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# Report ITU-R F.2416-1

**(12/2024)**

M Series: Mobile, radiodetermination, amateur and related satellite services

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

## Foreword

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***Note**: This ITU-R Report was approved in English by the Study Group under the procedure detailed in Resolution ITU-R 1.*

*Electronic Publication*
Geneva, 2025

# REPORT ITU-R F.2416-1

## 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)

(2017-2024)

NOTE – Due to the lack of time, some Administration have not been able to follow the preparation of this Report and may have further comments in its implementation.

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## 1 Introduction

Due to progress of RF integrated devices and circuits in the frequency band above 275 GHz, contiguous frequency bands with large bandwidth are now available for fixed service applications, as identified under Radio Regulations (RR) No. **5.564A**. Some applications in the frequency band above 275 GHz such as point-to-point backhaul and fronthaul for mobile services may be introduced in the future. By utilizing this spectrum, ultra-high-speed data transmission between fixed stations may become feasible.

Radio Regulations No. **5.565** identifies the specific frequency bands for applications of the radio astronomy service, the earth exploration-satellite service (passive), and the space research service (passive) in the frequency range 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. Report ITU-R SM.2450 provides the results of sharing and compatibility studies between LMS and FS applications planning to operate in the frequency range 275-450 GHz and passive services: radio astronomy service and Earth exploration-satellite service (passive).

Furthermore, RR No. **5.564A** identifies the frequency bands 275-296 GHz, 306-313 GHz, 318-333 GHz and 356-450 GHz for use by administrations for the implementation of land mobile and fixed service applications, where no specific conditions are necessary to protect Earth exploration-satellite service (passive) applications and indicates that the frequency bands 296-306 GHz, 313-318 GHz and 333-356 GHz 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-19)**.

## 2 Scope

This Report describes the fixed service applications and their technical and operational characteristics for operation in the frequency range 275-450 GHz. This information can be used for sharing and compatibility studies between fixed service applications and passive services, as well as between fixed and other active services in the frequency range 275-450 GHz (see Table 2).

## 3 Related Recommendations and Reports

| | |
|---|---|
| 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 F.699 | Reference radiation patterns for fixed wireless system antennas for use in coordination studies and interference assessment in the frequency range from 100 MHz to 86 GHz |
| 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 P.838 | Specific attenuation model for rain for use in prediction methods |
| Recommendation ITU-R P.840 | Attenuation due to clouds and fog |

| | |
|---|---|
| Recommendation ITU-R F.1245 | Mathematical model of average and related radiation patterns for line-of-sight point-to-point fixed wireless system antennas for use in certain coordination studies and interference assessment in the frequency range from 1 GHz to 86 GHz |
| Recommendation ITU-R M.2083 | IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond |
| 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 F.2323 | Fixed service use and future trends |
| Report ITU-R SM.2352 | Technology trends of active services in the frequency range 275-3 000 GHz |
| Report ITU-R F.2393 | Use of fixed service for transport of traffic, including backhaul, for IMT and other terrestrial mobile broadband systems |
| Report ITU-R SM.2450 | Sharing and compatibility studies between land-mobile, fixed and passive services in the frequency range 275-450 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

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. Gigahertz frequency bands may be subdivided into three ranges as shown in Table 1.

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 |

[1] Although it is not formally defined in the Radio Regulations, THF stands for tremendously high frequency. This terminology is used only within this Report.

It is noted that the Radio Regulations have not allocated the frequency band 275 GHz to 3 000 GHz to any services yet although the use of this frequency range by active and passive services is governed by footnotes RR No. **5.564A** and RR No. **5.565.**

## 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 RR No. **5.565** highlights that use 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, studies conducted under WRC-19 agenda item 1.15, resulted in the adoption of RR No. **5.564A** to identify candidate frequency bands for use by systems in the land mobile and fixed services while ensuring protection of the passive services identified in RR No. **5.565**.

#### 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). ETSI report GR mWT 022[2], published in April 2021, states the following: “Silicon technologies such as SOI (silicon on insulator) CMOS (complementary metal oxide semiconductor) and SiGe-HBT (silicon germanium-heterojunction bipolar transistor) are today feasible up to W-band (92 to 114,5 GHz) although the maximum output power is limited due to the low breakdown voltage of silicon and the noise figure is worse compared to GaAs (gallium arsenide) and InP (indium phosphide) technologies. The newer generations of SiGe/BiCMOS (bipolar CMOS) technologies have $f_{MAX}$ in the region of 300-400 GHz, further increase in $f_{MAX}$ above 400 GHz is under investigation, however as figure 6 shows, nMOS (SOI CMOS) seems to have an optimum of $f_{MAX}$ at 28 nm so may not catch up with SiGe (BiCMOS)”. “Silicon technologies are promising for short-range, low-cost applications due to the excellent properties for high integration however performance limitations are expected in the frequency bands above 140 GHz”.

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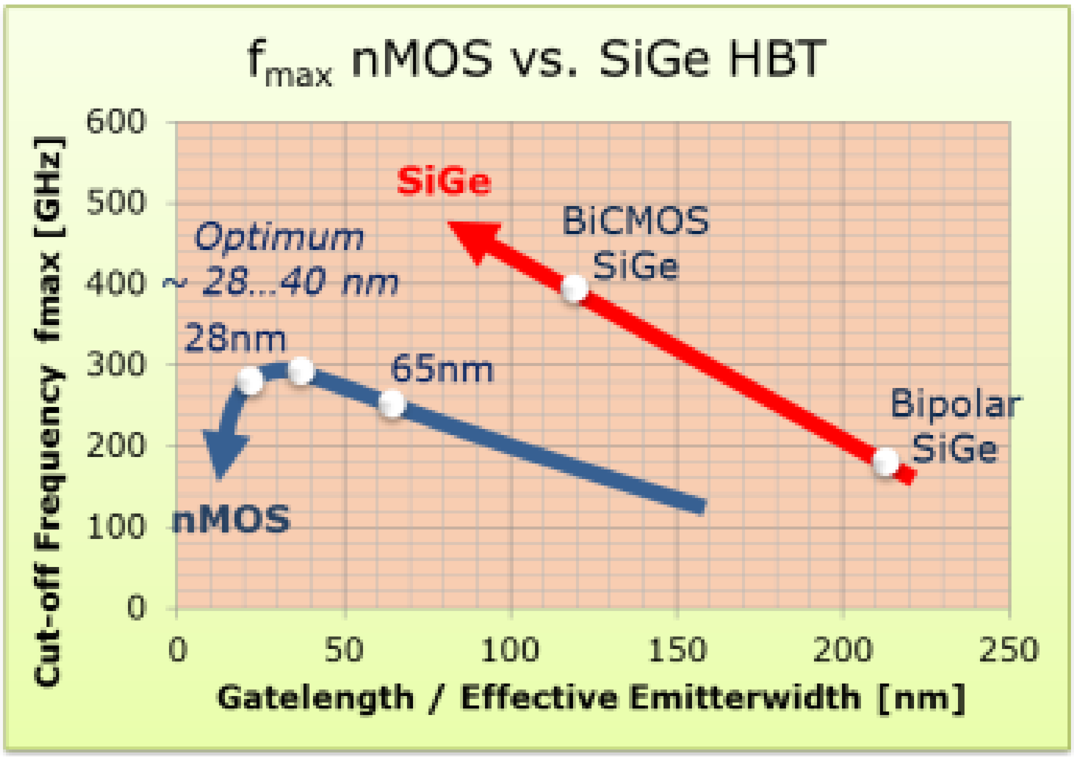
2 ETSI report GR mWT 022 is available from this link. Its Fig. 6 is reproduced here as Fig. 1.

FIGURE 1

**Overview of $f_{MAX}$ for SiGe (BiCMOS/HBT) and nMOS technologies**




Also, according to a report from the German Innovations for High Performance (IHP) microelectronics institute published in August 2021, "integrated HBTs with cut-off frequencies of up to 500 GHz" can be achieved[3].

The spectrum beyond 275 GHz is envisaged to enable emerging and future innovations that can support bit rate capacities on the road toward 100 Gbit/s, although at the expense of reducing the length of the link. The traditional link configurations, such as FDD, as well as complementary future innovations might better handle potential asymmetric and partly unpaired sub-bands. It should be noted that technology in these frequency ranges is under ongoing development.

### 6.1.3 Propagation aspects (see Annex 1)

Figure 2 shows the attenuation due to atmospheric gases up to 1 000 GHz as per Recommendation ITU-R P.676-13. The specific attenuation in THF is generally larger than that in SHF and millimetric wave regions. However, in the frequency range 275-450 GHz, the attenuation due to atmospheric gases are about 100 times less than for the 60 GHz band (which aligns with a resonant frequency for oxygen). As it is seen in this Figure, the attenuation rises from less than 1 dB/km at around 110 GHz to close to 10 dB/km around 310 GHz.

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[3] The IHP report is available from this link.

FIGURE 2

**Specific attenuation due to atmospheric gases, calculated at 1 GHz intervals, including line centres**

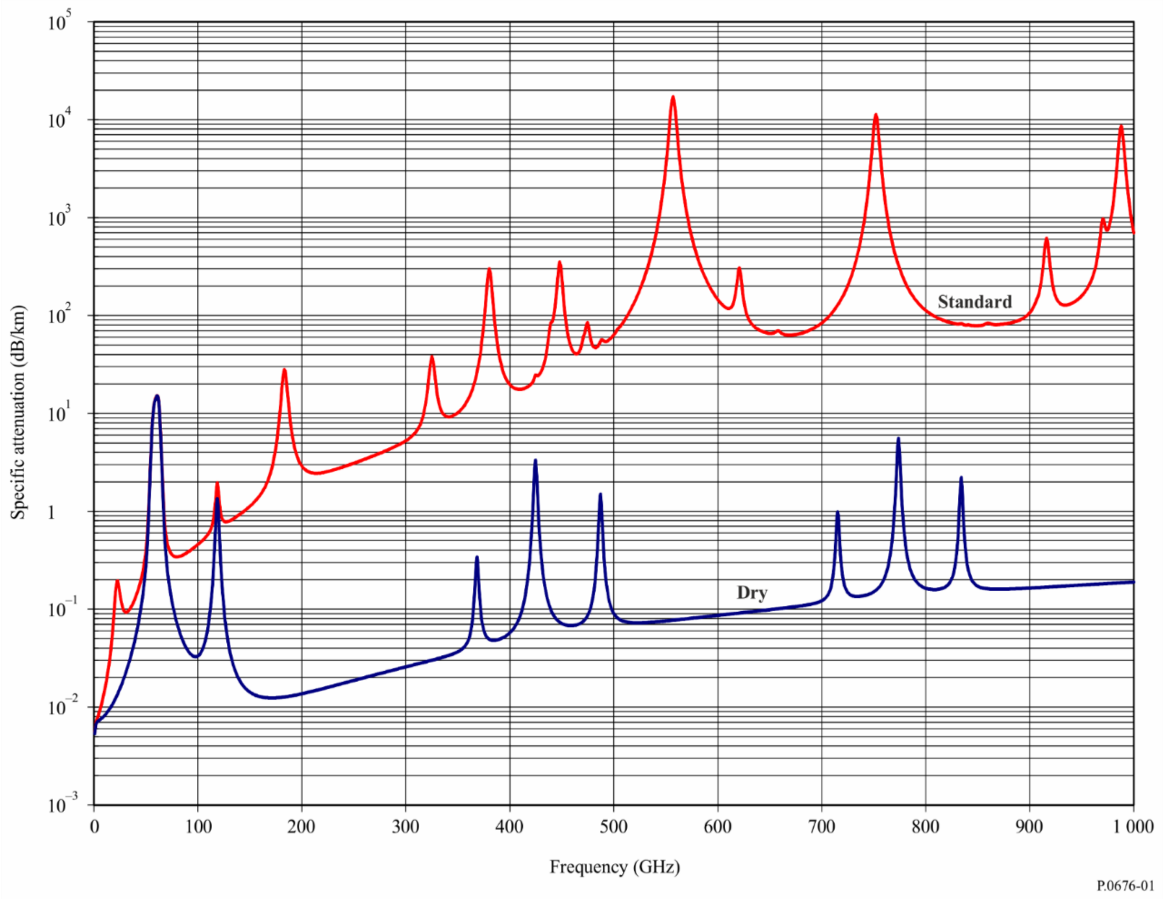
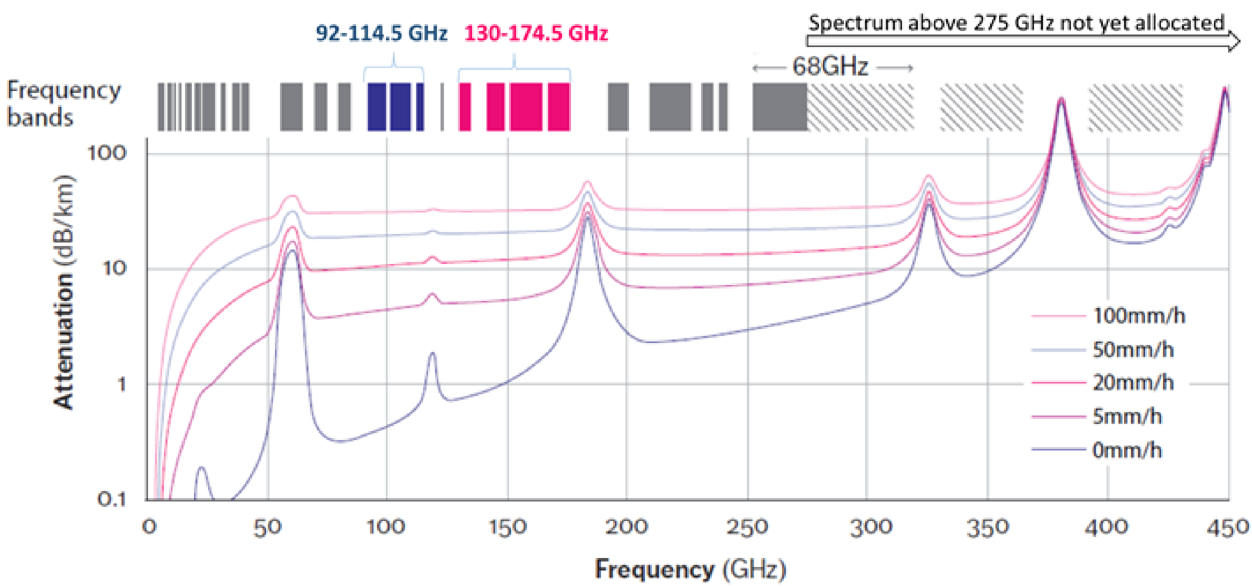



Figure 3 provides further details about absorption attenuation due to atmospheric gases (i.e. air) and rain with increasing frequency. The calculation method for these attenuation factors is described in Recommendation ITU-R P.530.

FIGURE 3

**Attenuation from atmospheric gases and rain**



As can be seen from Figs 2 and 3, even though free space path loss increases with frequency, the propagation losses due to rain don't show as strong a variation. At specific rain rates of 20, 50 or 100 mm/h, the rain attenuation conditions do not show significant variations 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. 3) which are allocated to the fixed service[4]. There is some interest in the use of frequencies beyond 174.5 GHz for fixed service systems within the next decade for applications such as backhaul and fronthaul for expected IMT-2020 mobile service applications, noting that RR No. **5.340** applies to EESS (passive) in some frequency bands beyond 174.5 GHz. It should also be noted that the 252-275 GHz frequency range is already allocated to the fixed service. Even though free space path and atmospheric losses increase with frequency, the rain attenuation levels in the range 275-320 GHz band are similar to that of frequency range 252-275 GHz, as shown in Fig. 3. Therefore, it is possible that the range 252-320 GHz could provide a continuous 68 GHz for radio systems capable of fulfilling high-capacity transmission. This frequency range may then, be used for outdoor point-to-point fixed service applications over a distance of up to 1 km[5], making it suitable for short distance and very high capacity fixed service applications as an alternative to wireline backhaul transport applications in dense urban areas.

## 6.2 Point-to-point fronthaul and backhaul

Figure 4 shows an example of the expected network architecture of mobile systems that 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, as defined in Report ITU-R F.2393. 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 of 10-20 Gbit/s for mobile terminals in a small cell, the transmission capacity of fronthaul and backhaul may need to exceed tens of Gbit/s substantially (see Annex 5).

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

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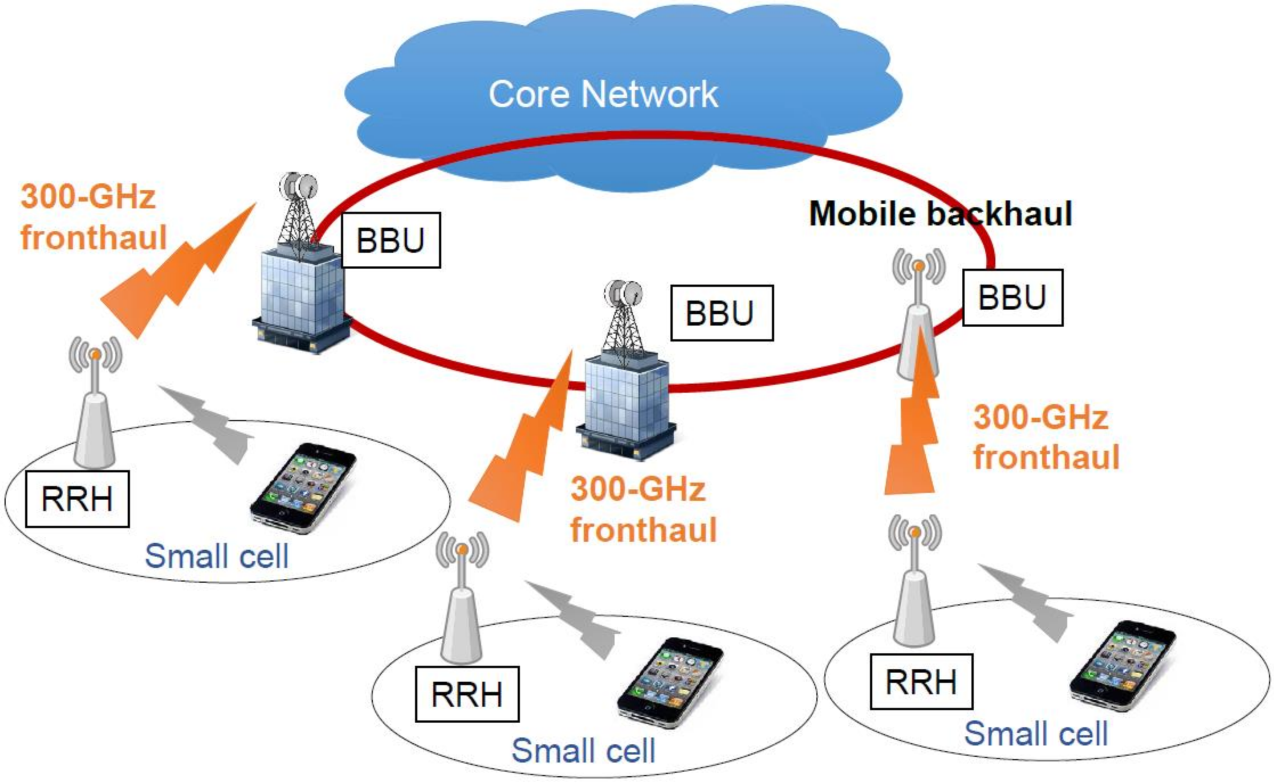
4 102-109.5 GHz, 111.8-114.25 GHz, 122.25-123 GHz, 130-134 GHz, 141-148.5 GHz, 151.5-164 GHz, 167-174.8 GHz, 191.8-200 GHz, 209-226 GHz, 231.5-235 GHz, 238-241 GHz, and 252-275 GHz.

5 Section 4.1.4 "Wireless Backhauling/Fronthauling" of Report ITU-R SM.2352-1, published in July 2022, indicates that "in the demonstration described in [1], a data rate of 24 Gbit/s has been achieved over a link distance of 1 km" (propagation conditions during the demonstration are not provided). In the same section of Report ITU-R SM.2352-1, it is noted in Table 4 that typically, a data speed of up to 100 Gbit/s is possible for a communication distance of 100 m to 300 m.

FIGURE 4

**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 380-445 GHz

An example of 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. It should be noted that the use of FS within the above-mentioned frequency ranges is required to comply with RR No. **5.564A** as mentioned in § 6.1.1.

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 |
| Modulation | BPSK/QPSK/8PSK/8APSK/ 16QAM/32QAM/64QAM<br>BPSK-OFDM/QPSK-OFDM/ 16QAM-OFDM/32QAM-OFDM/ 64QAM-OFDM | BPSK/QPSK/8PSK/8APSK/ 16QAM/32QAM, 8PSK, 8APSK<br>BPSK-OFDM/QPSK-OFDM/ 16QAM-OFDM/32QAM-OFDM |
| Channel bandwidth (GHz) | 2 to 25 (FDD)<br>2 to 50 (TDD) | 2 to 32.5 (FDD)<br>2 to 65 (TDD) |
| Spectrum mask | Annex 2 | Annex 2 |
| Tx output power range (dBm) | 0 to 20 | −10 to 10 |

TABLE 2 (*end*)

| **Frequency band (GHz)** | **275-325** | **380-445** |
|---|---|---|
| Tx output power density range (dBm/GHz) | −17 to 17 | −28 to 7 |
| Feeder/multiplexer loss range (dB) | 0 to 3 | 0 to 3 |
| Antenna gain range (dBi) | 24 to 50 | 24 to 50 |
| e.i.r.p. range (dBm) | 44 to 70 | 37 to 60 |
| e.i.r.p. density range (dBm/GHz) | 30 to 67 | 19 to 57 |
| Antenna pattern | Rec. ITU-R F.699 (single entry)<br>Rec. ITU-R F.1245 (aggregate) | Rec. ITU-R F.699 (single entry)<br>Rec. 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 $1\times10^{-6}$ BER (dBm/GHz) | −61 to −54 | −61 to −54 |
| Link length (m) | 100 to 300 | 100 to 300 |
| Deployment density | See § 8.1 | See § 8.1 |
| *I*/*N* protection criteria (dB) | –10 [(1)] | –10 [(1)] |

(1) The *I*/*N* of –10 dB refers to the long-term protection criteria, for the case of in-band sharing, not to be exceeded by more than 20% of the time. Recommendation ITU-R F.758 provides additional information on the protection criteria for the fixed service.

## 8 Deployment scenarios 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 wave bands, which are already allocated to the fixed service.

The density of BS in urban areas is estimated to be 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 cities in Japan are 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 from 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 representative. 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 (links per inhabitant 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 IMT-2020 services.

## 8.2 Elevation angles of antenna

The antenna heights of the base stations above ground level 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 take into account the different urban geographies around the world, it is assumed that a typical elevation would be within the range of ±20 degrees.

## 9 Summary

The technical and operational characteristics for fronthaul/backhaul links which are available at this time to operate in the frequency bands 275-325 GHz and 380-445 GHz in accordance with RR No. **5.564A**, are provided in this Report for use in sharing and compatibility studies.

The possible candidate frequency bands initially envisaged for fronthaul and backhaul applications are 275-325 GHz and 380-445 GHz and additional work would be required to possibly provide FS parameters in the frequency band 325-380 GHz, taking into account the appropriate technical and operational characteristics when they become known.

To this respect, it should also be highlighted that in accordance with RR No. **5.564A**, before the frequency bands 296-306 GHz, 313-318 GHz and 333-356 GHz can be used by fixed service applications, specific conditions to ensure the protection of the earth exploration-satellite service (passive) would have to be determined, which may have impact on the FS characteristics.

It should be noted that Annexes 1 to 5 provide further supplemental technical information which is related to the technical and operational characteristics of fixed service applications in 275-450 GHz.

# Annex 1

## Attenuation characteristics in the frequency range 275-450 GHz

This Annex gives information on attenuation characteristics calculated from Recommendation ITU-R P.676. The attenuation by rain rate and liquid water density in fog is also calculated from Recommendations ITU-R P.838 and ITU-R P.840. The difference of attenuation by atmospheric gases at 275 GHz and 325 GHz is about 34 dB, but those by rain rate and liquid water density in fog are −0.1 dB (1 mm/h) and +1.1 dB (0.5 g/$m^3$), respectively. These characteristics should be used for designing channel arrangement of point-to-point fronthaul and backhaul applications.

FIGURE 5

**Attenuation characteristics by atmospheric gases**

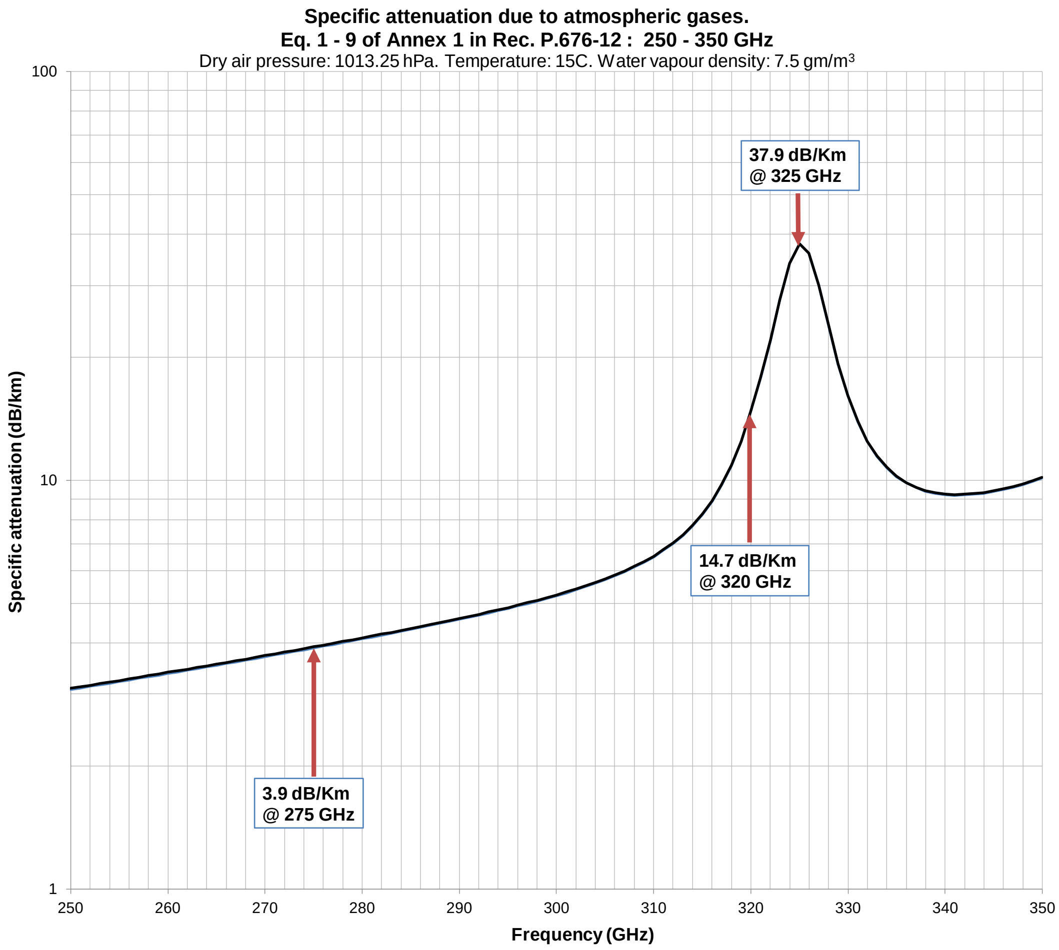


FIGURE 6

**Attenuation characteristics by rain rate**

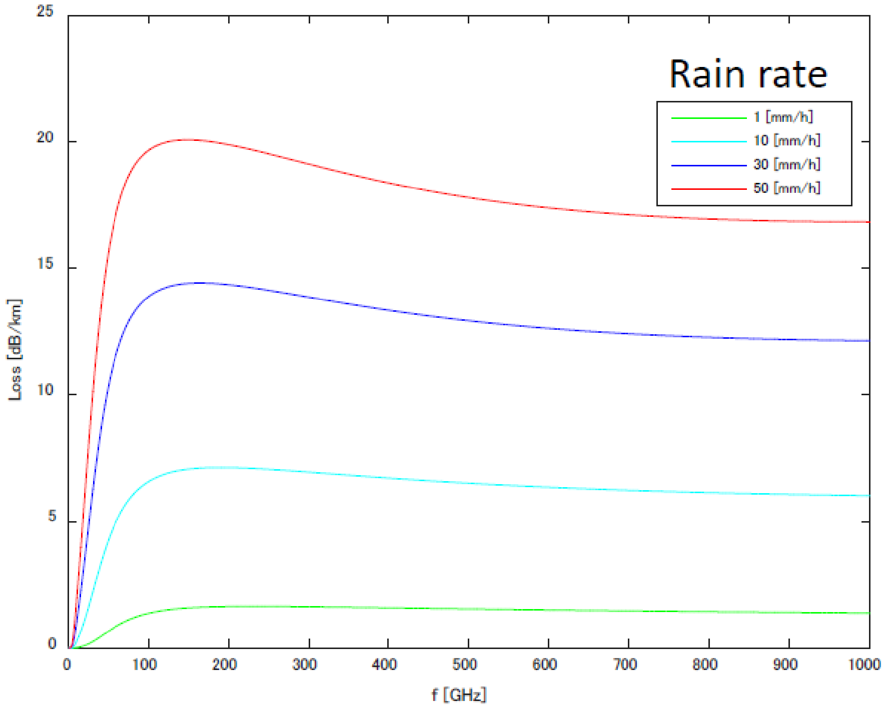
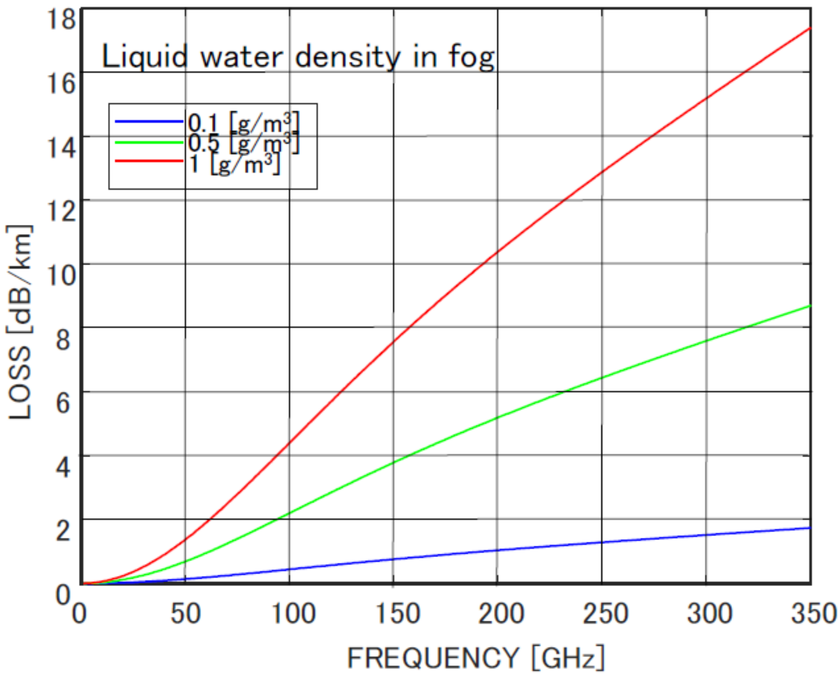



FIGURE 7

**Attenuation characteristics by liquid water density in fog.**
**The calculation results above 200 GHz are extrapolated using Rec. ITU-R P.840**



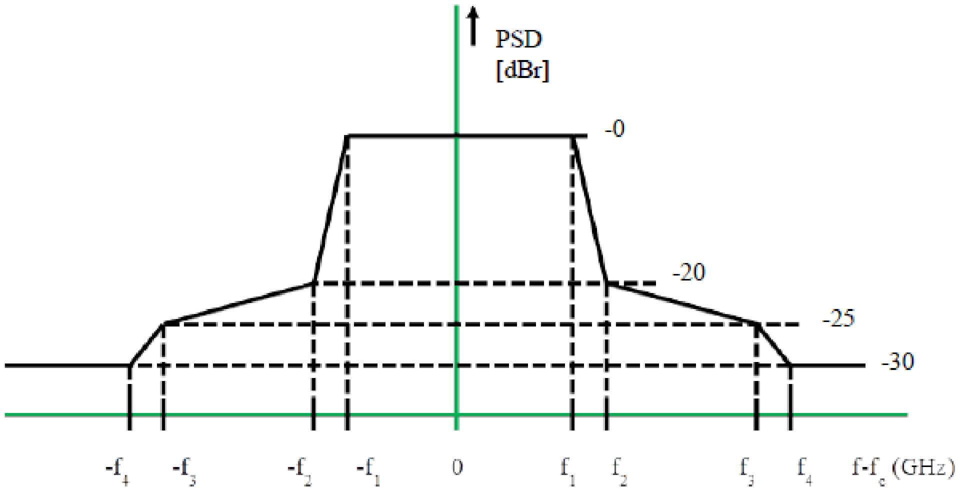
# Annex 2

## Transmitter spectrum mask

The following spectrum mask is taken from section 13.1.3 of IEEE Standard 802.15.3d™-2017 (Figures 13-1 and Table 13-2) as shown in Fig. 8 and Table 4.

FIGURE 8

**Generic transmit spectral mask**




The parameters of the power spectrum density (PSD) indicated in Fig. 8 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* calculation of a 300 GHz wireless link

This Annex evaluates the carrier-to-noise ratio of a 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. Fig. 9 shows *C*/*N* as a function of transmission bandwidth associated with a 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. Fig. 10 shows *C*/*N* as a function of distance for the 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. 11. This test did not find a 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 was assumed to be 100%.

FIGURE 9

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

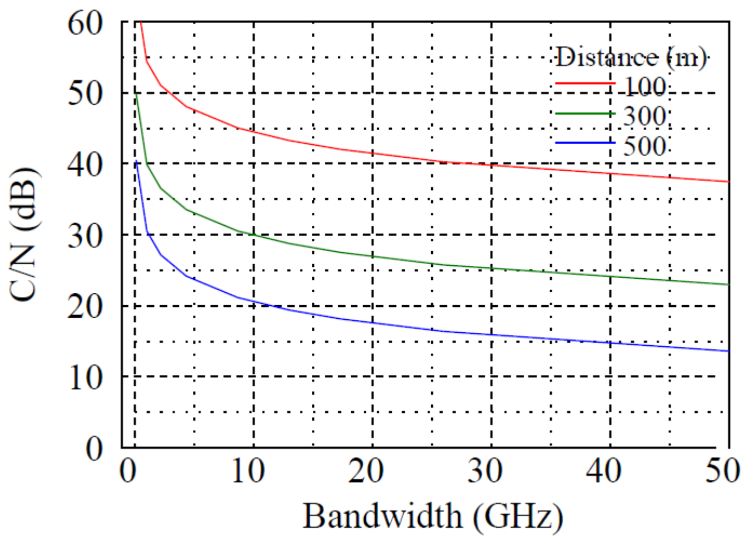


FIGURE 10

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

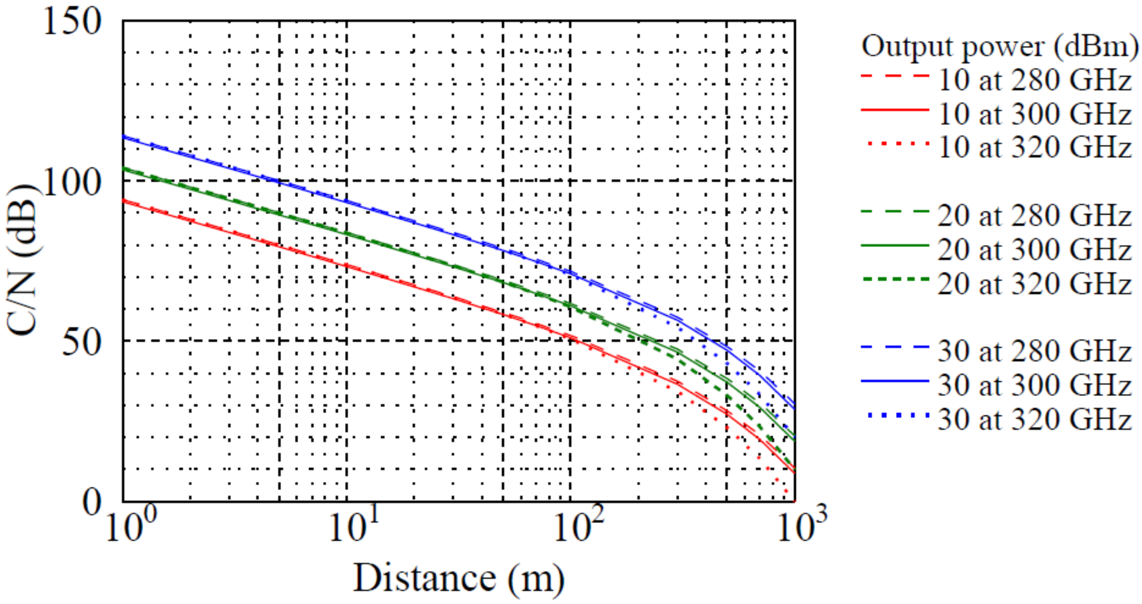
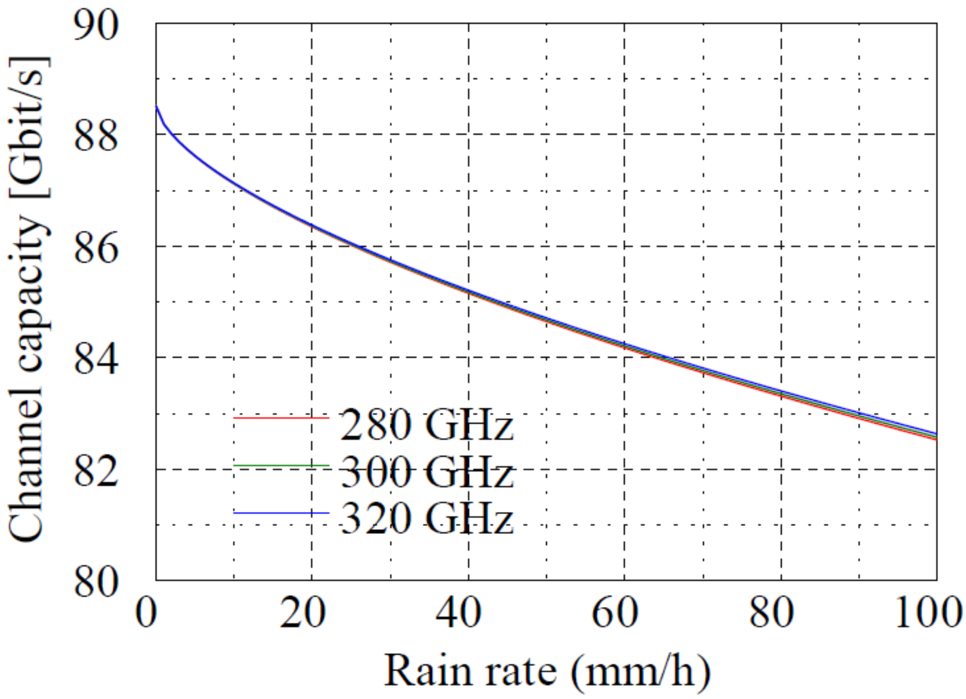



FIGURE 11

**Channel capacity versus rain rate**



# Annex 4

## Measurement results of antenna radiation patterns

This Annex provides measurements of antenna radiation patterns in the frequency range 220-500 GHz which assist development of fixed wireless systems operating in the frequency range 220-500 GHz. Table 5 summarizes the physical dimension of four antennas. The offset parabola, standard gain horn and corrugated horn antennas were measured at the frequencies of 220 GHz, 250 GHz, 275-GHz, 300 GHz, 330 GHz, 350 GHz, 400 GHz, 450 GHz and 500 GHz. The Cassegrain antenna was measured at 220 GHz, 250 GHz, 275 GHz, 300 GHz and 330 GHz.

TABLE 5

**Physical dimension of each antenna**

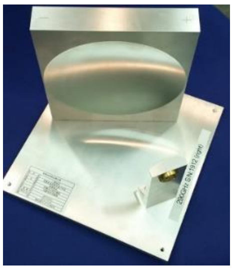
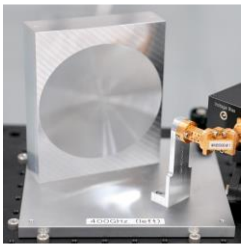
| **Type of antenna** | **Figure No.** | **External view** | **Size** | **D/λ** | **Comment** |
|---|---|---|---|---|---|
| Offset parabola | 12 |  | ϕ 150 mm | 110-165 | Prototype |
| | 16 |  | ϕ 109 mm | 127-181.8 | Prototype |
| Cassegrain | 13 |  | ϕ 152 mm | 111.5-167.2 | Product |

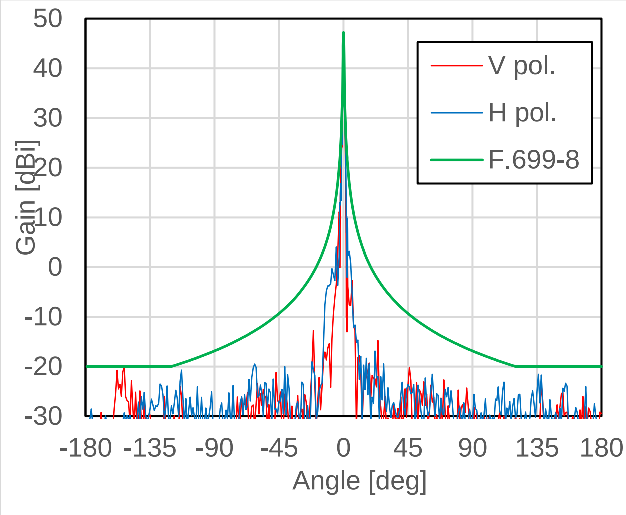
TABLE 5 (*end*)

| Type of antenna | Figure No. | External view | Size | D/λ | Comment |
|---|---|---|---|---|---|
| Standard gain horn | 14 |  | 8.36 mm × 5.5 mm | 4.03-9.20 | Product |
| | 17 |  | 4.98 mm × 3.81 mm | 4.44-8.30 | Product |
| Corrugated horn | 15 |  | ϕ 4.4 mm | 3.23-4.84 | Product |
| | 18 |  | ϕ 2.96 mm | 3.45-4.93 | Product |

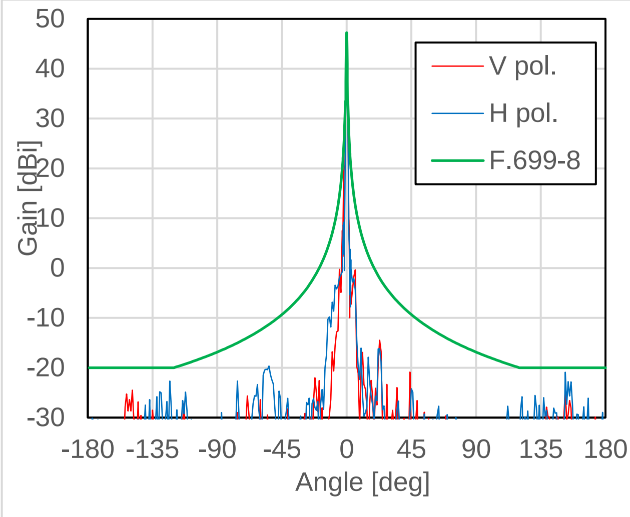
FIGURE 12

**Measured characteristics of offset parabola antenna (D/λ > 100, diameter = 150 mm), where the green lines are calculated from Rec. ITU-R F.699-8**

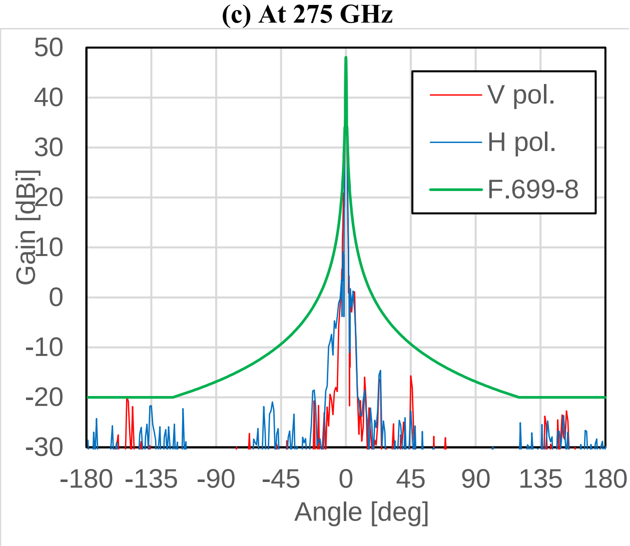
**(a) At 220 GHz**



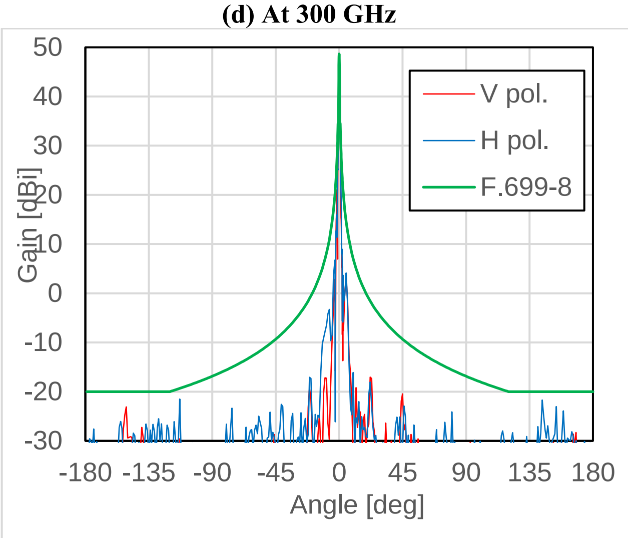

**(b) At 250 GHz**




**(c) At 275 GHz**




**(d) At 300 GHz**




**(e) At 330 GHz**

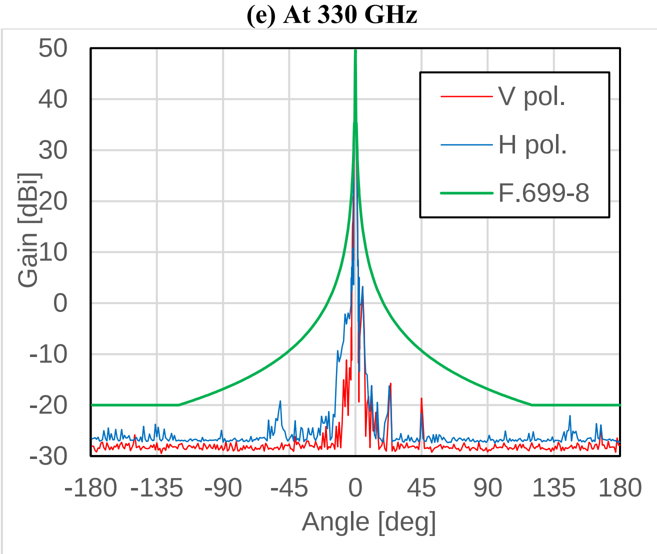
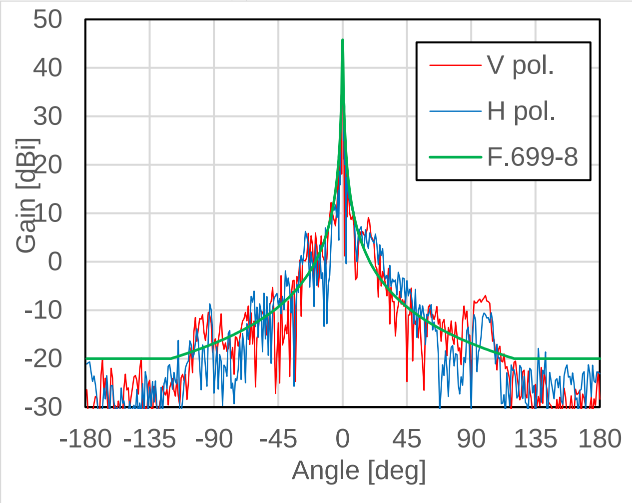


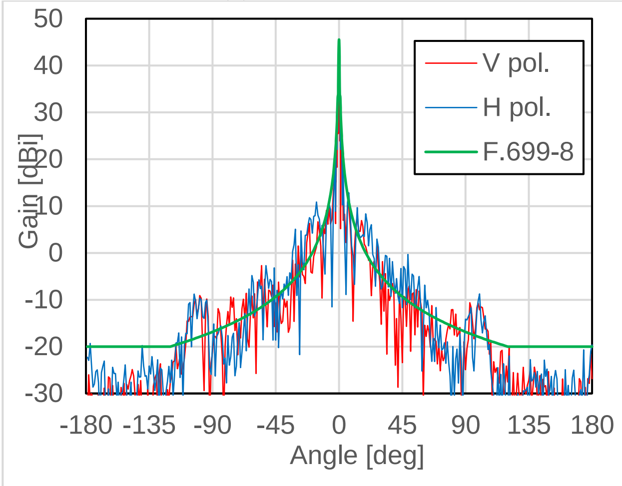
FIGURE 13

**Measured characteristics of Cassegrain antenna (D/λ > 100, diameter = 152 mm), where the green lines are calculated from Rec. ITU-R F.699-8**

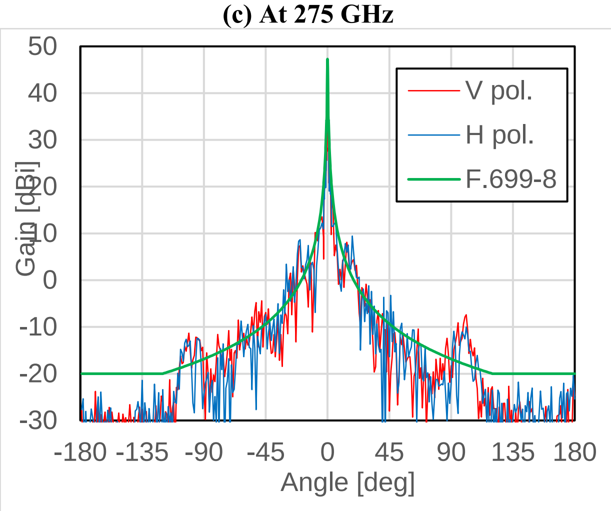
**(a) At 220 GHz**



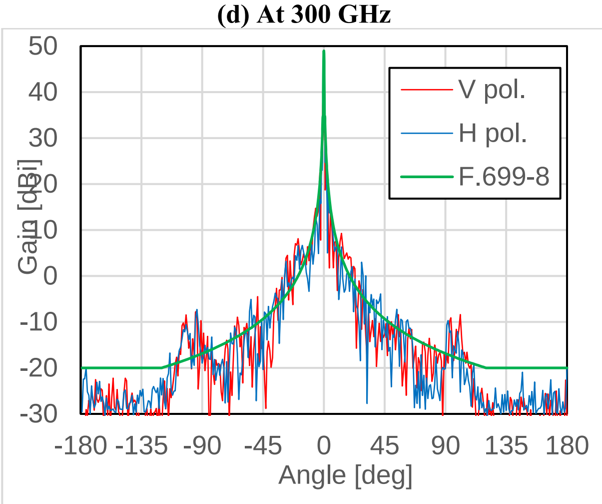

**(b) At 250 GHz**




**(c) At 275 GHz**




**(d) At 300 GHz**




**(e) At 330 GHz**

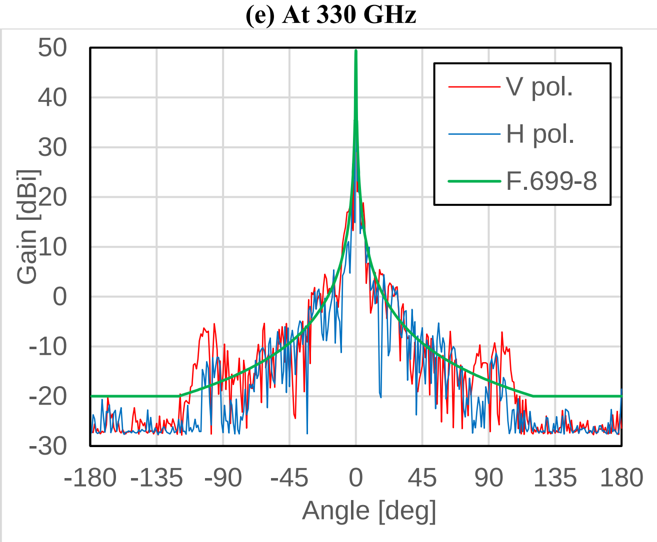
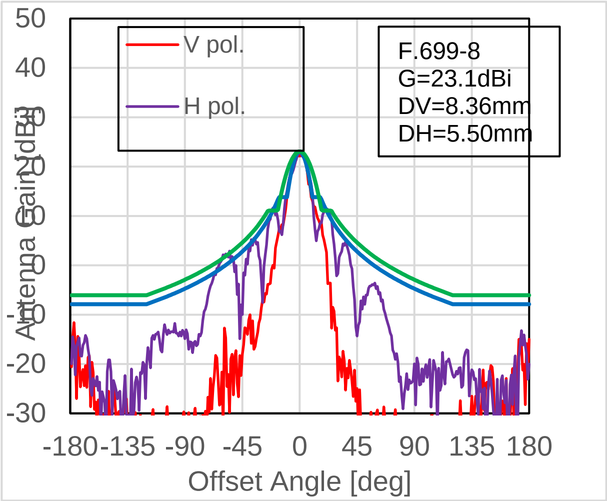


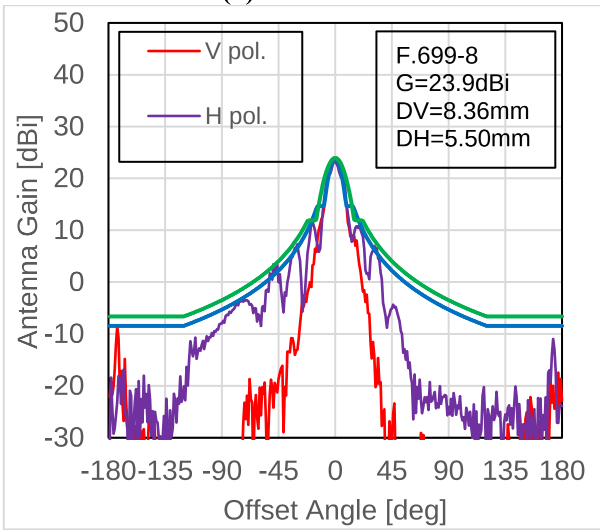
FIGURE 14

**Measured characteristics of a standard gain horn antenna (D/λ < 100, width = 8.36 mm, height = 5.5 mm), where two (green and blue) lines are calculated from Rec. ITU-R F.699-8***

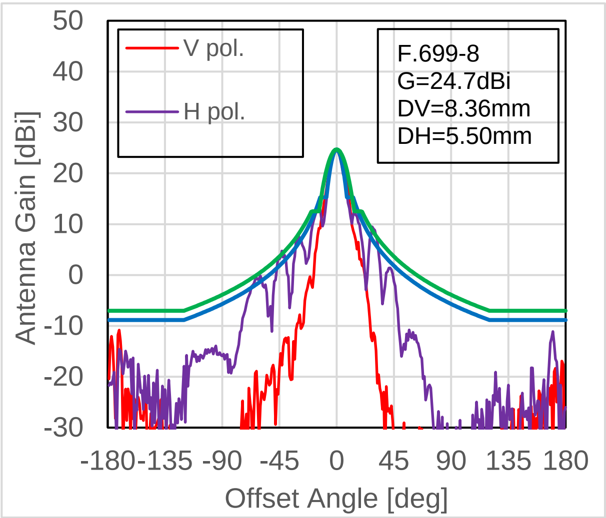
**(a) At 220 GHz**



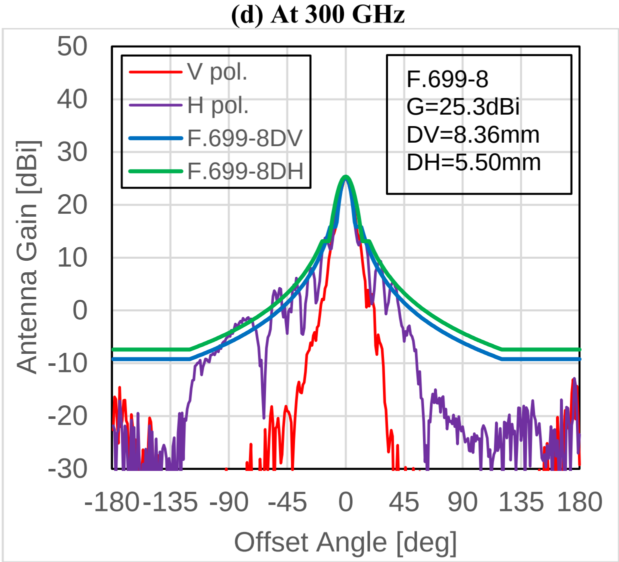

**(b) At 250 GHz**



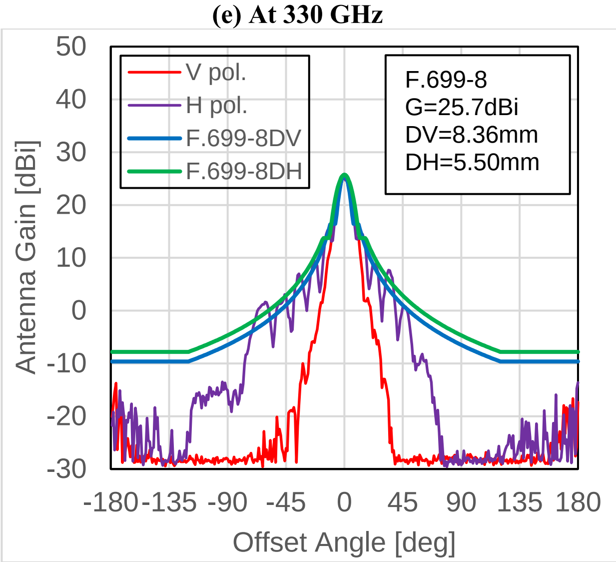

**(c) At 275 GHz**




**(d) At 300 GHz**




**(e) At 330 GHz**

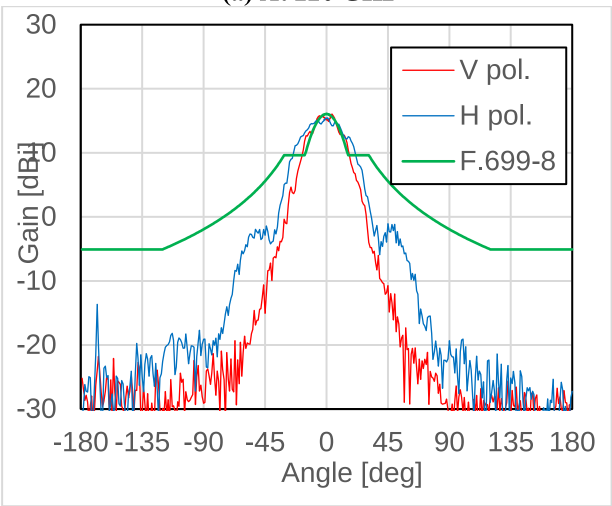



NOTE – DV and DH are used as an equivalent parameter of D (antenna diameter) for calculation and they do not specify any polarization characteristics.

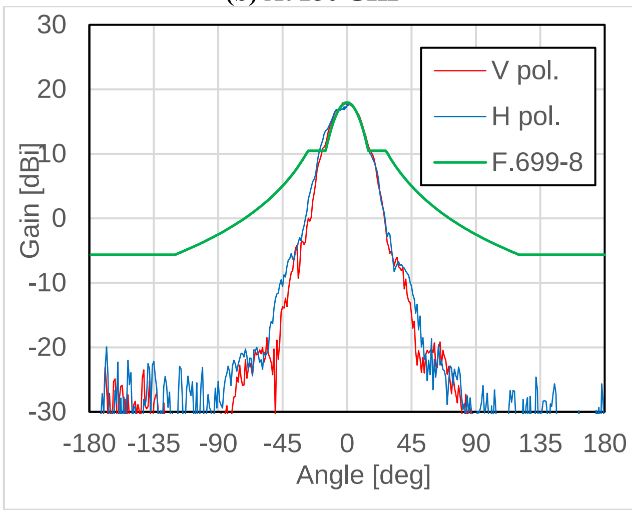
FIGURE 15

**Measured characteristics of corrugated horn antenna (D/λ < 100, diameter = 4.4 mm), where the green lines are calculated from Rec. ITU-R F.699-8**

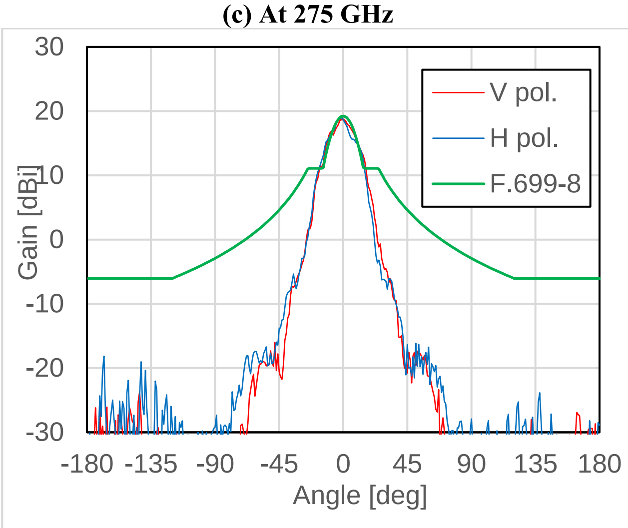
**(a) At 220 GHz**



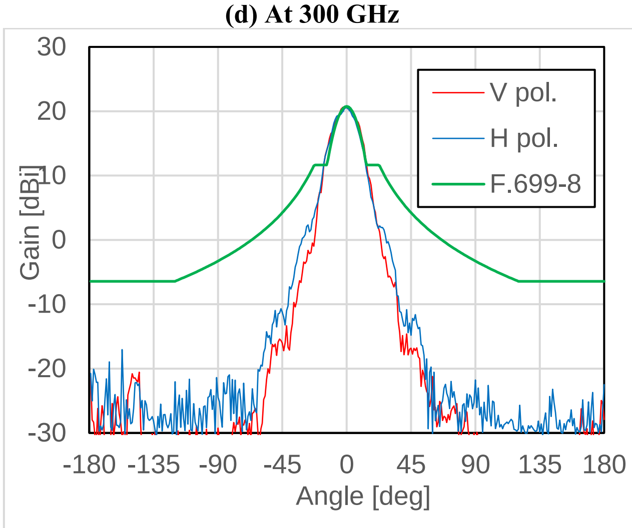

**(b) At 250 GHz**




**(c) At 275 GHz**




**(d) At 300 GHz**




**(e) At 330 GHz**

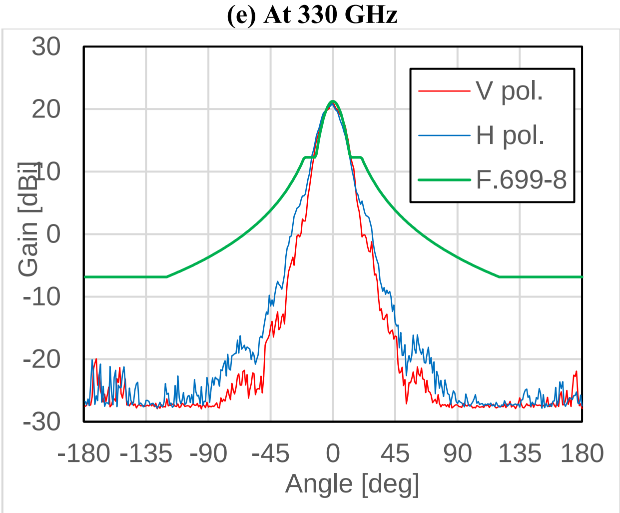


FIGURE 16

**Measured characteristics of offset parabola antenna (D/λ > 100, diameter = 109 mm), where the blue lines are calculated from Rec. ITU-R F.699-8**

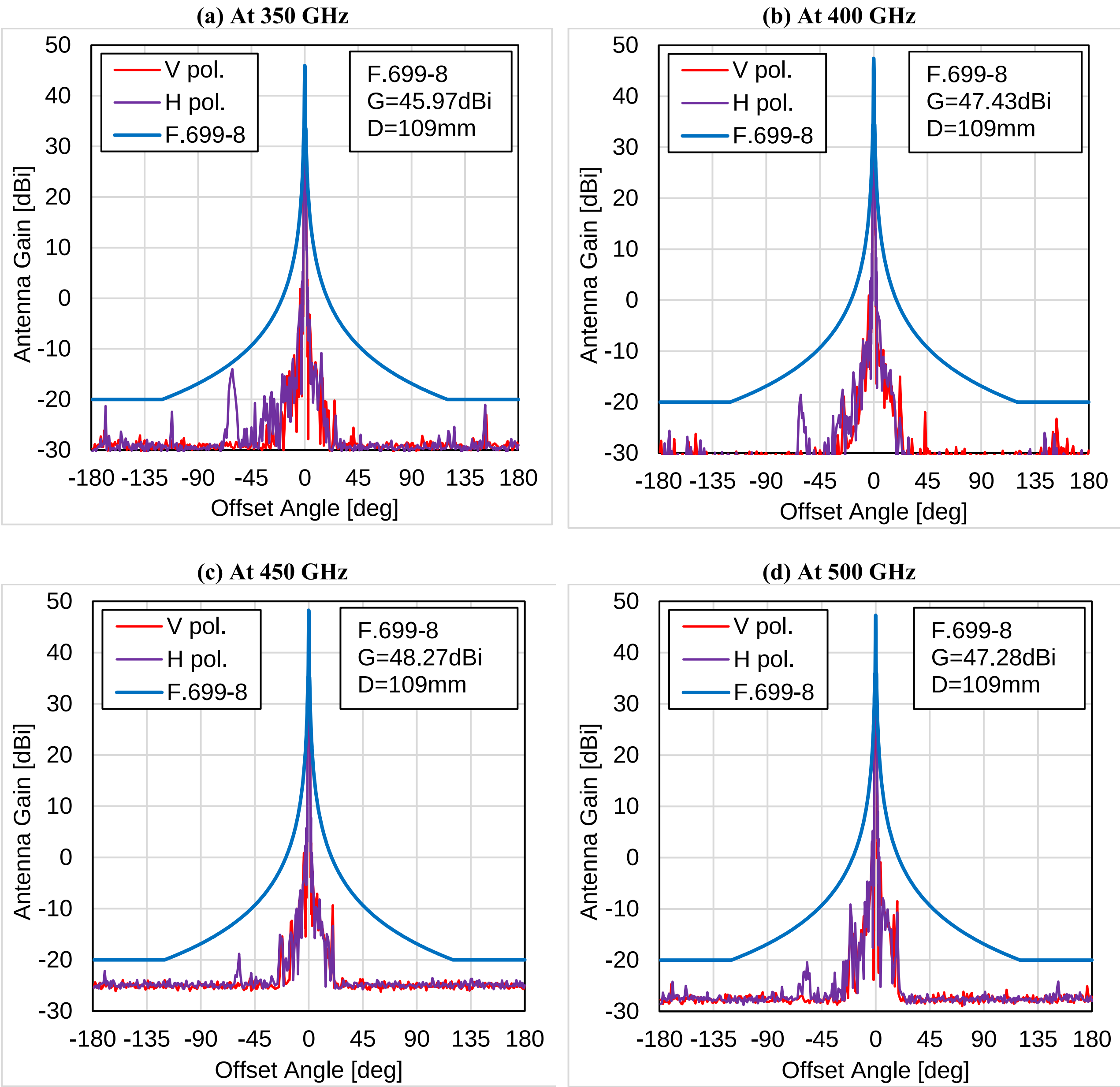
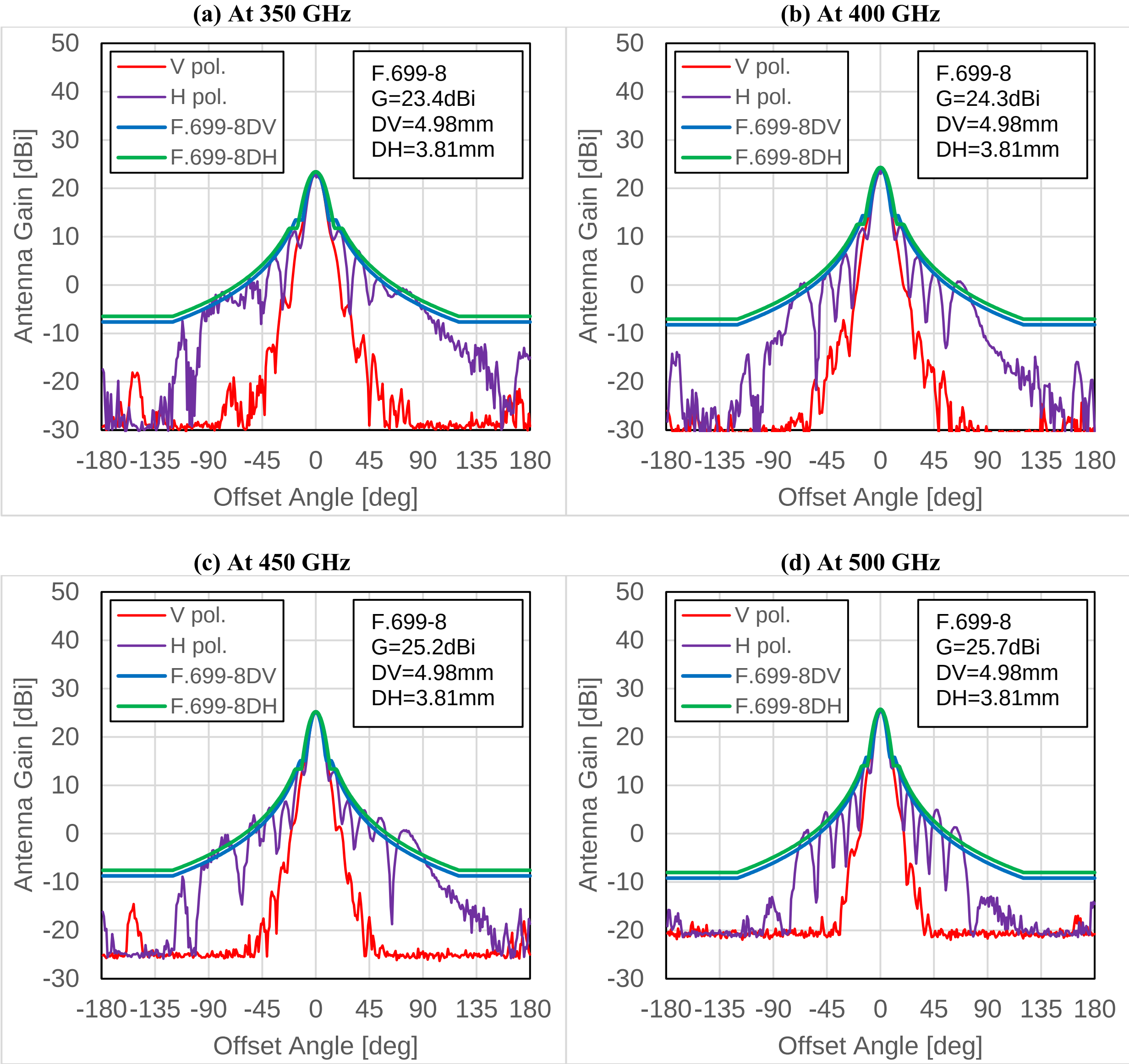


FIGURE 17

**Measured characteristics of standard gain horn antenna (D/λ < 100, width = 4.98 mm, height = 3.81 mm), where two (green and blue) lines are calculated from Rec. ITU-R F.699-8***

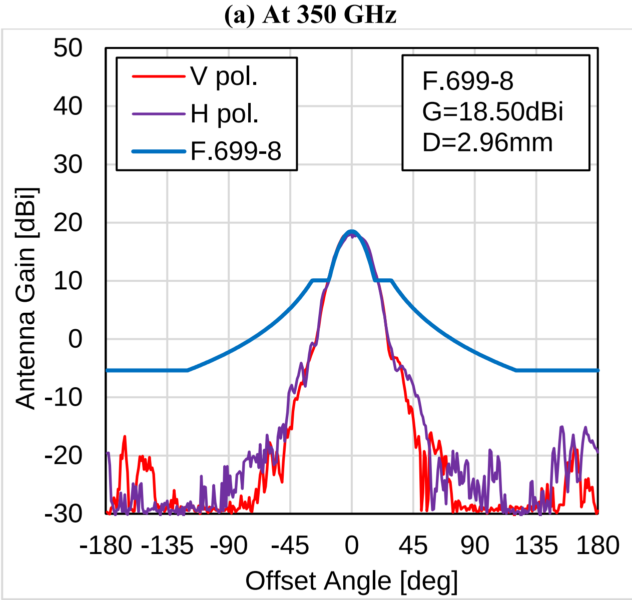



NOTE – DV and DH are used as an equivalent parameter of D (antenna diameter) for calculation and they do not specify any polarization characteristics.

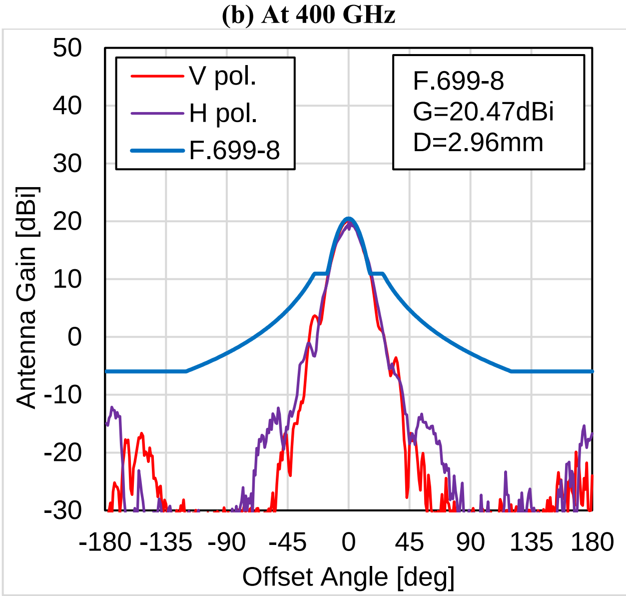
FIGURE 18

**Measured characteristics of corrugated horn antenna (D/λ<100, diameter = 2.96 mm), where the blue lines are calculated from Rec. ITU-R F.699-8**

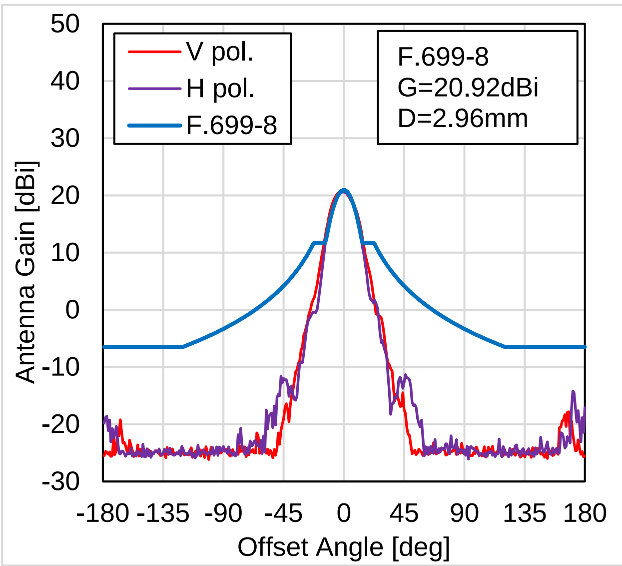
**(a) At 350 GHz**



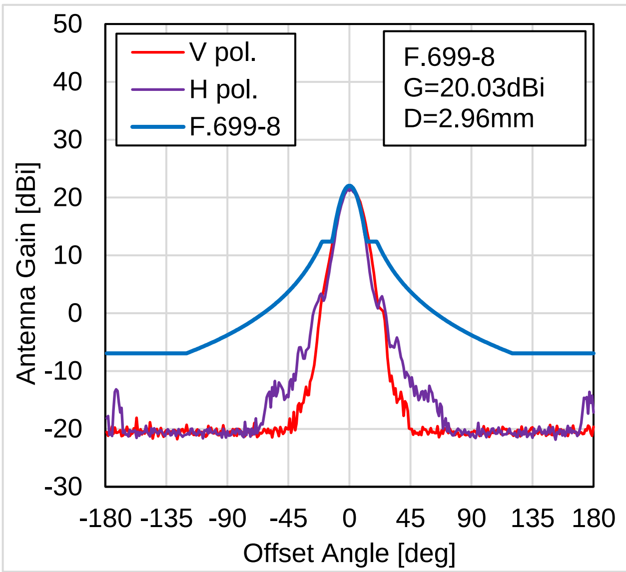

**(b) At 400 GHz**




**(c) At 450 GHz**




**(d) At 500 GHz**




# Annex 5

## A study on expected spectrum needs for Fronthaul

This Annex provides for information, a study on spectrum needs related to potential THz FS applications.

The fronthaul is defined as link connection between the base station baseband unit (BBU) and remote radio head (RRH), as introduced in Report ITU-R F.2393. Although the architecture, topology and transport requirements of IMT networks are found in Report ITU-R M.2375, spectrum needs for fronthaul are not clearly indicated. This study is focused on the spectrum needs for fronthaul depicted in Fig. 4, taking into account study results on capabilities of IMT-2020 described in Recommendation ITU-R M.2083 on the framework and the overall objectives for the future development of IMT for 2020 and beyond.

Recommendation ITU-R M.2083 specifies key parameters such as the total traffic throughput served per geographic area of 10 Mbit/s/$m^2$ and the user experienced data rate of 1 Gbit/s in hotspot areas. Fronthaul throughputs between BBU and RRH (illustrated in Fig. 4) is estimated by taking into account those two parameters and spectrum efficiency in the range of 2-10 (bit/s/Hz)[6] and SISO transmission of fronthaul. Table 6 summarizes estimated spectrum needs for fronthaul links, which is categorized into two groups. The spectrum needs for the first group (A1, B1, C1) and the second group (A2, B2, C2) are calculated from the number of users whose experienced data rate of 1 Gbit/s and the size of footprint whose total traffic is 10 Mbit/s/$m^2$, respectively. If the number of users in a small cell varies from 10 to 400, spectrum required to support a user experienced rate of 1 Gbit/s changes from 1 to 200 GHz depending on system spectrum efficiency determined from multilevel modulation schemes, RF channel aggregation/bonding, single/multi carriers and MIMO transmission technologies. Another example also indicates that spectrum needs of 0.1-200 GHz are estimated in the footprint range 100 $m^2 - 4 \times 10^4$ $m^2$ to support an area traffic capacity of 10 Mbit/s/$m^2$. Although spectrum needs shown in Table 6 depend on large numbers of parameters, it should be noted that the sufficient frequency bandwidth is required to support high-speed data traffic of fronthaul.

TABLE 6

**Estimated spectrum needs to support a user experienced data rate of 1 Gbit/s or a total traffic throughput served per geographic area of 10 Mbit/s/$m^2$ in a hotspot area specified in Rec. ITU-R M.2083**

| Example of hotspot | Number of users | Total traffic (Gbit/s) | Footprint ($m^2$) | Total traffic (Gbit/s) | Spectrum needs (GHz) |
|---|---|---|---|---|---|
| A1 | 10 | 10 | | | 1-5 |
| A2 | | | 100 | 1 | 0.1-0.5 |
| B1 | 100 | 100 | | | 10-50 |
| B2 | | | 104 | 100 | 10-50 |
| C1 | 400 | 400 | | | 40-200 |
| C2 | | | 4 × 104 | 400 | 40-200 |

NOTE − The spectrum efficiency of fronthaul link is assumed to be in the range 2-10 bit/s/Hz for estimation.

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[6] Those numbers are estimated from examples of spectrum efficiency of fixed wireless systems operating in the millimeter-wave bands provided in Report ITU-R F.2107 and Report ITU-R F.2323, as well as the presentation material of "Microwave and millimeter-wave technology overview and evolution introduction" at ITU-R Workshop on evolution of fixed service in backhaul support of IMT 2020/5G held on April 29, 2019.