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(11/2017)

Technical and operational characteristics and applications of the point-to-point fixed service applications operating in the frequency band 275-450 GHz

F Series

Fixed service

International Telecommunication Union

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REPORT ITU-R F.2416-0

Technical and operational characteristics and applications of the point-to-point fixed service applications operating in the frequency band 275-450 GHz

Question ITU-R 257/5

(2017)

1 Introduction

Due to progress of RF integrated devices and circuits operating in the frequency band above 275 GHz, the contiguous frequency bands become available for fixed service applications. Some applications operating in the frequency band above 275 GHz such as the point-to-point backhaul and fronthaul for mobile services are introduced and the ultra-high-speed data transmission between fixed stations become feasible.

Radio Regulations No. **5.565** identifies the specific frequency bands for the radio astronomy service, the earth exploration satellite service (passive), and the space research service (passive) in the frequency range of 275-1 000 GHz. Although the use of the frequency 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

This Report intends to provide the technical and operational characteristics of the fixed service applications operating in the frequency range 275-450 GHz which will be useful for the sharing and compatibility studies between the fixed service applications and the already identified passive services.

2 Scope

This Report provides the fixed service applications and their technical and operational characteristics operating in the frequency range 275-450 GHz for sharing and compatibility studies between fixed service applications and passive services, as well as among active services in the frequency range 275-450 GHz.

3 Related Recommendations and Reports

Recommendation ITU-R F.758	System parameters and considerations in the development of criteria for sharing or compatibility between digital fixed wireless systems in the fixed service and systems in other services and other sources of interference
Recommendation ITU-R M.2083	IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond
Recommendation ITU-R M.2101	Modelling and simulation of IMT networks and systems for use in sharing and compatibility studies
Recommendation ITU-R P.525	Calculation of free-space attenuation
Recommendation ITU-R P.530	Propagation data and prediction methods required for the design of terrestrial line-of-sight systems
Recommendation ITU-R P.676	Attenuation by atmospheric gases

Recommendation ITU-R P.838	Specific attenuation model for rain for use in prediction methods
Recommendation ITU-R P.840	Attenuation due to clouds and fog
Report ITU-R F.2323	Fixed service use and future trends
Report ITU-R M.2376	Technical feasibility of IMT in bands above 6 GHz
Report ITU-R RA.2189	Sharing between the radio astronomy service and active services in the frequency range 275-3 000 GHz
Report ITU-R SM.2352	Technology trends of active services in the frequency range 275-3 000 GHz

4 List of acronyms and abbreviations

BS	Base Station
BBU	Base band unit
RRH	Remote radio head
THF	Tremendously high frequency

5 Frequency ranges under consideration of WRC-19 agenda item 1.15

As the unit of frequency is the hertz (Hz), frequencies shall be expressed in gigahertz (GHz), above 3 GHz, up to and including 3 000 GHz in accordance with Radio Regulations. However, the gigahertz frequency range is subdivided into three ranges as shown in Table 1. Because the frequency ranges of WRC-19 agenda item 1.15 is 275-450 GHz, two frequency bands i.e. EHF and THF must be included in the study of agenda item 1.15.

TABLE 1

Frequency bands above 3 GHz

Band number	Symbols	Frequency range (lower limit exclusive, upper limit inclusive)	Corresponding metric subdivision
10	SHF	3 to 30 GHz	Centimetric waves
11	EHF	30 to 300 GHz	Millimetric waves
12	THF[1]	300 to 3000 GHz	Decimillimetric waves

6 Overview of fixed service applications operating in the frequency range 275-450 GHz

6.1 Regulatory information and technology trend above 275 GHz

6.1.1 Regulatory information

WRC-12 agenda item 1.6 covered the review of the Radio Regulations to update the spectrum use by the passive services between 275 GHz and 3 000 GHz. The revised footnote **5.565** highlights that use

[1] THF stands for tremendously high frequency, this terminology is used only within this Report.

of the range 275-1 000 GHz by the passive services does not preclude use of this range by active services. It also states that administrations wishing to use the frequency range 275-1 000 GHz for active services are urged to take all practicable steps to protect passive services from harmful interference. Subsequently, WRC-19 agenda item 1.15 invites ITU-R to identify candidate frequency bands for use by systems in the land-mobile and fixed services while maintaining protection of the passive services identified in RR No. **5.565**:

5.565 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)

6.1.2 Technology trends

Progress in semiconductor and photonic devices has enabled handling spectrum above 200 GHz with a simple configuration. Oscillators and amplifiers with operating frequencies from 200 GHz to 400 GHz have been developed by using compound semiconductor technologies, such as Indium Phosphide (InP) and Gallium Arsenide (GaAs) high electron mobility transistors (HEMTs) and heterojunction bipolar transistors (HBTs). According to the International Technology Roadmap for Semiconductors (ITRS), the cut-off frequency of silicon complementary metal–oxide–semiconductors (Si CMOS) will reach 1 THz before 2021.

The spectrum beyond 275 GHz would enable emerging and future innovations that can support bit rate capacities on the road toward 100 Gbit/s. The traditional link configurations, such as FDD, as well as complementary future innovations might better handle potential asymmetric and partly unpaired sub-bands.

6.1.3 Propagation aspects

Figure 1 shows the attenuation coefficient in the frequency range 100-1 000 GHz, calculated from Recommendation ITU-R P.676. The attenuation coefficient in THF is generally larger than that in SHF and millimetric wave region. However, in the frequency range of 100-370 GHz, the attenuation coefficient is smaller than in the 60 GHz band.

FIGURE 1

Attenuation coefficient in the frequency range 100-1 000 GHz
(Dashed line indicates attenuation coefficient highest peak of 60 GHz band)

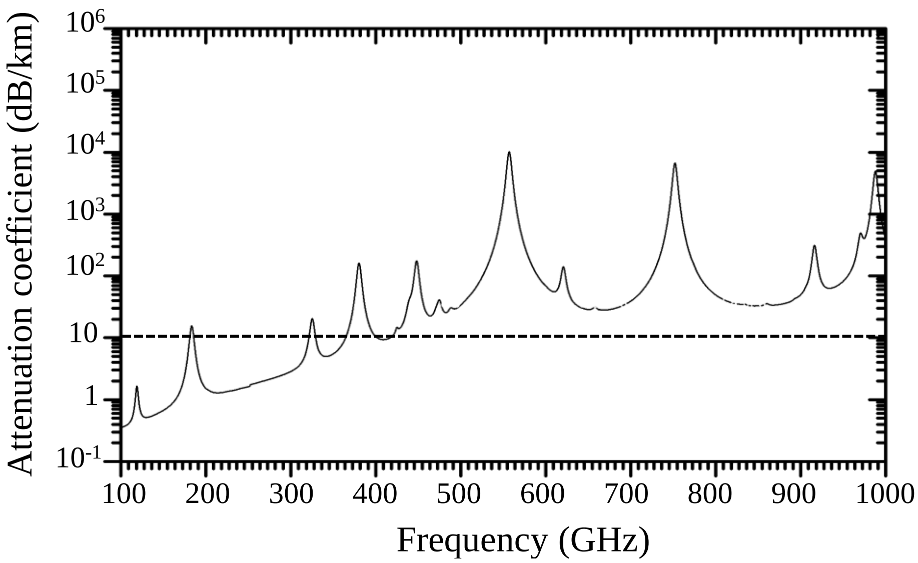
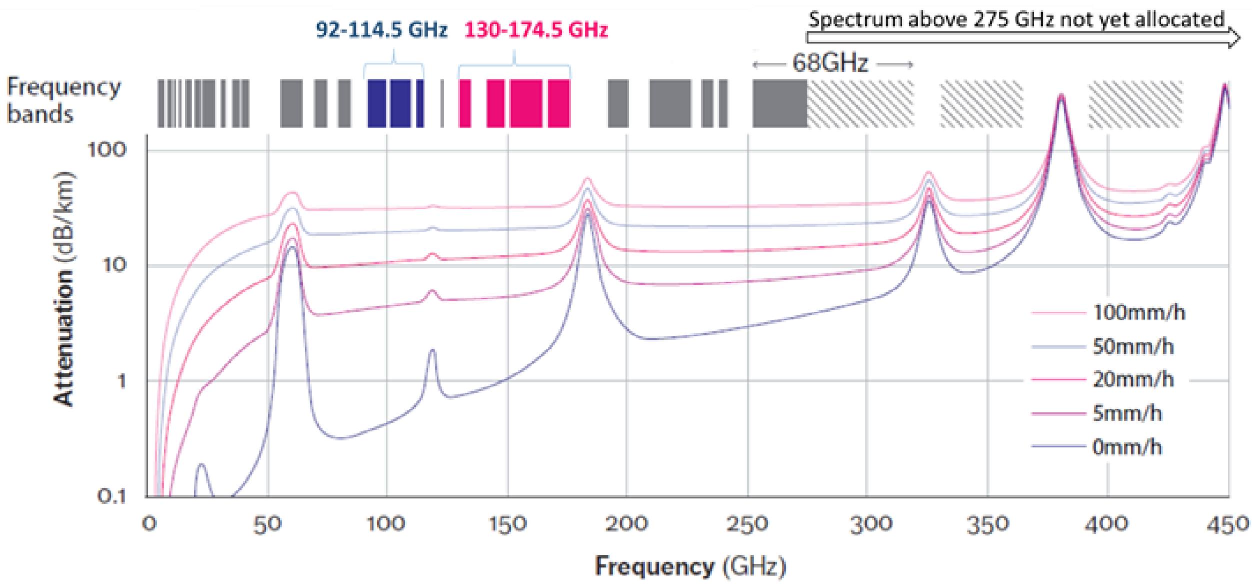


Figure 2 provides further details about the trends of absorption attenuation due to atmospheric gases (i.e. air) and rain with increasing frequency. The calculation method for these attenuation factors are described in Recommendation ITU-R P.530.

FIGURE 2

Attenuation from atmospheric gases and rain



As can be seen from Figs 1 and 2, even though free space path loss increases with frequency, the overall propagation conditions are only slightly worse in the 275-450 GHz band compared to the frequency ranges 92-114.5 GHz and 130-174.5 GHz, outside the frequency portions having absorption peaks.

The spectrum above 100 GHz consists of a multitude of different sized bands (coloured boxes in Fig. 2 which are allocated to the fixed service[2]. There is some interest in the use of frequencies beyond the frequency range 130-174.5 GHz for fixed service systems within the next decade for applications such as backhaul and fronthaul for IMT-2020 mobile services networks. It should also be noted that the 252-275 GHz frequency range is already allocated to the fixed service. Even though free space path loss increases with frequency, the overall propagation conditions in the range 275-320 GHz band are similar to the frequency range 252-275 GHz, as shown in Fig. 2, thus the range 252-320 GHz would enable 68 GHz for radio systems capable of fulfilling high capacity transmission. Therefore, this frequency range may be used for outdoor point-to-point fixed service applications over a distance of several hundred meters, making it suitable for short distance and very high capacity fixed services as an alternative to wireline backhaul transport applications in dense urban areas.

6.2 Point-to-point fronthaul and backhaul

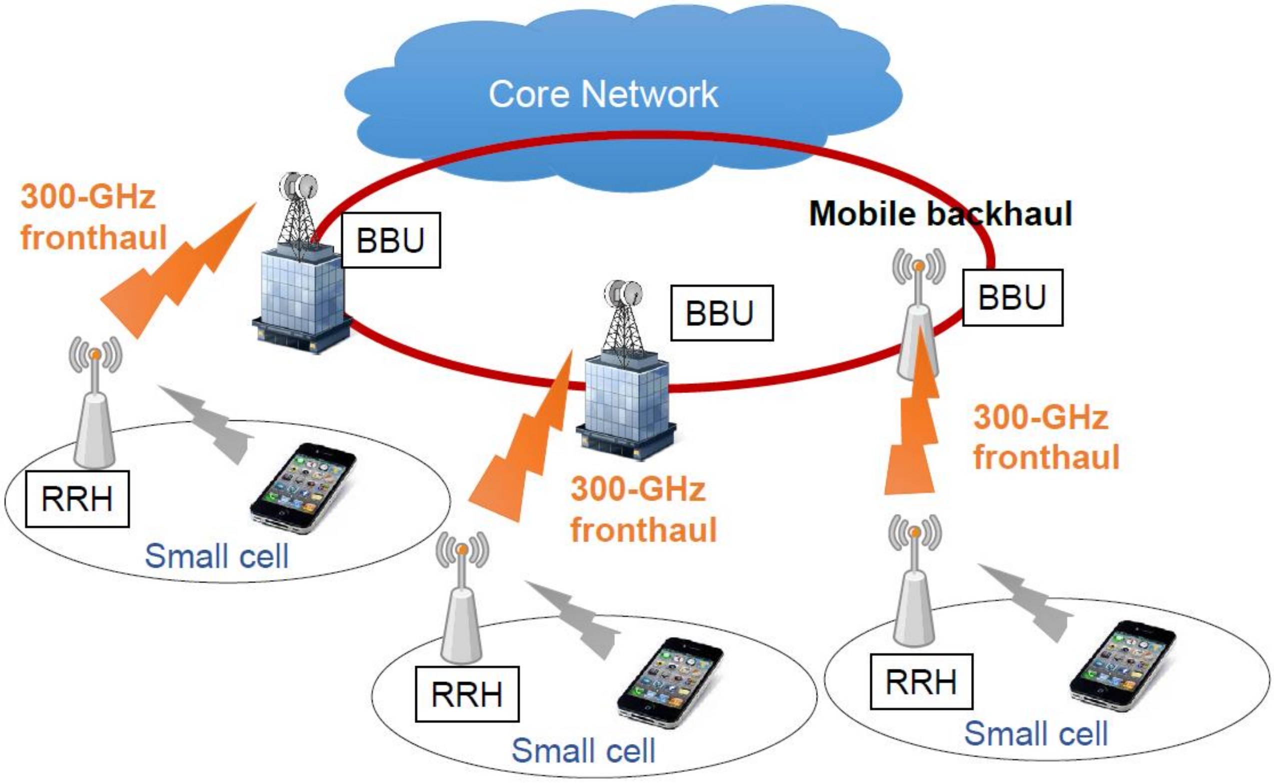
Figure 3 shows the network architecture of mobile systems which support high-capacity transmission between a base station and a mobile terminal. The fronthaul is defined as a link connection between the base station's baseband unit (BBU) and the remote radio head (RRH), while the backhaul is a link between the base station and the higher level network elements. According to Recommendation ITU-R M.2083 and Report ITU-R M.2376, fronthaul and backhaul are critical challenges to accommodate the increase in data throughput of future mobile traffic. In order to meet the peak data rate 10-20 Gbit/s of the mobile terminals in a small cell, the transmission capacity of fronthaul and backhaul may exceed tens of Gbit/s substantially.

The frequency band above 275 GHz can meet the requirement of transmission capacity of fronthaul and backhaul.

[2] 102-109.5 GHz, 111.8-114.25 GHz, 122.25-123 GHz, 130-134 GHz, 141-148.5 GHz, 151.5-164 GHz, 167-174.8 GHz, 191.8-200 GHz, 209-226 GHz, 231.5-235 GHz, 238-241 GHz, and 252-275 GHz.

FIGURE 3

Fronthaul and backhaul operation to be used for mobile system network



7 System characteristics

7.1 Characteristics for systems planned to operate in the bands 275-325 GHz and 380-44 GHz

The technical and operational characteristics of fixed point-to-point systems planned to operate in the bands 275-325 GHz and 380-445 GHz is shown in Table 2, provided that sharing analysis will show that FS can coexist with the passive services.

TABLE 2

Technical and operational characteristics of the fixed service applications planned to operate

Frequency band (GHz)	275-325	380-445
Duplex Method	FDD/TDD	FDD/TDD Editor’s note: Other duplex in schemes are possible
Modulation	BPSK/QPSK/8PSK/8APSK/16QAM/32QAM/64QAM BPSK-OFDM/QPSK-OFDM/16QAM-OFDM/32QAM-OFDM/64QAM-OFDM	BPSK/QPSK/8PSK/8APSK/16QAM/32QAM, 8PSK, 8APSK BPSK-OFDM/QPSK-OFDM/16QAM-OFDM/32QAM-OFDM
Channel bandwidth (GHz)	2…..25 (FDD) 2…..50 (TDD)	2…..32.5 (FDD) 2…..65 (TDD)
Spectrum mask	Annex 2	Annex 2

TABLE 2 (*end*)

Frequency band (GHz)	275–325	380–445
Tx output power range (dBm)	0 ... 20	−10 ... 10
Tx output power density range (dBm/GHz)	−17 ... 17	−28 ... 7
Feeder/multiplexer loss range (dB)	0 … 3	0 … 3
Antenna gain range (dBi)	24 … 50	24 … 50
e.i.r.p. range (dBm)	44 … 70	37 … 60
e.i.r.p. density range (dBm/GHz)	30 … 67	19 … 57
Antenna pattern	Recommendation ITU-R F.699 (Single entry) Recommendation ITU-R F.1245 (Aggregate)	Recommendation ITU-R F.699 (Single entry) Recommendation ITU-R F.1245 (Aggregate)
Antenna type	Parabolic Reflector	Parabolic Reflector
Antenna height (m)	6-25	10-25
Antenna elevation (degree)	±20 (typical)	±20 (typical)
Receiver noise figure typical (dB)	15	15
Receiver noise power density typical (dBm/GHz)	−69	−69
Normalized Rx input level for 1×10^{-6} BER (dBm/GHz)	−61 … −54	−61 … −54
Link length (m)	100 … 300	100 … 300
Deployment Density	See § 8.1	See § 8.1
I/N protection criteria	Recommendation ITU-R F.758	Recommendation ITU-R F.758

8 Deployment scenario of fronthaul/backhaul

8.1 Estimation of density of FS links

According to Recommendation ITU-R M.2101, the deployment scenarios of radio access networks for IMT are categorized into four base station locations, i.e. rural, suburban, urban and indoor. Suburban and urban scenarios are further divided into macro and micro locations whose coverage areas are distinguished. The coverage areas of the micro scenario are included in the macro area.

The fixed service applications such as fronthaul and backhaul links are expected to provide a high capacity link between BBU and RRH. The location of BBU may correspond to the macro-cellular base station and that of RRH to the micro-cellular base station, in both urban and suburban areas. However, due to the distance between the BS in suburban areas, the FS links operating in the range 275-450 GHz are assumed to be used only in urban environment whereas other links will be connected through other millimetric waves bands which are already allocated to the fixed service.

The density of BS in urban areas is estimated to 30 BS/km^2 in each of the frequency ranges expected for IMT-2020 (i.e. 24.25-33.4 GHz, 37-43.5 GHz, 45.5-52.6 GHz and 66-86 GHz). The FS link will be used for ultra-high-capacity link for dense urban area only. Although the percentage of dense urban area per 1 km^2 is not specifically indicated in any ITU-R publications, a ratio of 7 % of BS is assumed in dense urban areas.

According to this assumption, the total number of BS in Tokyo metropolitan district is calculated by 7% of 120 BS multiplied by 619 km^2, i.e. 5 200, as shown in Table 3, for the whole 275-450 GHz band. The other major city in Japan is also included in Table 3. This calculation shows that a density of 8.4 FS links/km^2 can be expected in the whole range 275-450 GHz, hence considering a density of 4.2 FS link/km^2 in each of the 275-325 GHz and 380-445 GHz bands for the evaluation of aggregate effect of emission form FS links.

Although only based on some highly populated cities in Japan, this 4.2 FS link/km^2 figure is assumed to be globally representatives. Alternatively, another way of addressing the FS links distribution could be to use population densities together with the above ratio of 0.0007 links /inhab (for the whole 275-450 GHz range), i.e. a density of 0.00035 FS link/inhab in each of the 275-325 GHz and 380-445 GHz bands.

TABLE 3

Calculation of FS links in the 275-450 GHz range for some highly populated cities in Japan

Name of city	**Size (km^2)**	**Population (M)**	**No. of FS links**	**FS links[(1)] / km^2**	**FS links / inhab**
Tokyo district	619	9.37	5 200	8.4	0.0006
Yokohama	437.4	3.73	3 674	8.4	0.0010
Osaka	223	2.70	1 873	8.4	0.0007
Nagoya	326.4	2.30	2 742	8.4	0.0012
Total	1 605.8	18.1	13 489	**8.4**	**0.0007**

(1) The FS link density is estimated on the condition that all four proposed millimetric waves will be regulated to use for IMT-2020 services

8.2 Elevation angles of antenna

The antenna heights of the base stations in the urban area are estimated in the range 6-25 m. The elevation angles of the antenna are calculated from the antenna height of FS stations and the distance between FS links. Although the distance between the base stations in the dense urban area is also indicated to be 200 m, the distance range of 100-300 m is assumed to be used for calculation of elevation angle of antenna.

In the metropolitan area of Tokyo, the elevation angle is estimated to be less than ±12 degrees taking into account the above parameters as well as the surface deviation of Tokyo area.

In order to taking in account the different urban are around the world, it is assumed that a typical elevation would be ±20 degrees.

8.3 Spectrum need

According to spectrum need of IMT system in the frequency range between 24.5 GHz and 86 GHz, one study result shows the estimated spectrum need of 18.7 GHz, and another study result was that of 27.4 GHz which includes indoor hotspot system.

Taking into account these study results, the channel bandwidth of 24.5 GHz is sufficient to provide high-capacity link for fronthaul/backhaul for IMT system. If the requirements are similar, the same bandwidth of around 25 GHz may satisfy the initial typical deployment scenarios.

9 Summary

According to the previous discussion a total long term spectrum bandwidth of about 50 GHz will sufficiently support the evolution of IMT traffic between BBU and RRH. The possible candidate frequency bands for fronthaul and backhaul applications are 275-325 GHz and 380-445 GHz. The frequency band 330-370 GHz may also be considered in the future, if and when parameters are available for that range.

Annex 1

Attenuation characteristics in the frequency range 275-445 GHz

This Annex gives information on attenuation characteristics calculated from Recommendation ITU-R P.676-10. The attenuation by rain rate and liquid water density in fog is also calculated from Recommendations ITU-R P.838-3 and ITU-R P.840-6. The difference of attenuation by atmospheric gases at 275 GHz and 325 GHz is about 33 dB, but those by rain rate and liquid water density in fog are −0.1 dB and +0.7 dB, respectively. These characteristics should be used for designing channel arrangement of point-to-point fronthaul and backhaul applications.

FIGURE 4

Attenuation characteristics by atmospheric gases

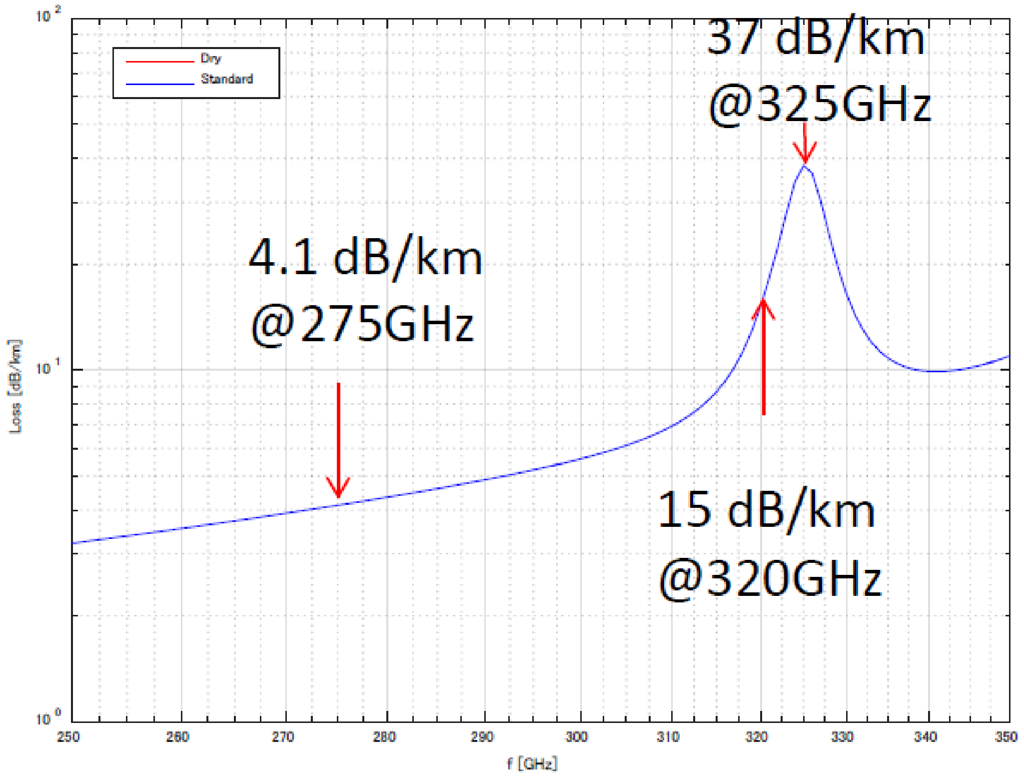


FIGURE 5

Attenuation characteristics by rain rate

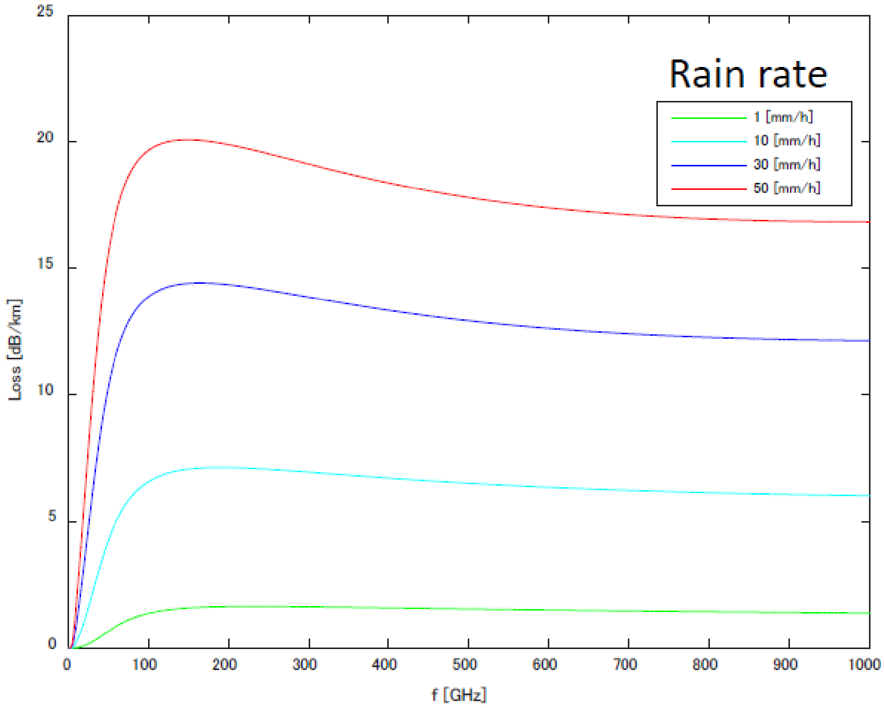
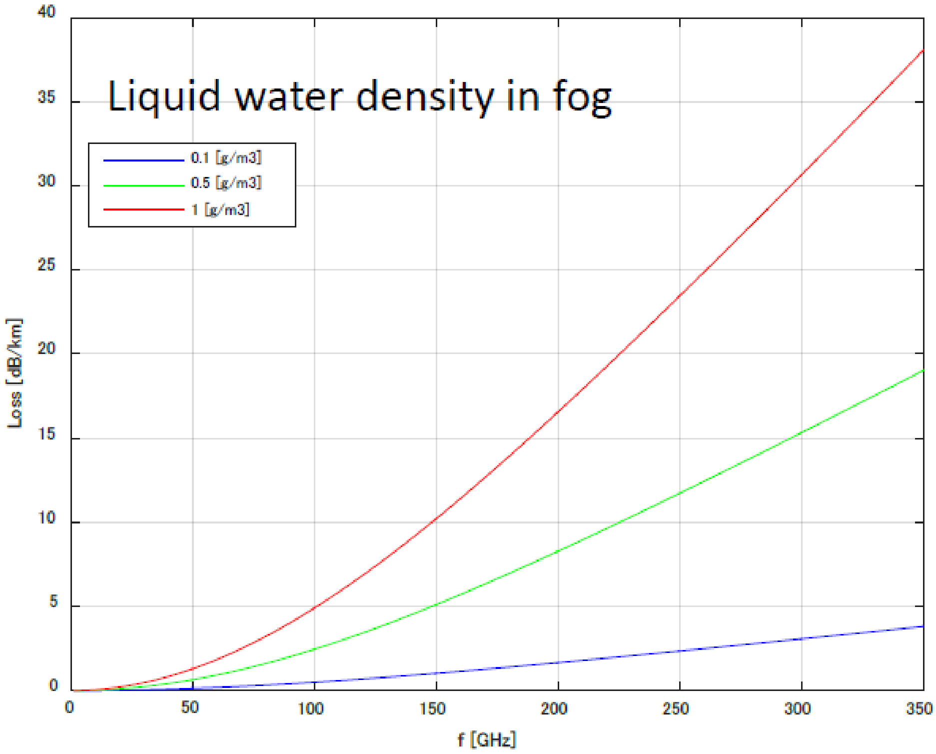


FIGURE 6

Attenuation characteristics by liquid water density in fog. The calculation results above 200 GHz is extrapolated using Recommendation ITU-R P.840-6



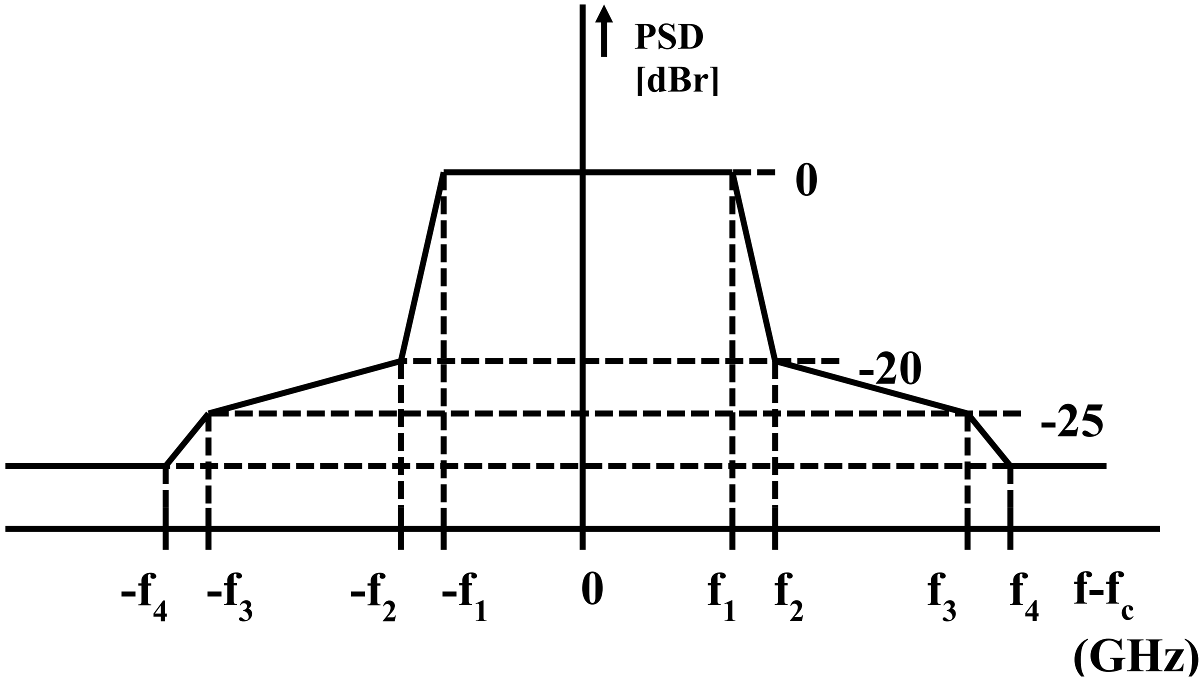
Annex 2

Transmitter spectrum mask

The following spectrum mask is taken from IEEE Std 802.15.3d™-2017 as shown in Fig. 7 and Table 4.

FIGURE 7

Generic transmit spectral mask



The parameters of the PSD indicated in Fig. 7 are defined in Table 4.

TABLE 4

Transmit spectrum mask parameters

Channel bandwidth [GHz]	f_1 (GHz)	f_2 (GHz)	f_3 (GHz)	f_4 (GHz)
2.160	0.94	1.10	1.60	2.20
4.320	2.02	2.18	2.68	3.28
8.640	4.18	4.34	4.84	5.44
12.960	6.34	6.50	7.00	7.60
17.280	8.50	8.66	9.16	9.76
25.920	12.82	12.98	13.48	14.08
51.840	25.78	25.94	26.44	27.04
69.120	34.42	34.58	35.08	35.68

Annex 3

C/*N* evaluation of 300 GHz wireless link

This Annex evaluates the carrier-to-noise ratio of 300 GHz wireless link using the characteristics shown in Table 2. The Tx and Rx antenna gains of 50 dBi, noise figure of 15 dB, rainfall rate of 50 mm/h are used for calculation. Figure 8 shows *C*/*N* as a function of transmission bandwidth of 300-GHz wireless link whose output power is 10 dBm. The wider transmission bandwidth is used, the larger attenuation deviation is observed in that bandwidth. In order to achieve *C*/*N* over 30 dB in the 50-GHz bandwidth, the output power over 20 dBm is required to transmit the signal up to 300 m. Figure 9 shows *C*/*N* as a function of distance of 300 GHz wireless link and *C*/*N* over 40 dB is obtained if output power is over 20 dBm. The sufficient channel capacity in the condition of the output power of 20 dBm, the centre frequency of 300 GHz, the distance of 300 m and the bandwidth of 2.16 GHz is obtained even if the rainfall rate is 100 mm/h, as shown in Fig. 10. There is no big difference of the channel capacity between carrier frequencies from 280 to 320 GHz. In the calculation of *C*/*N* and channel capacity, the system availability is assumed to be 100%.

FIGURE 8

***C*/*N* versus bandwidth for signal transmission**

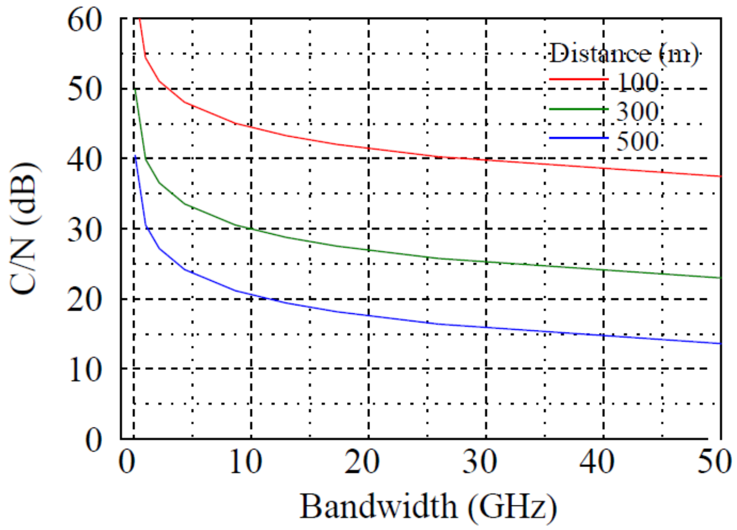


FIGURE 9

***C*/*N* versus distance of 300-GHz wireless link**

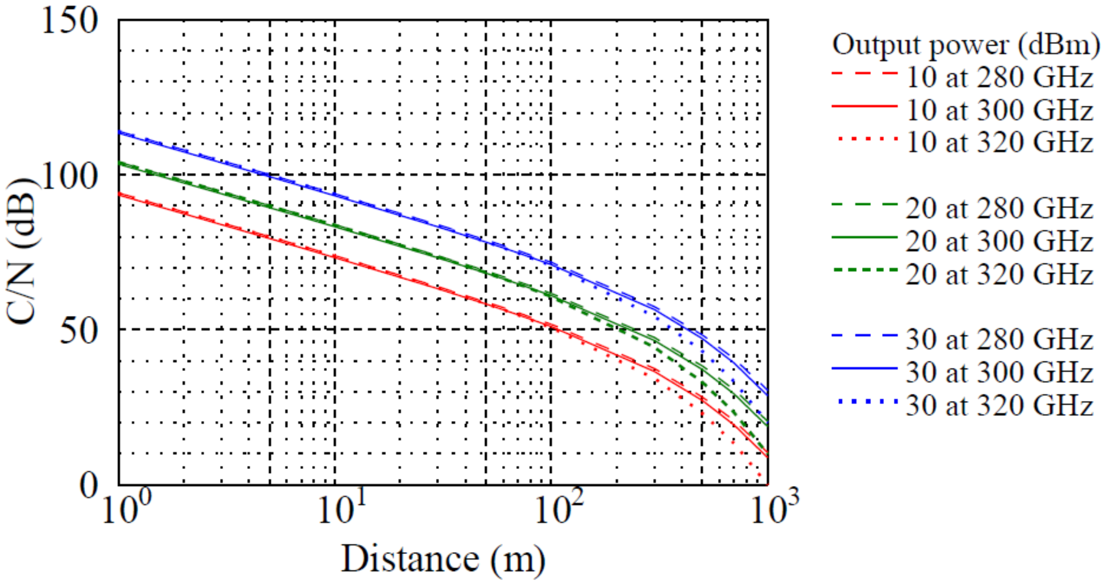
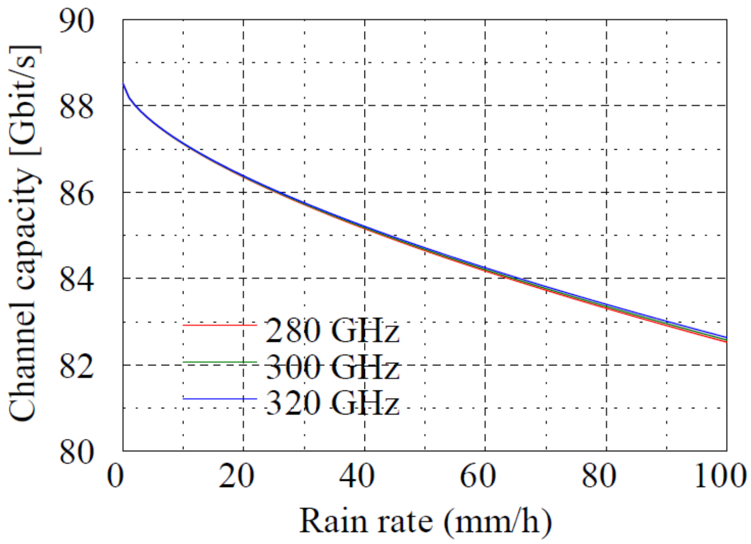


FIGURE 10

Channel capacity versus rain rate



Annex 4

Measurement results of antenna pattern at 300-GHz

FIGURE 11

Measured characteristics of offset parabola antenna with a maximum gain of 49 dBi, where the dotted line is calculated from Recommendation ITU-R F.699-7