International Telecommunication Union

ITU-R

Radiocommunication Sector of ITU

Report ITU-R M.2417-0

(11/2017)

# Technical and operational characteristics of land-mobile service applications in the frequency range 275-450 GHz

M Series

Mobile, radiodetermination, amateur and related satellite services

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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, 2018

REPORT ITU-R M.2417-0

# Technical and operational characteristics of land-mobile service applications in the frequency range 275-450 GHz

(2017)

## 1 Introduction

Due to the progress of RF integrated devices and circuits operating in the frequency band above 275 GHz, the contiguous frequency bands become available for land-mobile service applications. Applications operating in the frequency band above 275 GHz, such as KIOSK downloading, ticket gate downloading, and intra-rack and intra-chip communications, are introduced, and ultra-high-speed data transmission between terminals whose transmission distance is in the order of centimetres becomes 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 275-1 000 GHz. Although the use of the frequency range 275-1 000 GHz by the passive services does not preclude the 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.

## 2 Scope

This Report provides the technical and operational characteristics of land-mobile service applications in the frequency range 275-450 GHz for sharing and compatibility studies.

## 3 Related Recommendations and Reports

| | |
|---|---|
| Recommendation ITU-R M.2003: | Multiple Gigabit Wireless Systems in frequencies around 60 GHz |
| 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 SM.2352-0: | Technology trends of active services in the frequency range 275-3 000 GHz |

## 4 List of acronyms and abbreviations

| | |
|---|---|
| CPMS | Close proximity mobile system |
| OFDM | Orthogonal Frequency-Division Multiplexing |
| SC | Single-Carrier |

## 5 Frequency ranges

As the unit of frequency is Hertz (Hz), frequencies are expressed in Gigahertz (GHz), above 3 GHz, up to and including 3 000 GHz in accordance with Radio Regulations. However, the Gigahertz frequency ranges are subdivided into three ranges as shown in Table 1.

TABLE 1

**Frequency bands above 3 GHz**

| Band number | Frequency range (lower limit exclusive, upper limit inclusive) | Corresponding metric subdivision |
|---|---|---|
| 10 | 3 to 30 GHz | Centimetric waves |
| 11 | 30 to 300 GHz | Millimetric waves |
| 12 | 300 to 3 000 GHz | Decimillimetric waves |

## 6 Overview of land-mobile service applications in the frequency range 275-450 GHz

### 6.1 Close proximity mobile systems in the frequency band on 275-325 GHz and 275-450 GHz

#### 6.1.1 KIOSK downloading mobile system

In order to enjoy movies, news, magazines, and music by smart phones and tablet terminals, the terminals should have high-data-speed transmission capability and be wirelessly connected to the network to download various contents from the content providers.

Several wireless devices provide wireless broadband connectivity, but the maximum speed of these devices is limited by operational and environmental conditions of the systems, and the actual observed transmission rate is sometimes far from the specifications. KIOSK systems, as shown in Fig. 1, are introduced to download heavy contents to the user terminals wirelessly.

KIOSK terminals are connected to the network through wired systems and located in public areas such as train stations, airports, and shopping malls. The distance between the user and the KIOSK terminal is typically less than 10 cm, and contents are downloaded and/or uploaded to/from user terminals. In order to download a two-hour movie whose size is about 900 MB to the user terminal, the required downloading times are 1.6 s, 1.1 s, and 0.11 s if effective throughput of devices are 4.6 Gbit/s, 6.9 Gbit/s and 66 Gbit/s, respectively. The data transfer speed in the range around 100 Gbit/s is achieved applying multi-modulation method and carrier frequencies above millimetre waves. If the large contiguous bandwidth is feasible in the frequency band above 275 GHz, a simple modulation scheme such as BPSK, QPSK can be applied to transmit heavy contents in a short time period.

FIGURE 1

**KIOSK downloading mobile system**

### 6.1.2 Ticket gate downloading mobile system

The ticket gate downloading devices have two functions, i.e. fare-paying and large-file downloading functions. Figure 2 illustrates the user terminal for paying fare and simultaneously downloading video contents, such as news, movies, etc. In order to download the contents at the ticket gate, high-speed data transmission capability is required for both mobile terminal and ticket gate station. The transmission range covered by these devices is limited to about 10 cm to avoid interference between mobile terminals. To meet these requirements, the spectrum above 275 GHz whose features are a broadband bandwidth and short transmission distance can be utilized by this type of application.

FIGURE 2

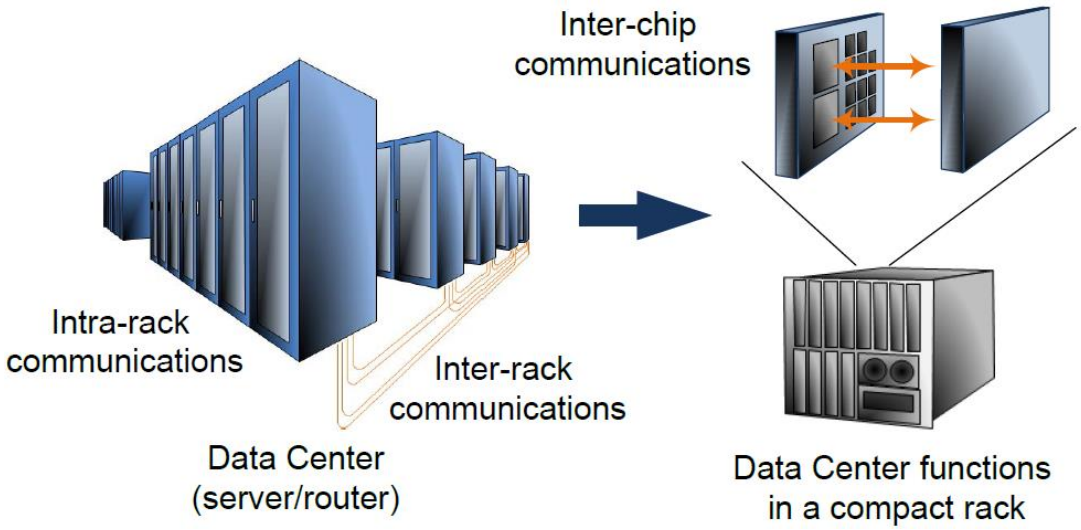
**Ticket gate downloading mobile system**

### 6.1.3 Inter-chip communication system

There has been increasing interest in applying wireless links for data centres to replace optical wired connections, because the current device technologies can make it possible to reduce the size of racks of servers/routers in data centre. Figure 3 shows how these devices can be integrated into the compact rack of servers/routers. If the same cabling connections are used in the compact rack, cabling and cooling problems in the rack cannot be avoided. The inter-chip communication between boards in the rack can eliminate cabling and cooling problems in the rack. The frequency band above 275 GHz is suitable for inter-chip communication because the antenna diameter is inversely proportional to the operational frequency.

FIGURE 3

**Inter-chip communication system**



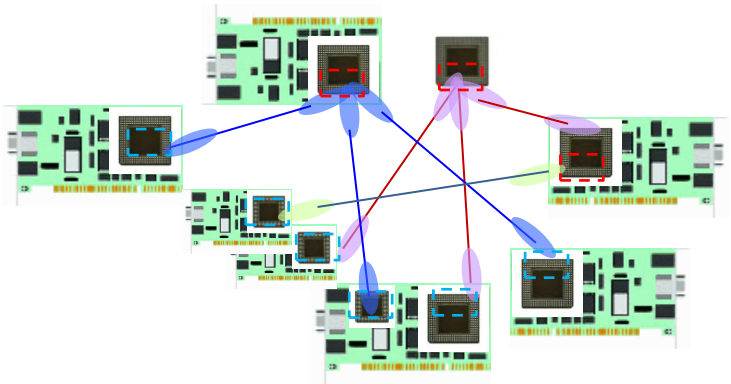

## 6.2 Intra-device communications

In intra-device communications, one or more communication links are operated within a device. High speed terahertz wireless links could connect two or more Printed Circuit Boards (PCBs) or even chips on the same PCB inside a device. Typically, these devices will be shielded, not only preventing emission of THz-radiation but also blocking incoming THz signals.

The terahertz band is large, hence several channels could be used in a small area (within one device). The following figure illustrates the envisaged concept of THz point-to-point communications between boards, where the colour of the beams indicates different frequencies.

FIGURE 4

**Intra-device communication system**

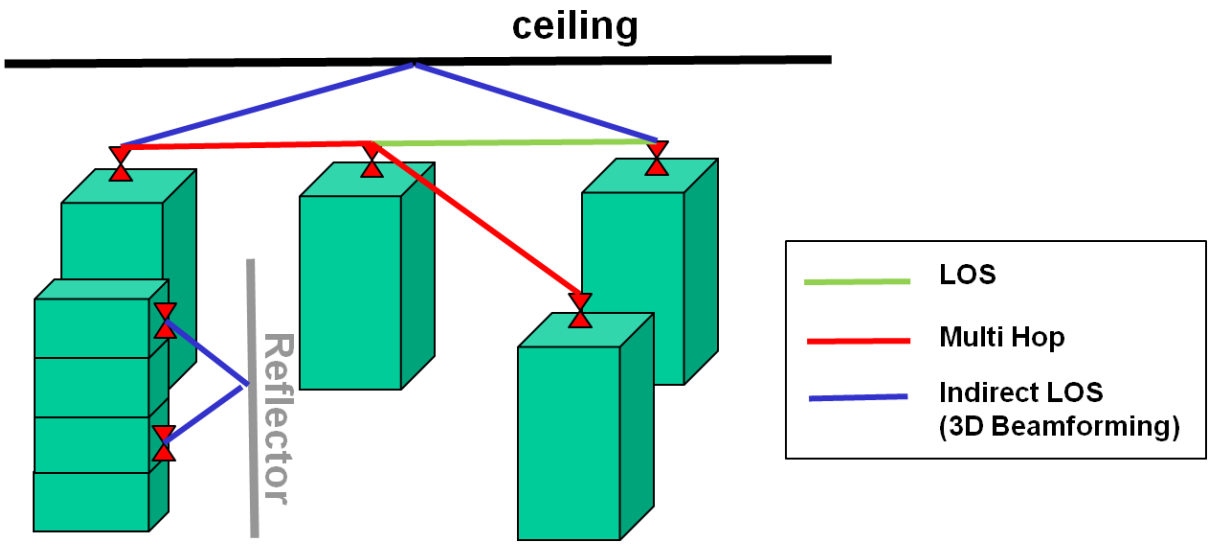


## 6.3 Wireless links for data centers

The goal of the introduction of wireless data links in addition to the existing fibres is to provide flexibility by providing reconfigurable routes within a data centre. In the figure some examples are illustrated between or inside the server racks (green colour boxes) for possible line-of-sight (LOS) or multi hop links.

FIGURE 5

**Wireless links for data centre**




## 7 System characteristics

### 7.1 Close proximity mobile systems (CPMSs) operating in the frequency range 275-450 GHz

Technical and operational characteristics for close proximity mobile systems planned to operate in the band 275-325 GHz and in the band 275-450 GHz are shown in Table 2.

Two possible radio-frequency channel arrangements for land-mobile service applications operating in the frequency range 275-450 GHz are shown in Annex 1. Annex 2 contains the measurement results of antenna patterns at 300 GHz.

The relationship between transmission data rate and total antenna gain of transmitter and receiver under the spectrum efficiency of 1 b/s/Hz is shown in Annex 5 to clearly indicate that the multilevel modulation is indispensable to transmit high-speed data to CPMS devices.

TABLE 2

**Technical and operational characteristics of land-mobile CPMS applications in the frequency range 275-450 GHz for use in sharing and compatibility studies**

| Parameters | Values | |
|---|---|---|
| | CPMS application | Enhanced CPMS application |
| Frequency band (GHz) | 275-325 | 275-450 |
| Deployment density[1] | 0.6 devices/km$^2$ | 0.6 devices/km$^2$ |
| Tx output power density (dBm/GHz) | -3.8….6.9 | -10.1…6.7 |
| Max. e.i.r.p. density(dBm/GHz) | 26.2…...36.9 | 19.9…36.7 |
| Duplex Method | FDD/TDD | FDD/TDD |

TABLE 2 (*end*)

| Parameters | Values | |
|---|---|---|
| | **CPMS application** | **Enhanced CPMS application** |
| Modulation | OOK-SC/BPSK-SC/QPSK-SC/16QAM-SC/64QAM-SC BPSK-OFDM/QPSK-OFDM/ 16QAM-OFDM/32QAM-OFDM/64QAM-OFDM | OOK-SC/BPSK-SC/QPSK-SC/16QAM-SC/64QAM-SC/8PSK-SC/8APSK-SC BPSK-OFDM/QPSK-OFDM/ 16QAM-OFDM/32QAM-OFDM/64QAM-OFDM |
| Average distance between CPMS fixed and mobile devices (m) | 0.1 | 0.1 |
| Maximum distance between CPMS fixed and mobile devices (m) | 1 | 1 |
| Antenna height (m) | 1…2 | - |
| Antenna beamwidth (degree) | 3…10 | 5…90 |
| Antenna elevation (degree) | ±90 | ±90 |
| Frequency reuse | 1 | 1 |
| Antenna type | Horn | Horn |
| Antenna pattern | Gaussian | Gaussian |
| Antenna polarization | Linear | Linear |
| Indoor CPMS fixed device deployment (%) | 100 | 90 |
| Feeder loss (dB) | 2 | 2 |
| Maximum CPMS fixed/mobile device output power (dBm) | 10 | 10 |
| Channel bandwidth (GHz) | 2.16/4.32/8.64/12.96/17.28/ 25.92/51.8 | 2.16/4.32/8.64/12.96/17.28/25.92/51.84/69.12/103.68 |
| Transmitter spectrum mask | see Annex 4 | see Annex 4 |
| Maximum CPMS fixed device antenna gain (dBi) | 30 | 30 |
| Maximum CPMS mobile device antenna gain (dBi) | 15 | 15 |
| Maximum CPMS fixed device output power (e.i.r.p.) (dBm) | 40 | 40 |
| Maximum CPMS mobile device output power (e.i.r.p.) (dBm) | 25 | 25 |
| Average activity factor (%) | 0.76 | 0.2 |
| Average CPMS fixed device power (dBm (e.i.r.p)) | 20 | 20 |
| Receiver noise figure typical (dB) | 15 | 15 |

[1] Detailed information of deployment density is shown in Annex 3.

## 7.2 Intra-device communications

Technical and operational characteristics for wireless THz intra-device links planned to operate in the band 275-450 GHz are shown in Table 3. As an example, inside a camera the data rate between the optical sensor and the image processor is 72 Gbit/s for an 8K video with a frame rate of 60 Hz and a resolution of 12 bit for each color [4]. Therefore, a bandwidth of 50 GHz is sufficient to provide such data rate with a simple QPSK modulation. Annex 4 proposes a Transmitter Spectrum Mask. Annex 2 contains the measurement results of antenna patterns at 300 GHz.

TABLE 3

**Technical and operational characteristics of wireless THz intra-device links in the frequency band 275-450 GHz for use in sharing and compatibility studies**

| Parameter | Value |
|---|---|
| Frequency band (GHz) | 275-450 |
| Deployment density | 0.23(1) /km$^2$ |
| Maximum device output power (dBm) | 10 |
| Maximum device output power (e.i.r.p.) (dBm) | 30 |
| Maximum Tx output power density (dBm/GHz) | -10.1…6.7 |
| Maximum e.i.r.p. density (dBm/GHz) | 19.9…36.7 |
| Indoor Deployment (%) | 50 |
| Duplex Method | TDD, FDD, SDD |
| Modulation | OOK-SC/BPSK-SC/QPSK-SC/16QAM-SC/64QAM-SC 8PSK-SC/8APSK-SC |
| Maximum distance between devices | <1 m |
| Antenna height (m) | 1…3 |
| Antenna beamwidth (degree) | 15…180 (expected) |
| Frequency reuse | 1 |
| Antenna pattern | Gaussian |
| Antenna polarization | Linear |
| Channel bandwidth (GHz) | 2.16/4.32/8.64/12.96/17.28//25.92/ 51.84/69.12/103.68 |
| Maximum device antenna gain (dBi) | 20 |
| Typical expected device antenna gain (dBi) | 6 |
| Maximum device activity (%) | 100 |
| Receiver noise figure typical (dB) | 10(2) |

(1) The deployment density is estimated as an average based on assuming that everyone thousandths citizen in Germany is using such a device. In highly populated cities the density could increase to e.g. 3.95/km$^2$ under the same assumptions.

(2) Also systems with a noise figure as low as 8 dB have been reported in publications. This value is a worst case of the published parameters.

### 7.3 Wireless links in data centers

Technical and operational characteristics for wireless links in data centers planned to operate in the band 275-450 GHz are shown in Table 4. A bandwidth of 50 GHz is necessary to achieve a data rate of at least 100 Gbit/s with a simple QPSK modulation and enable compatibility with 100 Gbit/s Ethernet links. Annex 2 contains the measurement results of antenna patterns at 300 GHz. Annex 4 proposes a Transmitter Spectrum Mask.

TABLE 4

**Technical and operational characteristics of wireless links in data centers in the frequency band 275-450 GHz for use in sharing and compatibility studies**

| Parameter | Values |
|---|---|
| Frequency band (GHz) | 275-450 |
| Deployment density | 0.07(1) /km$^2$ |
| Maximum device output power (dBm) | 10 |
| Maximum device output power (e.i.r.p.) (dBm) | 40 |
| Tx output power density (dBm/GHz) | -10.1…6.7 |
| e.i.r.p. density (dBm/GHz) | 9.9…26.7 |
| Duplex Method | TDD, FDD, SDD |
| Modulation | OOK-SC/BPSK-SC/QPSK-SC/16QAM-SC/64QAM-SC 8PSK-SC/8APSK-SC |
| Maximum distance between devices | 100 m |
| Antenna beamwidth (degree) | < 25 (expected) |
| Frequency reuse | 1 |
| Antenna pattern | Gaussian |
| Antenna polarization | Linear |
| Indoor deployment (%) | 100 |
| Channel bandwidth (GHz) | 2.16/4.32/8.64/12.96/17.28/ 25.92/51.84/69.12/103.68 |
| Maximum device antenna gain (dBi) | 30 |
| Maximum device activity (%) | 100 |
| Receiver noise figure typical (dB) | 10[2] |

(1) Based on an evaluation in Germany [3] there are 2170 data centres with more than 100 servers. Assuming that in each 10 links are deployed and taking the area of Germany into account a density of approx. 0.07 links per k m$^2$

(2) Also systems with a noise figure as low as 8 dB have been reported in publications. This value is a worst case of the published parameters.

## 8 Summary of spectrum needs for land-mobile service applications in the 275-450 GHz frequency range

The spectrum needs for the land-mobile service applications contained in § 7 of this Report are 50 GHz of total spectrum bandwidth. Given the current status of technologies and applications, a total spectrum bandwidth of 50 GHz is sufficient to provide high-data rate transmissions between CPMS

devices for KIOSK applications, as well as, intra device applications, and wireless links for data centers.

TABLE 5

**Spectrum needs for land-mobile service applications in the 275-450 GHz frequency range**

| Applications | Spectrum needs |
|---|---|
| CPMS application | 50 GHz (see Annex 5) |
| Intra-device communication | 50 GHz (see Note 1) |
| Wireless links for data centers | 50 GHz (see Note 1) |

*Note* 1: For intra-device communication and data center wireless link center applications operating simultaneously in close proximity, different channels should be used.

## 9 Bibliography

[1] APT/AWG/REP-66, APT Report on "Short Range Radiocommunication Systems and Application Scenarios Operating in the Frequency Range 275-1 000 GHz".

[2] IEEE802.15-15-0109-06-003e, "TG3e Technical Guidance Document (TGD)".

[3] Study of the existing data centres in Germany by the German Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, http://www.umweltbundesamt.de/sites/default/files/medien/461/publikationen/4037.pdf

[4] IEEE802.15-14-0304-16-003d, "TG3d Applications Requirements Document (ARD)".

**Annexes:** 5

# Annex 1

## Examples of radio-frequency channel arrangement

In Figs 6 and 7, two examples of channel arrangements are illustrated. The basic channel bandwidth which is widely used for Radio LAN is 2.16 GHz, and the other channels bandwidths are 4.32 GHz, 8.64 GHz, 12.96 GHz, 17.28 GHz, 25.92 and 51.8 GHz. The extra channels are embedded as additional channels in the remaining frequency band. In Fig. 7 the Radio-frequency channel arrangement described in IEEE Std 802.15.3d™-2017 is provided as an example. The frequency range considered by IEEE begins at approximately 252 GHz though WRC-19 agenda item 1.15 covers only frequencies above 275 GHz.

FIGURE 6

**Radio-frequency channel arrangement for CPMS application**

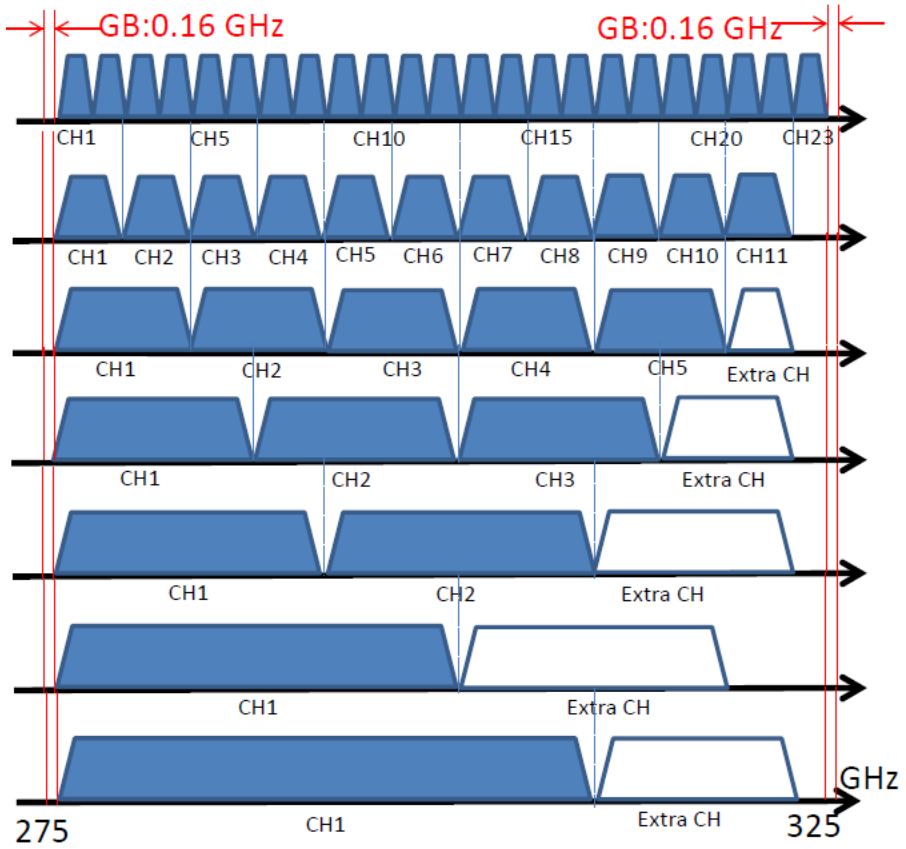
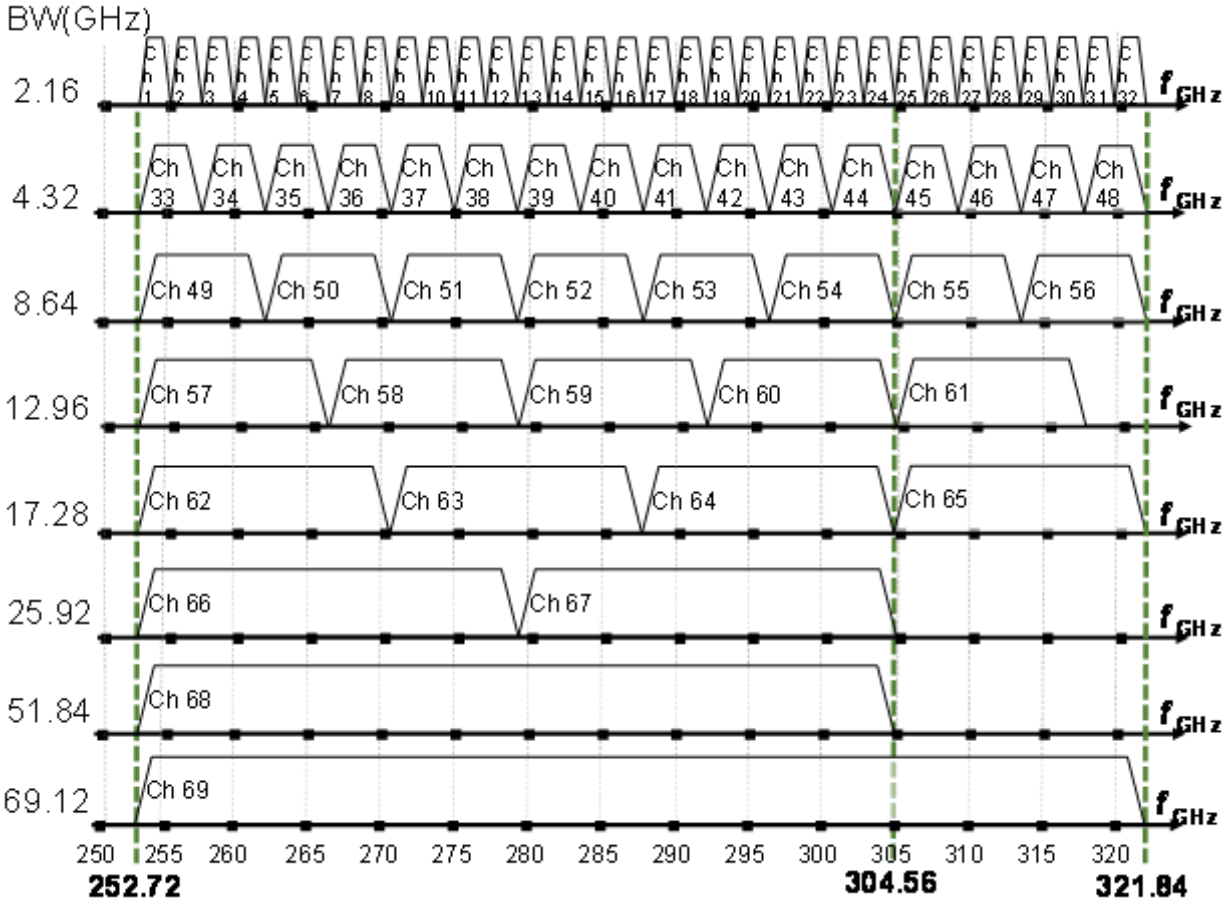


FIGURE 7

**Radio-frequency channel arrangement example for CPMS, intra device communications and wireless links in data centres, which is currently described in IEEE Std 802.15.3d™-2017**



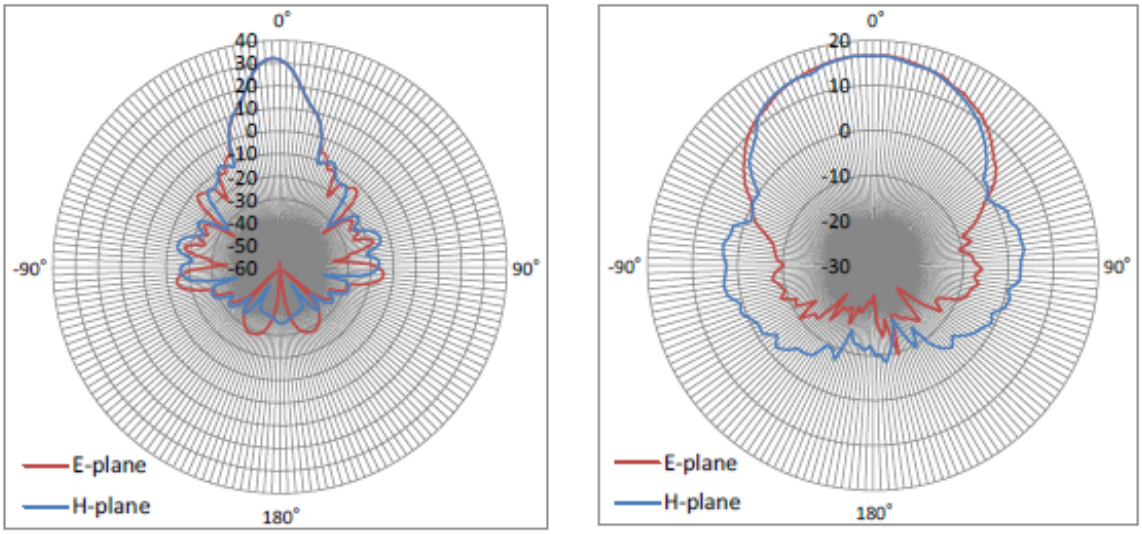
# Annex 2

## Measurement results of antenna patterns at 300 GHz

FIGURE 8

**Measured characteristics of 30-dBi and 15-dBi antennas**

**(a) 30-dBi Horn antenna** **(b) 15-dBi CPMS antenna**




# Annex 3

## Deployment density and activity factor of KIOSK downloading systems

KIOSK downloading system will be used in stations, airport terminals, convenience stores. It will mainly be deployed in an indoor environment. Since the number of stations and airports is much smaller than that of convenience stores, this report summarizes deployment densities of KIOSK terminals equipped at convenience stores. The total number of convenience stores in Japan is 55,129, but 19,571 convenience stores, i.e. 35% of all stores, are distributed in the Kanto area whose size is 32,420 km$^2$. This concludes that deployment density in Kanto is 0.6 stores/km$^2$ and that in Tokyo is 3.28 stores/km$^2$, which is the maximum density in Japan.

The average number of customers of major convenience stores in Japan is about 1,000, but the busiest store, which is located nearby stations in Tokyo, has a peak number of customers of nearly 2,000. The following assumption is introduced for estimation of the activity factor/store:

1. Average number of customers of convenience store 1,000
2. Percentage of customers bringing CPMS devices 20%
3. Downloaded 2-hour movies by one customer 2
4. CPMS device throughput 6.9 Gb/s (see Table 4)
5. Intrinsic time of downloading by one customer 2.2 s

6. Total time of downloading 440 s
7. Typical opening hour of convenience store 7 am-11 pm (57,600 s)
8. Estimated activity factor/store 0.76 %

TABLE 6

**Numbers of convenience stores and stations in Kanto area**

| Metropolitan and Prefecture | Number of convenience store | Size ($km^2$) |
|---|---|---|
| Tokyo | 7,183 | 2,190 |
| Kanagawa | 3,765 | 2,415 |
| Saitama | 2,833 | 3,797 |
| Chiba | 2,637 | 5,157 |
| Ibaraki | 1,315 | 6,096 |
| Gunma | 950 | 6,362 |
| Tochigi | 888 | 6,408 |
| Kanto area[1] | 19,571 | 32,425 |

[1] Kanto is the regional name of Tokyo metropolitan plus the above 6 prefectures.

TABLE 7

**Estimated downloading time of magazine and movie**

| Content type | File size (MB) | Download time (s) | | |
|---|---|---|---|---|
| | | Throughput 4.6 Gb/s | Throughput 6.9 Gb/s | Throughput 66 Gb/s |
| Magazine | 300 | 0.5 | 0.3 | 0.03 |
| Movie (2 hour) H.265 (Hi-definition) | 900 | 1.6 | 1.1 | 0.11 |

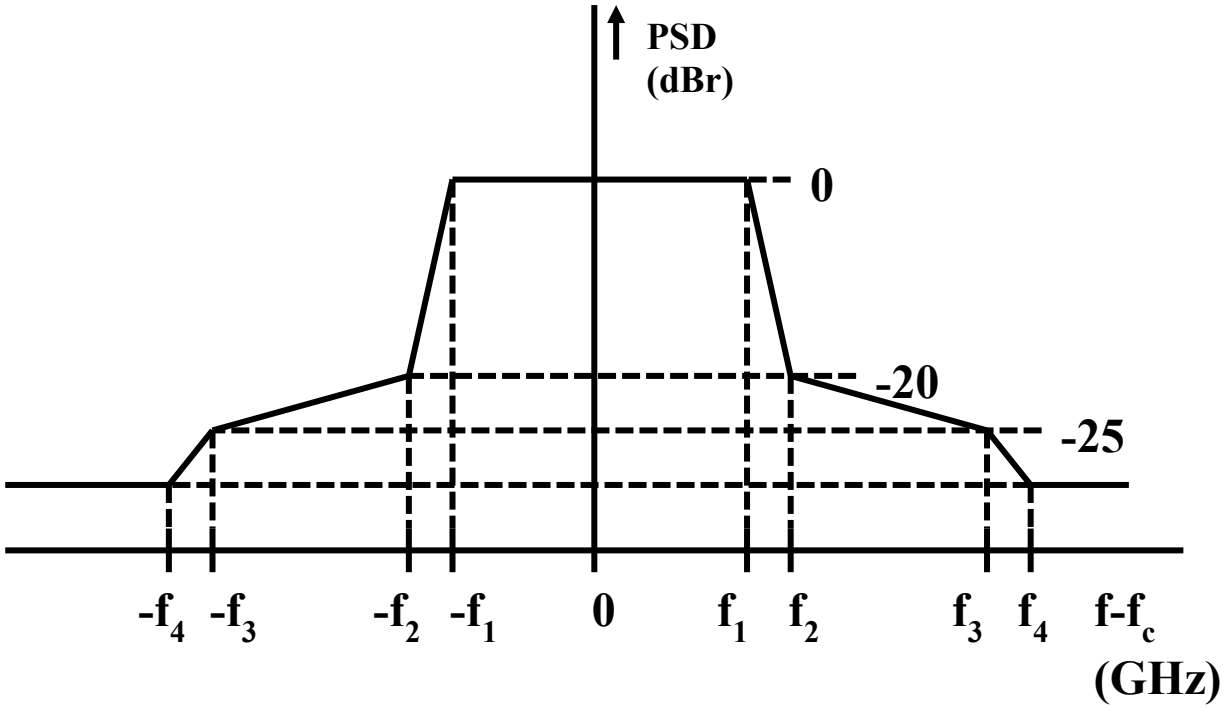
# Annex 4

## Example of a Transmitter Spectrum Mask

The transmitter spectrum mask described in IEEE Std 802.15.3d™-2017 is shown as an example in Fig. 9 and Table 8.

FIGURE 9

**Generic transmit spectral mask**




The parameters of the mask expressed in Power Spectral Density (PSD) indicated in Fig. 9 are defined in Table 8.

TABLE 8

**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 5

## Information on link budget of KIOSK downloading system

One example of the link budget is shown in Fig. 10. The transmitting power, carrier frequency, and transmission distance are 10 dBm, 300 GHz and 1 m, respectively, as indicated in Table 2. The total antenna gain of transmitter and receiver over 45 dBi is required to attain a data rate of 50 Gbit/s by ASK with FEC if BER is less $10^{-9}$. Since the spectrum efficiency is 1 b/s/Hz in this case, a bandwidth of 50 GHz is needed to attain 50 Gbit/s. If the maximum bandwidth of 50 GHz is identified for such applications as discussed in § 7.1, the multilevel modulation scheme such as QPSK and 16QAM whose spectrum efficiency over 2 bit/s/Hz is preferable to increase the transmission data rate.

FIGURE 10

**Relationship between data rate and total antenna gain under the condition of spectrum efficiency of 1 bit/s/Hz**

| Quantity | Symbol | Value |
|---|---|---|
| Transmitting power | $P_t$ | **10 dBm** |
| Carrier frequency | $f_c$ | 300 GHz |
| Wavelength | $\lambda_c$ | 1 mm |
| Distance | $d$ | **1 meter** |
| Atmospheric attenuation | $\alpha_a$ | 0.1 dB/m @$f_c$ |
| Noise spectral density | $N_0$ | -178 dBm/Hz |
| Spectral efficiency | | 1 bps/Hz |
| Noise bandwidth | $B$ | Data rate × spectral efficiency |
| **Total noise figure** | **NF** | **15 dB** |
| System margin | M | 10 dB |