEE 802.15.3d-2017 will be necessary and may trigger standardization activities at IEEE 802.

In order to implement changes in [1] a project authorisation project within IEEE 802 might be considered. In order to avoid frequent amendments, it is recommended to await the analysis of ThoR's DEMO-3, which might reveal hints for further improvements of [1].

7.3. Potential Activities towards future WRCs

The potential agenda item on the identification of spectrum for radio location applications in the range 275-700 GHz will require sharing studies with THz communications as the incumbent application. This may trigger another potential regulatory activity towards WRC 2027 apart from the one described in section 7.2

8. CONCLUSION

In this paper, the outcome of WRC 2019 w.r.t. THz communications is described. WRC 2019 has added a new footnote to the radio regulations, which describes the conditions for the use of the spectrum between 275 and 450 GHz by land mobile and fixed services. Totally, 160 GHz of spectrum are now available for THz communications, where no specific conditions are necessary to protect EESS. This includes two big contiguous spectrum bands with 44 GHz and 94 GHz bandwidth, respectively. This provides a sound basis for the future implementation of THz communications. Due to its planned experiments, ThoR is directly affected by the outcome of WRC 2019. Appropriate mitigation technique regarding the use of spectrum in the range 296-306 GHz have been defined. In addition, a couple of future regulatory and standardization activities have been identified.

9. References

[1] IEEE Standard for High Data Rate Wireless Multi-Media Networks--Amendment 2: 100 Gb/s Wireless Switched Point-to-Point Physical Layer," in IEEE Std 802.15.3d-2017 (Amendment to IEEE Std 802.15.3-2016 as amended by IEEE Std 802.15.3e-2017) , pp.1-55, Oct. 18, 2017.

[2] World Radiocommunication Conference, „Radio Regulations, Edition of 2016," [Online]. Available: https://www.itu.int/pub/R-REG-RR.

[3] S. Rey, Initial results on sharing studies, Thor Deliverable D5.1; available at https://thorproject.eu/results/

[4] RESOLUTION 767(WRC-15): Studies towards an identification for use by administrations for land-mobile and fixed services applications operating in the frequency range 275-450 GHz [Online]. Available: https://www.itu.int/dms_pub/itu-r/oth/0c/0a/R0C0A00000C0016PDFE.pdf

[5] ITU-R, Report SM.2450-0, "Sharing and compatibility studies between land-mobile, fixed and passive services in the frequency range 275-450 GHz," 2019.

[6] ITU-R, „Recommendation ITU-R RS.2017: Performance and interference criteria for satellite passive remote sensing," [Online]. Available: https://www.itu.int/rec/R-REC-RS.2017/en.

[7] ITU-R, "Report ITU-R F.2416: Technical and operational characteristics and applications of the point-to-point fixed service applications operating in the frequency band 275-450 GHz," [Online]. Available: https://www.itu.int/pub/R-REP-F.2416.

[8] T. Kürner, "Regulatory Aspects of THz Communications and Related Activities Towards WRC," 2019, Proc. European Conference on Networks and Communications, 18-21 Jun-2019; Valencia, Spain; electronic (2 pages), [online] https://doi.org/10.24355/dbbs.084-201908211524-0.

[9] Priebe, S.; Britz, D. M.; Jacob, M.; Sarkozy, S.; Leong, K. M. K.; Logan, J. E.; Gorospe, B.; Kürner, T.: Interference Investigations of Active Communications and Passive Earth Exploration Services in the THz Frequency Range. IEEE Transactions on Terahertz Science and Technology, Vol. 2, No. 5, pp. 525– 537, 2012.

[10] A. Clegg, Sharing between radio astronomy and active services at THz frequencies, [online] https://mentor.ieee.org/802.15/dcn/10/15-10-0829-00-0thz-sharing-between-active-and-passive-services-at-thz-frequencies.ppt

[11] World Radiocommunication Conference 2019 (WRC-19) Provisional Final Acts; [online]: http://www.itu.int/pub/R-ACT-WRC.13-2019.

[12] T. Kürner, A. Hirata, "On the Impact of the Results of WRC 2019 on THz Communications", submitted to the International Workshop on mobile THz Systems, Essen, Germany, 2-3 July 2020#

[13] J. Laurenz, I. Dan, S. Cartier, I. Kallfass, G. Guillaume, "Specification of RF Design," Thor Deliverable D2.3;

[14] J. Laurenz, I. Dan, I. Kallfass, "300 GHz circuits validation," Thor Deliverable D4.3;

