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Deliverable D2.1a

Situation of THz spectrum in Europe

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Abstract

In this deliverable, an overview of radio / optical spectrum above 90GHz in Europe is presented. Regulation situation and high level propagation characteristics in these bands (mainly for the radio case) are analysed in order to select spectrum of interest for WORTECS system studies and proof of concepts

Keyword list

THz spectrum, radio spectrum, light spectrum

Executive Summary

The primary challenge addressed by WORTECS is the development of a system able to deliver ultra-high throughput (up to Tbps) based on the exploitation of spectrum beyond 90GHz.

This deliverable D2.1a, entitled “Situation of THz spectrum in Europe”, gives an overview of the current situation of the (radio / optical) spectrum in Europe beyond the range currently considered by ITU for IMT-2020 (= “5G”) technologies (i.e. >90GHz).

On the optical side (more specific focus on [30 THz – 1500 THz]), the situation is rather straightforward as no regulation applies for the time being; in particular, the visible light spectrum is unlicensed and can be used freely, provided operation of lighting systems remains safe.

On the radio side, an analysis of the services allocations, by ITU, from 86 GHz to 3 THz combined together with an overview of propagation characteristics (atmospheric absorption) have led to prioritize the following bands for WORTECS system studies and proof of concepts:

- [158,5 – 164] GHz
- [174,5 – 174,8] GHz
- [231,5 – 235] GHz
- [238 – 241] GHz

The spectrum bands prioritized here are only working assumptions for WORTECS and in any case recommendations from WORTECS partners towards regulation bodies. Such activity need to take into account other parameters such as real usage of bands by administrations, harmonized / fragmented usage of bands... that have not been taken into account at all in this basic analysis.

The proposals done in this deliverable will be reviewed by WORTECS Work Package 3 and final decisions will be taken for simulation and implementation purposes.

This document will be updated once next World Radio Conference (2019) is achieved.

Impact on the other Work-packages

WP3: propagation channel model used in the simulations is related to the frequency selected

WP4: PoCs operation frequency driven by D2.1a recommendation.

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1 Regulation bodies overview

1.1 Radio communications

International Telecommunication Union (ITU), whose headquarters are in Geneva (Switzerland), is an international organization of the United Nations, within which States and private sector coordinate networks and world of services telecommunications. ITU is structured in three distinct sectors:

- ITU-D: Development
- ITU-T: Standardization
- ITU-R: Radiocommunication.

The activities related to radiocommunications are part of the last sector and address in particular the usages of the radio-frequency spectrum. The revision of attributions of the bands plans and the division of the spectrum is carried out during the World Radiocommunication Conferences (WRC) at the end of each operating cycle of ITU-R study group. WRC meets approximately every three years, to develop, adopt and revise the Radio Regulations (RR). The WRC decides attribution of the frequency bands to the various services of radiocommunications (fixed service, mobile, broadcasting, satellite, radiolocation, space research, exploration of the Earth, radioastronomy, etc...). Each ITU country must conform to these attributions and conditions of sharing, as fixed by ITU. Attributions, access and sharing conditions are described in the RR.

At the European level, the organization of reference is the CEPT (European Conference of the Posts and Telecommunication). CEPT gathers 44 countries. The permanent office, European Communication Office, is based in Copenhagen (Denmark). By the decisions and recommendations of its Committee of the Electronic Communications, CEPT decides, within the framework of the attributions fixed by ITU-R, the particular conditions which prevail for the use of these attributions: reservation of frequency bands for particular systems (3GPP, DECT...), determination of the channels for the fixed service in the various frequency bands which are allocated to him by ITU-R and technical and lawful conditions of operating. These decisions or these recommendations aim to harmonize the frequencies uses by the various European countries, with the objective to facilitate the development of a European market, as well as the problems of coordination at the borders. The various European countries should conform to the decisions of CEPT while the recommendations aim to harmonize the use of the spectrum without having constraining character. The acceleration of the rhythm of the WRC and the need for reaching a consensus more easily within the framework of these conferences, led the European countries to gather their forces to carry out together the preparation of the WRC. The role played by CEPT within this framework is significant; CEPT provides the views of national administrations but not of the European Commission. The Conference Preparatory Group, a working group of the CEPT, coordinates this effort and prepares the common European positions to the WRC.

1.2 Optical Wireless communications

In 2016, ITU published "Radio Regulations Articles" describing the current situation of the radio spectrum; the document "contains the complete texts as adopted by the World Radiocommunication Conference (Geneva, 1995) (WRC-95) and subsequently revised and adopted by World Radiocommunication Conferences, including all Appendices, Resolutions, Recommendations and ITU-R Recommendations incorporated by reference" ([2]). It gives for each frequency bands the services currently allocated and the deployment constraints for each regions / countries.

Article 1.5 of the document specifies what radio waves / Hertzian waves are: "electromagnetic waves whose frequency is by convention lower than 3 000 GHz, being propagated in space without artificial guide".

The wavelengths used by wireless optical equipment are not currently covered by the clauses of the RR document, which are limited to radio transmissions and to the frequencies lower than 3 000 GHz. Wireless optical equipment operate at frequencies between 300 GHz and 30 PHz.

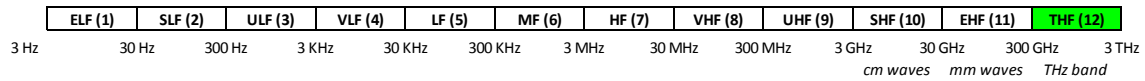
At the present time, there is no regulation nor management and attribution of this part of spectrum. So there is no need for a license before transmitting in this spectrum band but no coexistence rules have been defined between technologies neither.

It should however be noted that in 2002 the ITU Plenipotentiary conference – supreme body of the ITU –, noting well that radiocommunication techniques showed it was possible to use electromagnetic waves in space, without artificial guide at frequencies higher than 3 000 GHz, adopted a new resolution on the study of the use of the spectrum above 3 000 GHz (resolution 118 - Marrakech, 2002). Consequently and during the WRC 2007, resolution 955 (Geneva, 2007) proposes to consider a process of installation of free space optics, with definition of spectral limitation and measurement, in order to allow the sharing with other services, if allocation to various services in the radio regulation above 3 000 GHz are considered feasible.

2 Current situation of THz spectrum

2.1 Definition of THz spectrum

According to ITU definition, the Terahertz (radio) band is the spectrum band that spans from 300 GHz to 3 THz (see Figure 1 below). In order to cover the spectrum addressed by ICT-09-2017 call, the band between 90 GHz and 300 GHz will also be part of the analysis.



(n): ITU band number

- ELF: Extremely low frequency
- SLF: Super low frequency
- ULF: Ultra low frequency
- VLF: Very low frequency
- LF: Low frequency
- MF: Medium frequency
- HF: High frequency
- VHF: Very high frequency
- UHF: Ultra high frequency
- SHF: Super high frequency
- EHF: Extremely high frequency
- THF: Tremendously high frequency

Figure 1 – Radio spectrum

As far as “optical spectrum” is concerned, infra-red roughly spans between 300 GHz and 400 THz, visible light between 400 and 750 THz, and ultra-violet between 750 THz and 30 PHz (see for instance [1]).

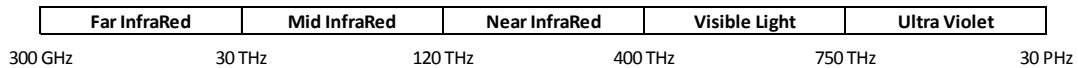
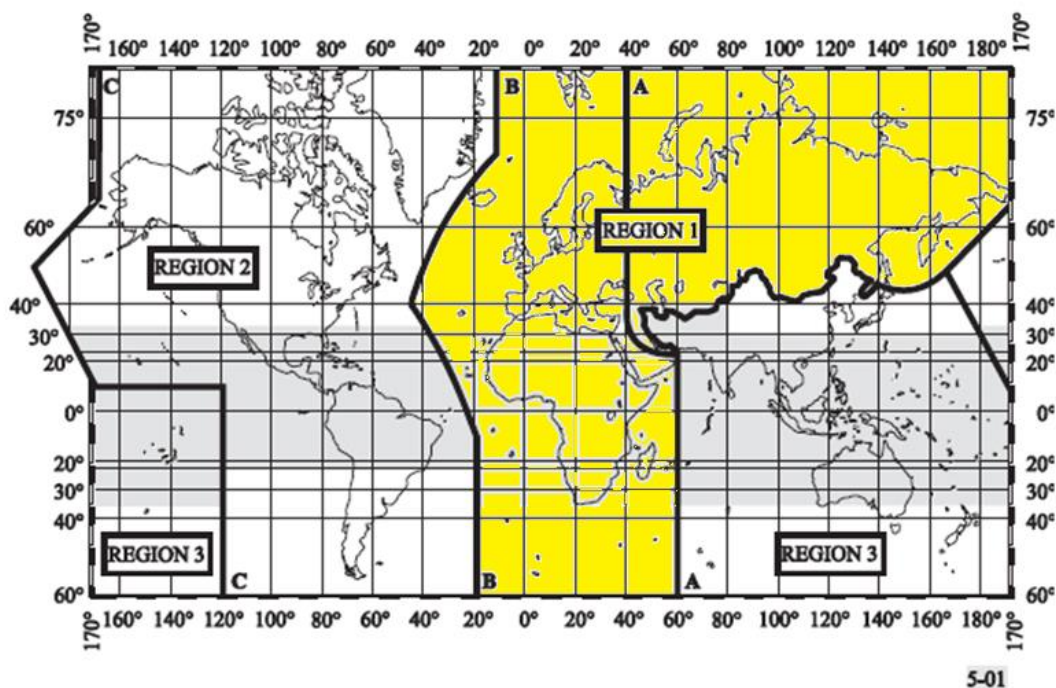


Figure 2 – Optical spectrum

It is interesting to notice that radio spectrum and optical spectrum overlap between 300 GHz and 3 THz, where radio and wireless optical technologies could cooperate to deliver Tbps.

2.2 Radio communications

In this section, a focus will be put on Region 1 (Europe / Africa – see figure below) in order to be more specific in the European context of WORTECS project.



The shaded part represents the Tropical Zones as defined in Nos. 5.16 to 5.20 and 5.21.

Figure 3 – Region 1 in yellow, as defined by ITU

Table 1 below summarizes the services allocations from 86 GHz to 3 THz.

The focus of WORTECS project is on “mobile service” type of bands (“mobile service” is defined as “a radio-communication service between mobile and land stations, or between mobile stations”). When a specific band is able to host mobile services (if not the case, the band is “discarded” – box left blank in the table), the potential deployment constraints for this band and this service are then analysed. When some difficulties may be encountered, the related line is highlighted in orange; when no difficulty is foreseen, a green colour is applied.

- some limitations for mobile services
- green light for mobile services

| F1 (GHz) | F2 (GHz) | Allocations to Services | Deployment constraints |
|----------|----------|---|---|
| 86 | 92 | EARTH EXPLORATION-SATELLITE (passive) RADIO ASTRONOMY SPACE RESEARCH (passive) 5.340 | 5.340 : all emissions are prohibited in a list of bands including [86-92]GHZ band. |
| 92 | 94 | FIXED 5.338A MOBILE RADIO ASTRONOMY RADIOLOCATION 5.149 | 5.149 : administrations are urged to take all practicable steps to protect the radio astronomy service from harmful interference. |
| 94 | 94,1 | EARTH EXPLORATION-SATELLITE (active) RADIOLOCATION SPACE RESEARCH (active) Radio astronomy 5.562 5.562A | |
| 94,1 | 95 | FIXED MOBILE RADIO ASTRONOMY RADIOLOCATION 5.149 | 5.149 : administrations are urged to take all practicable steps to protect the radio astronomy service from harmful interference. |

| | | | |
|--------|--------|--|---|
| 95 | 100 | FIXED MOBILE RADIO ASTRONOMY RADIOLOCATION RADIONAVIGATION RADIONAVIGATION-SATELLITE 5.149 5.554 | 5.149 : administrations are urged to take all practicable steps to protect the radio astronomy service from harmful interference. 5.554 : In the bands 43.5-47 GHz, 66-71 GHz, 95-100 GHz, 123-130 GHz, 191.8-200 GHz and 252-265 GHz, satellite links connecting land stations at specified fixed points are also authorized when used in conjunction with the mobile-satellite service or the radionavigation-satellite service. (WRC-2000). |
| 100 | 102 | EARTH EXPLORATION-SATELLITE (passive) RADIO ASTRONOMY SPACE RESEARCH (passive) 5.340 5.341 | |
| 102 | 105 | FIXED MOBILE RADIO ASTRONOMY 5.149 5.341 | 5.149 : administrations are urged to take all practicable steps to protect the radio astronomy service from harmful interference. 5.341: In the bands 1 400-1 727 MHz, 101-120 GHz and 197-220 GHz, passive research is being conducted by some countries in a programme for the search for intentional emissions of extraterrestrial origin. |
| 105 | 109,5 | FIXED MOBILE RADIO ASTRONOMY SPACE RESEARCH (passive) 5.562B 5.149 5.341 | 5.149 : administrations are urged to take all practicable steps to protect the radio astronomy service from harmful interference. 5.341: In the bands 1 400-1 727 MHz, 101-120 GHz and 197-220 GHz, passive research is being conducted by some countries in a programme for the search for intentional emissions of extraterrestrial origin. |
| 109,5 | 111,8 | EARTH EXPLORATION-SATELLITE (passive) RADIO ASTRONOMY SPACE RESEARCH (passive) 5.340 5.341 | |
| 111,8 | 114,25 | FIXED MOBILE RADIO ASTRONOMY SPACE RESEARCH (passive) 5.562B 5.149 5.341 | 5.149 : administrations are urged to take all practicable steps to protect the radio astronomy service from harmful interference. 5.341: In the bands 1 400-1 727 MHz, 101-120 GHz and 197-220 GHz, passive research is being conducted by some countries in a programme for the search for intentional emissions of extraterrestrial origin. |
| 114,25 | 116 | EARTH EXPLORATION-SATELLITE (passive) RADIO ASTRONOMY SPACE RESEARCH (passive) 5.340 5.341 | |
| 116 | 119,98 | EARTH EXPLORATION-SATELLITE (passive) INTER-SATELLITE 5.562C SPACE RESEARCH (passive) 5.341 | |
| 119,98 | 122,25 | EARTH EXPLORATION-SATELLITE (passive) INTER-SATELLITE 5.562C SPACE RESEARCH (passive) 5.138 5.341 | |

| | | | |
|--------|-------|--|--|
| 122,25 | 123 | FIXED INTER-SATELLITE MOBILE 5.558 Amateur 5.138 | 5.558: In the bands 55.78-58.2 GHz, 59-64 GHz, 66-71 GHz, 122.25-123 GHz, 130-134 GHz, 167-174.8 GHz and 191.8-200 GHz, stations in the aeronautical mobile service may be operated subject to not causing harmful interference to the inter-satellite service (see No. 5.43). (WRC-2000). 5.138: The following band [...] 122-123 GHz (centre frequency 122.5 GHz), and 244-246 GHz (centre frequency 245 GHz) are designated for industrial, scientific and medical (ISM) applications. The use of these frequency bands for ISM applications shall be subject to special authorization by the administration concerned, in agreement with other administrations whose radiocommunication services might be affected. In applying this provision, administrations shall have due regard to the latest relevant ITU-R Recommendations. |
| 123 | 130 | FIXED-SATELLITE (space-to-Earth) MOBILE-SATELLITE (space-to-Earth) RADIONAVIGATION RADIONAVIGATION-SATELLITE Radio astronomy 5.562D 5.149 5.554 | |
| 130 | 134 | EARTH EXPLORATION-SATELLITE (active) 5.562E FIXED INTER-SATELLITE MOBILE 5.558 RADIO ASTRONOMY 5.149 5.562A | 5.558: In the bands 55.78-58.2 GHz, 59-64 GHz, 66-71 GHz, 122.25-123 GHz, 130-134 GHz, 167-174.8 GHz and 191.8-200 GHz, stations in the aeronautical mobile service may be operated subject to not causing harmful interference to the inter-satellite service (see No. 5.43). (WRC-2000). 5.149 : administrations are urged to take all practicable steps to protect the radio astronomy service from harmful interference. |
| 134 | 136 | AMATEUR AMATEUR-SATELLITE Radio astronomy | |
| 136 | 141 | RADIO ASTRONOMY RADIOLOCATION Amateur Amateur-satellite 5.149 | |
| 141 | 148,5 | FIXED MOBILE RADIO ASTRONOMY RADIOLOCATION 5.149 | 5.149 : administrations are urged to take all practicable steps to protect the radio astronomy service from harmful interference. |
| 148,5 | 151,5 | EARTH EXPLORATION-SATELLITE (passive) RADIO ASTRONOMY SPACE RESEARCH (passive) 5.340 | |
| 151,5 | 155,5 | FIXED MOBILE RADIO ASTRONOMY RADIOLOCATION 5.149 | 5.149 : administrations are urged to take all practicable steps to protect the radio astronomy service from harmful interference. |
| 155,5 | 158,5 | EARTH EXPLORATION-SATELLITE (passive) FIXED MOBILE RADIO ASTRONOMY SPACE RESEARCH (passive) 5.562B 5.149 5.562F 5.562G | 5.149 : administrations are urged to take all practicable steps to protect the radio astronomy service from harmful interference. 5.562F In the band 155.5-158.5 GHz, the allocation to the Earth exploration-satellite (passive) and space research (passive) services shall terminate on 1 January 2018. (WRC-2000) 5.562G The date of entry into force of the allocation to the fixed and mobile services in the band 155.5-158.5 GHz shall be 1 January 2018. (WRC-2000). |
| 158,5 | 164 | FIXED FIXED-SATELLITE (space-to-Earth) MOBILE MOBILE-SATELLITE (space-to-Earth) | |

| | | | |
|-------|-------|---|--|
| 164 | 167 | EARTH EXPLORATION-SATELLITE (passive) RADIO ASTRONOMY SPACE RESEARCH (passive) 5.340 | |
| 167 | 174,5 | FIXED FIXED-SATELLITE (space-to-Earth) INTER-SATELLITE MOBILE 5.558 5.149 5.562D | 5.149 : administrations are urged to take all practicable steps to protect the radio astronomy service from harmful interference. 5.558: In the bands 55.78-58.2 GHz, 59-64 GHz, 66-71 GHz, 122.25-123 GHz, 130-134 GHz, 167-174.8 GHz and 191.8-200 GHz, stations in the aeronautical mobile service may be operated subject to not causing harmful interference to the inter-satellite service (see No. 5.43). (WRC-2000). |
| 174,5 | 174,8 | FIXED INTER-SATELLITE MOBILE 5.558 | 5.558: In the bands 55.78-58.2 GHz, 59-64 GHz, 66-71 GHz, 122.25-123 GHz, 130-134 GHz, 167-174.8 GHz and 191.8-200 GHz, stations in the aeronautical mobile service may be operated subject to not causing harmful interference to the inter-satellite service (see No. 5.43). (WRC-2000). |
| 174,8 | 182 | EARTH EXPLORATION-SATELLITE (passive) INTER-SATELLITE 5.562H SPACE RESEARCH (passive) | |
| 182 | 185 | EARTH EXPLORATION-SATELLITE (passive) RADIO ASTRONOMY SPACE RESEARCH (passive) 5.340 | |
| 185 | 190 | EARTH EXPLORATION-SATELLITE (passive) INTER-SATELLITE 5.562H SPACE RESEARCH (passive) | |
| 190 | 191,8 | EARTH EXPLORATION-SATELLITE (passive) SPACE RESEARCH (passive) 5.340 | |
| 191,8 | 200 | FIXED INTER-SATELLITE MOBILE 5.558 MOBILE-SATELLITE RADIONAVIGATION RADIONAVIGATION-SATELLITE 5.149 5.341 5.554 | 5.149 : administrations are urged to take all practicable steps to protect the radio astronomy service from harmful interference. 5.558: In the bands 55.78-58.2 GHz, 59-64 GHz, 66-71 GHz, 122.25-123 GHz, 130-134 GHz, 167-174.8 GHz and 191.8-200 GHz, stations in the aeronautical mobile service may be operated subject to not causing harmful interference to the inter-satellite service (see No. 5.43). (WRC-2000). 5.341: In the bands 1 400-1 727 MHz, 101-120 GHz and 197-220 GHz, passive research is being conducted by some countries in a programme for the search for intentional emissions of extraterrestrial origin. |
| 200 | 209 | EARTH EXPLORATION-SATELLITE (passive) RADIO ASTRONOMY SPACE RESEARCH (passive) 5.340 5.341 5.563A | |
| 209 | 217 | FIXED FIXED-SATELLITE (Earth-to-space) MOBILE RADIO ASTRONOMY 5.149 5.341 | 5.149 : administrations are urged to take all practicable steps to protect the radio astronomy service from harmful interference. 5.341: In the bands 1 400-1 727 MHz, 101-120 GHz and 197-220 GHz, passive research is being conducted by some countries in a programme for the search for intentional emissions of extraterrestrial origin. |

| | | | |
|-------|-------|--|--|
| 217 | 226 | FIXED FIXED-SATELLITE (Earth-to-space) MOBILE RADIO ASTRONOMY SPACE RESEARCH (passive) 5.562B 5.149 5.341 | 5.149 : administrations are urged to take all practicable steps to protect the radio astronomy service from harmful interference. 5.341: In the bands 1 400-1 727 MHz, 101-120 GHz and 197-220 GHz, passive research is being conducted by some countries in a programme for the search for intentional emissions of extraterrestrial origin. |
| 226 | 231,5 | EARTH EXPLORATION-SATELLITE (passive) RADIO ASTRONOMY SPACE RESEARCH (passive) 5.340 | |
| 231,5 | 232 | FIXED MOBILE Radiolocation | |
| 232 | 235 | FIXED FIXED-SATELLITE (space-to-Earth) MOBILE Radiolocation | |
| 235 | 238 | EARTH EXPLORATION-SATELLITE (passive) FIXED-SATELLITE (space-to-Earth) SPACE RESEARCH (passive) 5.563A 5.563B | |
| 238 | 240 | FIXED FIXED-SATELLITE (space-to-Earth) MOBILE RADIOLOCATION RADIONAVIGATION RADIONAVIGATION-SATELLITE | |
| 240 | 241 | FIXED MOBILE RADIOLOCATION | |
| 241 | 248 | RADIO ASTRONOMY RADIOLOCATION Amateur Amateur-satellite 5.138 5.149 | |
| 248 | 250 | AMATEUR AMATEUR-SATELLITE Radio astronomy 5.149 | |
| 250 | 252 | EARTH EXPLORATION-SATELLITE (passive) RADIO ASTRONOMY SPACE RESEARCH (passive) 5.340 5.563A | |
| 252 | 265 | FIXED MOBILE MOBILE-SATELLITE (Earth-to-space) RADIO ASTRONOMY RADIONAVIGATION RADIONAVIGATION-SATELLITE 5.149 5.554 | 5.149 : administrations are urged to take all practicable steps to protect the radio astronomy service from harmful interference. |
| 265 | 275 | FIXED FIXED-SATELLITE (Earth-to-space) MOBILE RADIO ASTRONOMY 5.149 5.563A | 5.149 : administrations are urged to take all practicable steps to protect the radio astronomy service from harmful interference. |
| 275 | 3000 | (Not allocated) 5.565 | |

Table 1 - Services allocations from 86 GHz to 3 THz

So in a first approach, the following bands can be identified as valuable candidates for WORTECS studies and demonstrators:

- [158,5 – 164] GHz
- [174,5 – 174,8] GHz
- [231,5 – 235] GHz
- [238 – 241] GHz

Interestingly, the band [275 – 3000] GHz has not been allocated, for which the following conditions apply:

“The following frequency bands in the range 275-1 000 GHz are identified for use by administrations for passive service applications:

- radio astronomy service: 275-323 GHz, 327-371 GHz, 388-424 GHz, 426-442 GHz, 453-510 GHz, 623-711 GHz, 795-909 GHz and 926-945 GHz;
- Earth exploration-satellite service (passive) and space research service (passive): 275-286 GHz, 296-306 GHz, 313-356 GHz, 361-365 GHz, 369-392 GHz, 397-399 GHz, 409-411 GHz, 416-434 GHz, 439-467 GHz, 477-502 GHz, 523-527 GHz, 538-581 GHz, 611-630 GHz, 634-654 GHz, 657-692 GHz, 713-718 GHz, 729-733 GHz, 750-754 GHz, 771-776 GHz, 823-846 GHz, 850-854 GHz, 857-862 GHz, 866-882 GHz, 905-928 GHz, 951-956 GHz, 968-973 GHz and 985-990 GHz.

The use of the range 275-1 000 GHz by the passive services does not preclude use of this range by active services. 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 until the date when the Table of Frequency Allocations is established in the above-mentioned 275-1 000 GHz frequency range.

All frequencies in the range 1 000 – 3 000 GHz may be used by both active and passive services. (WRC-12)”.

In addition, what has to be taken into account as well in order to select the “most relevant” band for WORTECS, is the atmospheric absorption that attenuates the on air signals. Figure below shows that the attenuation in some of the spectrum bands identified above are quite low:

- roughly around 0.5dB/km for [158,5 – 164] GHz band, and
- a little bit more than 1 dB/km for [231,5 – 235] GHz and [238 – 241] GHz bands.

The attenuation seems to be a little bit higher in the band [174,5 – 174,8] GHz, at least increasing drastically around 183GHz.

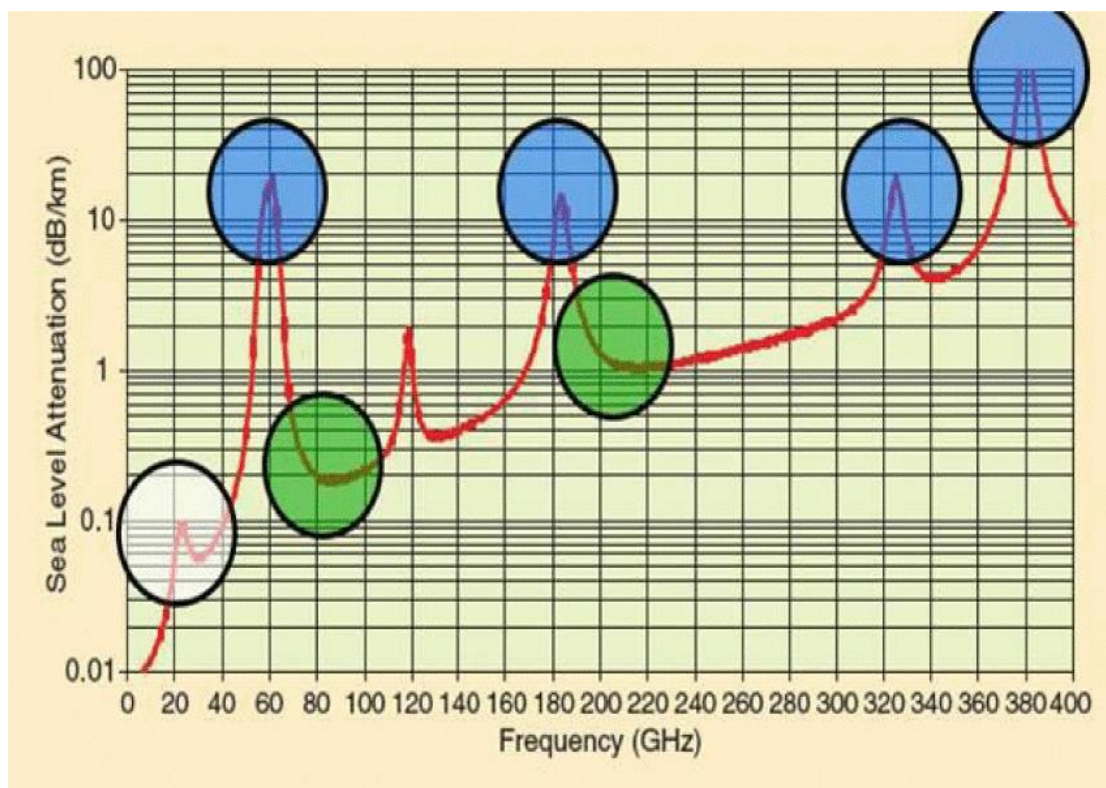


Figure 4 – Atmospheric absorption across mm-wave frequencies in dB/km [3]

2.3 Optical Wireless communications

Today, most of our wireless data transfer is done using radio frequencies. User demand for data has shown exponential growth with majority of the traffic delivered through WiFi [4]. Spectrum is scarce and there is increasing commercial pressure from competing technologies operating in the licensed band to access and influence access on currently license exempt spectrum [5].

In most countries as part of the radio frequency spectrum regulation, frequencies below 3THz are licensed [6]. The light spectrum offers a solution for the increasing demand and decreasing available spectrum. Li-Fi technologies make use of the light spectrum for wireless communication.

The 30 THz (10000 nm) to 1500 THz (200 nm) spectrum reaches from the Middle Infrared region and to the Mid Ultraviolet region. The visible light spectrum lies within, from 400 to 700 nm. This part of the electromagnetic spectrum is unlicensed and offers enormous bandwidth compared to RF, making them a promising alternative for wireless communication [7].

“The LiFi technology uses unregulated spectrum of visible light that does not need licensing. On the other hand, it has to be ensured that the LiFi systems do not pose any health hazards and that they are correctly installed so that they do not create any EMI.” – OFCOM Switzerland [8]

Eye safety considerations are covered by two sets of standards:

- IEC 60825-12 (lasers and high brightness LEDs for free space optical communications) (180nm to 10000nm)
- IEC 62471 (Photobiological safety for lamps and lamp systems) (200nm to 3000nm)

These cover the testing conditions for light sources within the wavelength range highlighted above. The limits for safe operation of lighting systems are defined in the standards based on the photobiological sensitivity of human tissue, in particular the eye and skin.

3 Conclusion

On a radio perspective, the most promising frequency bands for WORTECS studies and proof-of-concepts seem to be the following ones:

- [158,5 – 164] GHz
- [174,5 – 174,8] GHz
- [231,5 – 235] GHz
- [238 – 241] GHz

taking into account their allocation to mobile services and their interest in terms of propagation.

The spectrum bands prioritized here are only working assumptions for WORTECS and in any case recommendations from WORTECS partners towards regulation bodies. Such activity need to take into account other parameters such as real usage of bands by administrations, harmonized / fragmented usage of bands... that have not been taken into account at all in this basic analysis.

On the optical side, as the spectrum is not regulated, there is no strong constraint on the choice of spectrum used, provided safety requirements are met.

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