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ITU-APT Foundation of India (IAFI[1])

PROPOSED REVISION TO WORKING DOCUMENT TOWARDS A PRELIMINARY DRAFT REVISION OF APT REPORT ON POINT-TO-POINT RADIOCOMMUNICATION SYSTEMS OPERATING IN THE FREQUENCY RANGE 252-296 GHZ

1. Introduction

During AWG-26, Japan submitted Work Plan and outline Working Document for developing a new APT report on point-to-point radiocommunication system operating in the frequency band 252-296 GHz. Later during AWG-27, China and Japan proposed working documents and based on the discussion, TG FWS/GBRS developed the Working Document. During AWG-28, further modifications were suggested by Japan and China. During AWG-29, Japan and China suggested further updates to upgrade the working document to develop draft APT report. Draft APT report was developed as AWG-29/Out-21 (APT/AWG/REP-118). No progress was made during AWG-30. During AWG-31, Japan proposed to revise the APT report APT/AWG-REP-118. TG FWS/GBRS updated the report (AWG-31/TMP-12) and now same is under consideration during the AWG-32 meeting.

2. Proposal

This contribution proposes some further editorial revisions to the working document as contained in AWG-31/TMP-12. With these edits, this document can be upgraded and approved.

[1] IAFI is an affiliate member of APT.

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WORKING DOCUMENT TOWARDS A DRAFT REVISION OF APT REPORT ON POINT-TO-POINT RADIOCOMMUNICATION SYSTEMS OPERATING IN THE FREQUENCY RANGE 252-296 GHZ

Table of Contents

1. Introduction

APT Report on short range radiocommunication systems and application scenarios operating in the frequency range 275-1000 GHz was published in 2016, which introduces THz applications such as KIOSK and tollgate downloading, chip-to-chip communication link for data center, super high vision (4K/8K) video transmission and wireless LAN, and provides transceiver technologies based on integrated circuits. The information provided by this Report was helpful to develop APT Position on WRC-19 agenda item 1.15 during the study cycle 2015-2019.

At WRC-19, a new footnote RR No. **5.564A** which identifies four frequency bands (275-296 GHz, 306-313 GHz, 318-333 GHz and 356-450 GHz) for land mobile service (LMS) and fixed service (FS) applications was added in Radio Regulations. A total bandwidth of 137 GHz will be globally used for LMS applications such as IMT-2020 beyond without specific conditions to protect Erath exploration-satellite service (EESS) (passive) applications whose frequencies are identified in accordance with RR No. **5.565**.

The band 252-275 GHz is already allocated for mobile and fixed services in accordance with Article 5, Chapter II in Radio Regulations. The total bandwidth of 44 GHz can be used for LMS and FS applications such as point-to-point radiocommunication systems. Such broadband spectrum resources in the frequency range 252-296 GHz brings the possibility of ultra-high-capacity point-to-point radiocommunication systems which can transmit ultra-high-speed data rate over 100 Gbit/s.

This Report overviews the point-to-point radiocommunication technologies including antennas and application operating in the frequency range 252-296 GHz.

2. Scope

This Report provides advancements of technologies for use of point-to-point radiocommunication systems in the frequency range 252-296 GHz and also encourages APT member countries to develop such radiocommunication technologies for the future deployment of high-capacity point-to-point links.

3. References

Report ITU-R F.2416	Technical and operational characteristics and applications of the point-to-point fixed service applications operating in the frequency band 275-450 GHz
Report ITU-R M.2417	Technical and operational characteristics and applications of the land mobile service operating in the frequency band 275-450 GHz
Report ITU-R SM.2352	Technology trends of active services in the frequency range 275-3 000 GHz
Report ITU-R SM.2450	Sharing and compatibility studies between land-mobile, fixed and passive services in the frequency range 275-450 GHz
APT/AWG/REP-66	Short range radiocommunication systems and application scenarios operating in the frequency range 275-1000 GHz

Recommendation 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

4. Abbreviations and acronyms

BS Base station

FS Fixed service

LAN Local area network

LMS Land mobile service

RRH Remote radio head

5. Regulatory information

This section provides Table of Frequency Allocation in the frequency range 248-3 000 GHz, RR Nos. **5.564A** and **5.565**, as follows:

248-3 000 GHz

Allocation to services		
Region 1	**Region 2**	**Region 3**
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	
265-275	FIXED FIXED-SATELLITE (Earth-to-space) MOBILE RADIO ASTRONOMY 5.149 5.563A	
275-3 000	(Not allocated) 5.564A 5.565	

5.564A For the operation of fixed and land mobile service applications in frequency bands in the range 275-450 GHz:

The frequency bands 275-296 GHz, 306-313 GHz, 318-333 GHz and 356-450 GHz are identified for use by administrations for the implementation of land mobile and fixed service applications, where no specific conditions are necessary to protect Earth exploration-satellite service (passive) applications.

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)**.

In those portions of the frequency range 275-450 GHz where radio astronomy applications are used, specific conditions (e.g. minimum separation distances and/or avoidance angles) may be necessary to ensure protection of radio astronomy sites from land mobile and/or fixed service applications, on a case-by-case basis in accordance with Resolution **731 (Rev.WRC-19)**.

The use of the above-mentioned frequency bands by land mobile and fixed service applications does not preclude use by, and does not establish priority over, any other applications of radio services in the range of 275-450 GHz. (WRC-19)

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. Overview of point-to-point radiocommunication systems operating in the frequency range 252-296 GHz

There are a number of research activities on ultra-broadband wireless communication systems in the frequency range 252-296 GHz. Some research aims at ultra-high-speed wireless communication systems which interface ten to hundred Gbit/s Ethernet. Due to high-capacity transmission capability and large propagation loss of communication links using THz technologies, these links were operated as the last mile access links. With the development of semiconductor technologies and advanced antenna technologies in the THz frequency ranges in recent years, THz wireless communications are also deployed as an optical fiber replacement in short distance links. Several trials using the frequency range 252-296 GHz have been demonstrated by research and development organizations.

6.1. Point-to-point radiocommunication systems

Several applications of point-to-point radiocommunication systems are provided by Reports ITU-R F.2416, M.2417 and APT Report REP-66. Figure 6-1 shows some examples which requires high-speed transmission links between devices. The distance between devices varies from a few centi-meters for such as close proximity applications to a few hundred meters for outdoor fronthaul and backhaul applications.

Figure 6-1
Examples of point-to-point radiocommunication systems.

6.2. Wireless Backhauling/Fronthauling

A backhaul link is a connection between the base station and a more centralized network element, whereas the fronthaul link is the link between the radio equipment controller of a base station and the remote radio head (radio unit). Future developments like massive deployment of small cells, the implementation of cooperative multipoint transmission (CoMP) and/or Cloud Radio Access Networks (C-RAN) may increase the required data rates for either front haul ing and backhauling or both. Realizing these links using wireless links may be attractive in situations, where fiber links are challengingnot available.

In cases, where several tens of Gbit/s are required the THz frequency range can be seen as an attractive solution. Figure 6-2 shows THz fronthaul links which connect BS with RRH and THz multi-hop links one RRH with the other RRH. The multi-hop links can extend coverage areas of the BS and cover the shortcomings of terahertz nature.

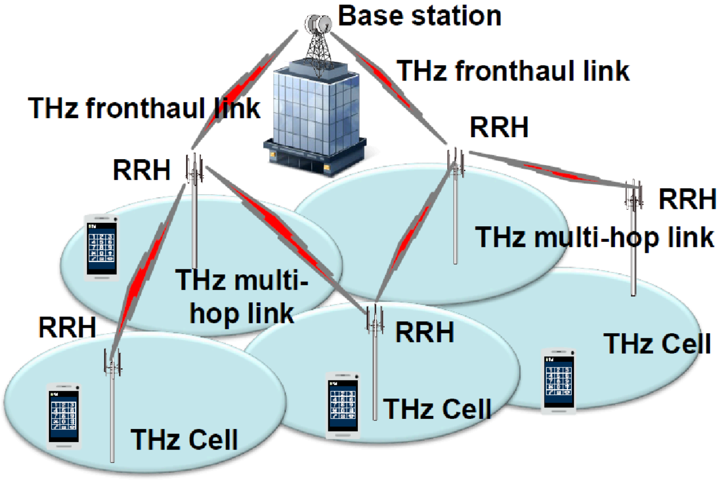


Figure 6-2
THz links between BS and RRH to cover high-speed traffic in dense urban area.

6.3. Device-to-Device communications (D2D)

Figure 6-3 shows an example of wireless D2D in the frequency range 252-296 GHz. The example describes a smart family, some typical fixed devices, such as television, ceiling lamp, air condition, refrigerator, who can coordinate and exchange information by themselves. If the load of house would like to remote control them, then a base station will be a bridge between fixed devices and their owner.

A D2D linkis an auxiliary peer-to-peer communication link, which reuses the key features of the radio access links and is an integral part of the radio access network. It enables mobile devices to communicate with the nearby devices directly over short or mid-range distance. Therefore, the data traffic of the base station is offloaded, whereas the interaction delay between these fixed devices is also reduced.

Nowadays, new wireless applications such as holographic interaction, automatic or assisted driving are emerged and have further requirements on bandwidth and transmission latency of communication links. It then is desirable to use D2D in the frequency range 252-296 GHz.

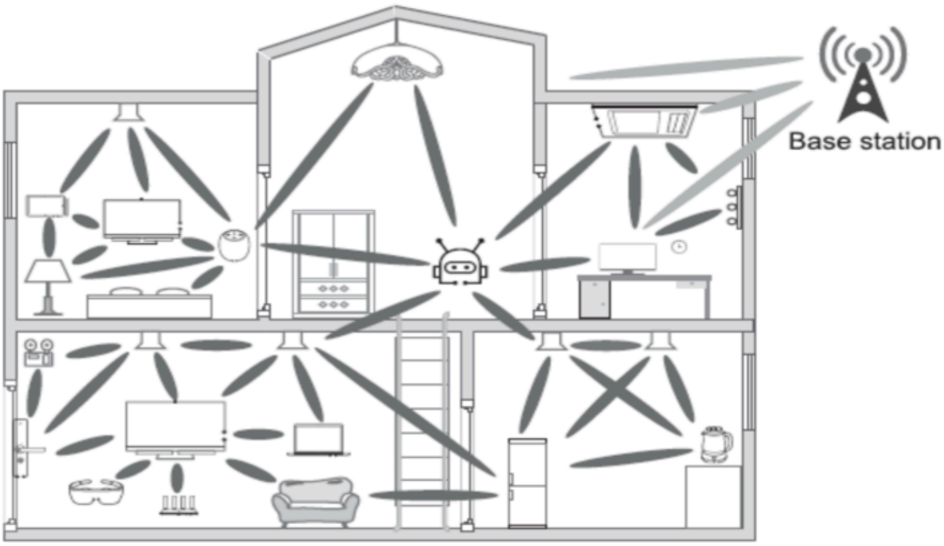


Figure 6-3
An example of THz Device-to-Device communication.

7. Technical overviews for point-to-point radiocommunication systems

7.1. CMOS single-chip transceiver

CMOS (Complementary metal-oxide-semiconductor) technology is expected to integrated digital signal processing circuits as well as RF circuits on a single chip and it can produce cost-effective transceivers for the microwave and millimeter-wave commercial market due to its mass production and high integration of chip devices. The current maximum oscillation frequency of 280 GHz is achieved by a 40-nm CMOS process, which enables CMOS devices to operate in the frequency above 250 GHz. Figure 7-1 shows a micrograph of single-chip transceiver. The RF components integrated within 4.915 mm × 2.25 mm are quadrature modulators, mixers, baseband amplifiers and passive circuits. The output power of -1.6 dBm and the noise figure of 23 dB are achieved without power amplifiers and low-noise amplifiers [1].

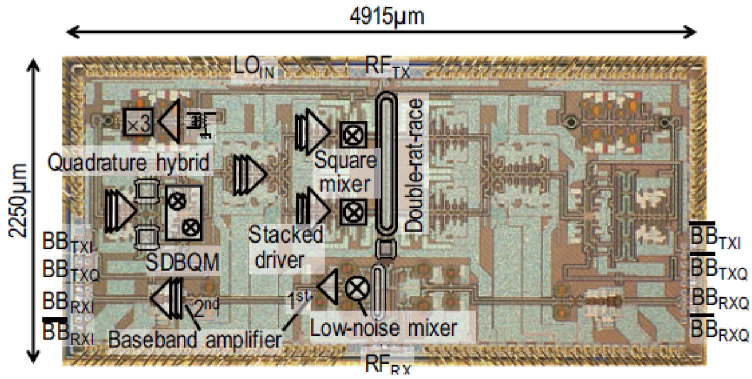
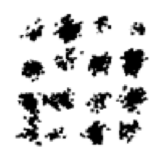
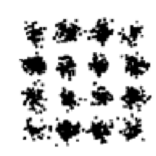
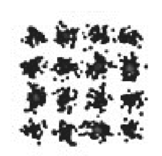
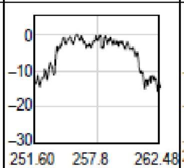
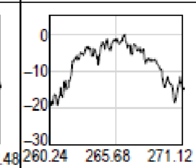
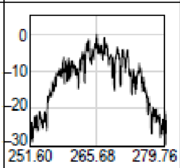


Figure 7-1
Micrograph of single-chip transceiver.

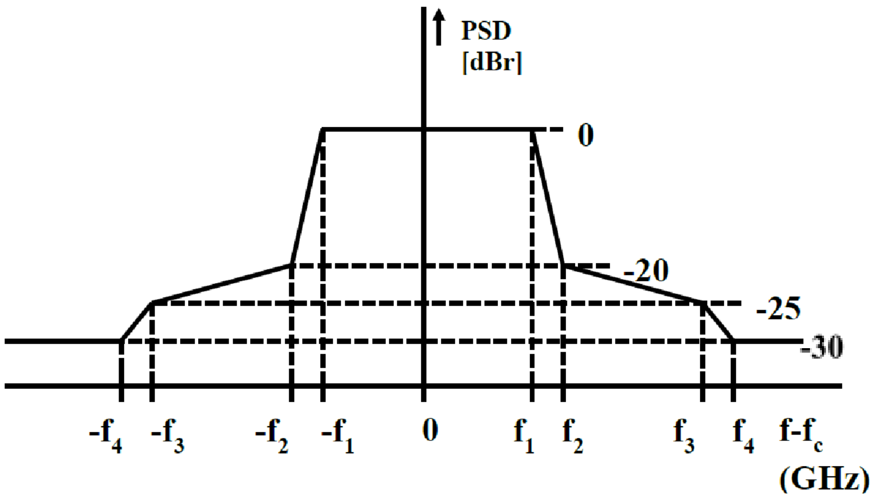
The performance of the single-chip transceiver is shown in Table 7-1. Three channels which are shown in Annex 1 are evaluated using 16-QAM modulation scheme. The maximum transmission data rate of 80 Gbit/s is achieved by the channel 66 whose bandwidth is 25.92 GHz.

Table 7-1
Characteristics of single-chip transceiver.

Channel	Ch. 49	Ch. 50	Ch. 66
Center freq.	257.04 GHz	265.68 GHz	265.68 GHz
Modulation	16 QAM	16 QAM	16 QAM
Data rate	28.16 Gb/s	28.16 Gb/s	80 Gb/s
Constellation (Equalized)			
Spectrum			
EVM	10.9%rms	11.3%rms	12.0%rms

7.2. Requirement of spectrum mask

The spectrum mask for fixed service applications in the frequency range 275-450 GHz is provided by Report ITU-R F.2416. Figure 7-3 shows the generic transmit spectrum mask and their parameters depending on their channel bandwidths.



(a) Generic transmit spectrum mask

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

(b) Transmit spectrum mask parameters

Figure 7-2

Spectrum mask specified for fixed service applications.

The measured spectrum of Ch. 66 in Table 7-1 is compared with the generic spectrum mask defined in Figure 7-2. Figure 7-3 shows the measured results (blue line) and the generic spectrum mask (red line). It could be noted that the out-of-band emission level of the measured spectrum is well suited within the generic spectrum mask.

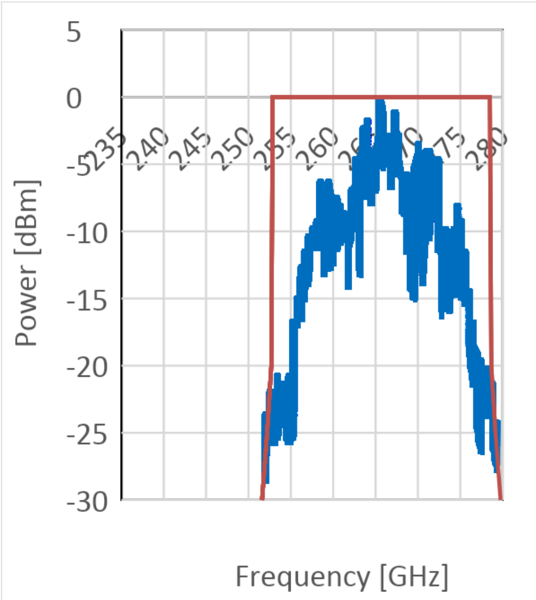


Figure 7-3
Comparison between measured spectrum and generic spectrum mask.

7.3. Channel arrangement

The basic channel bandwidth which is widely used for wireless PANs 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, as shown in Figure 7-2. In Figure 7-4, the channel arrangement described in IEEE Std 802.15.3d™-2017 is applied in the frequency range 252-296 GHz. Annex 1 defines the starting, center and stop frequencies of each channel according to the reference [2].

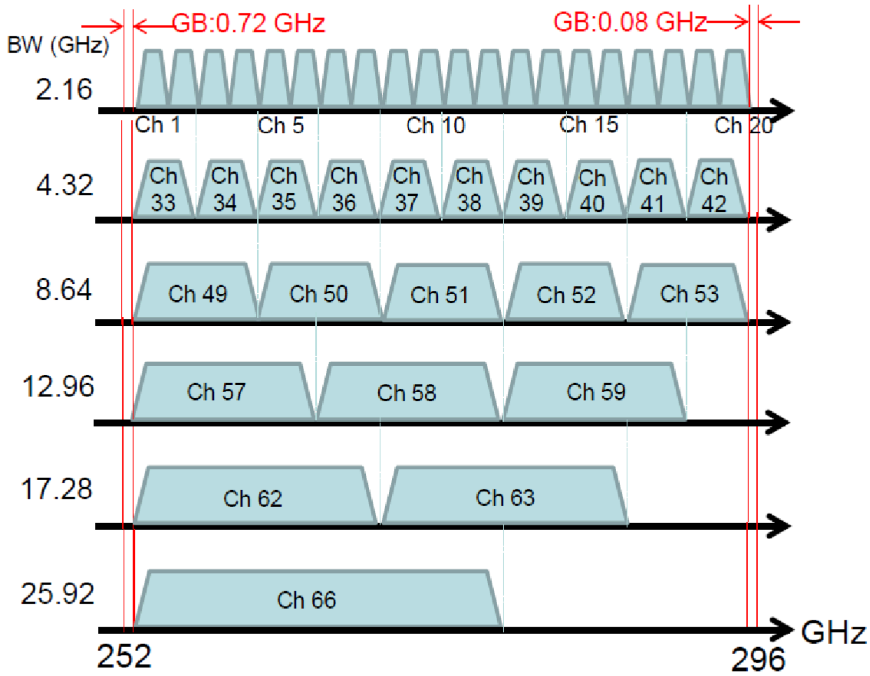


Figure 7-4
Channel arrangement for radiocommunication systems in the frequency range 252-296 GHz.

7.4. THz antenna and their performance

Several THz antenna structures for different applications are introduced and their measured radiation pattern are provided for preparation of sharing and compatibility studies between active and passive service applications, as well as among active service applications.

7.4.1 Dielectric cuboid antenna

The dielectric cuboid antenna shown in Figure 7-5 was proposed to increase an antenna gain with the small aperture size [3][4][5]. The size of antenna is determined using the mesoscopic scale of 1.36λ × 1.36 λ × 1.79 λ. Due to compactness of the cuboidal structure, this antenna could be integrated into smartphones, as schematically shown in Figure 8-1. The antenna gain of 15 dB at the frequency of 300 GHz is achieved by the dielectric cuboid whose size is 1.36 mm × 1.36 mm × 1.79 mm, as shown in Figure 7-6.

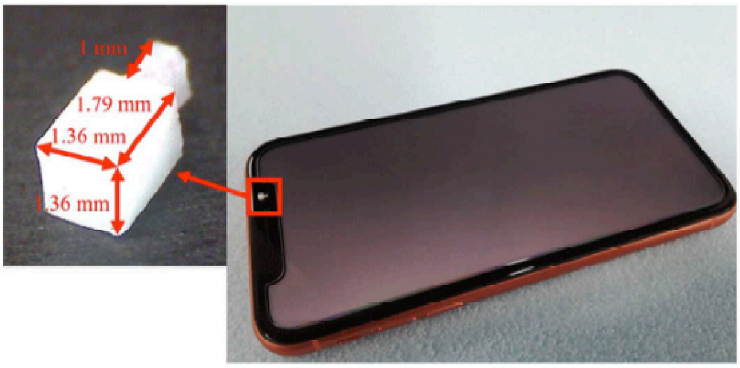
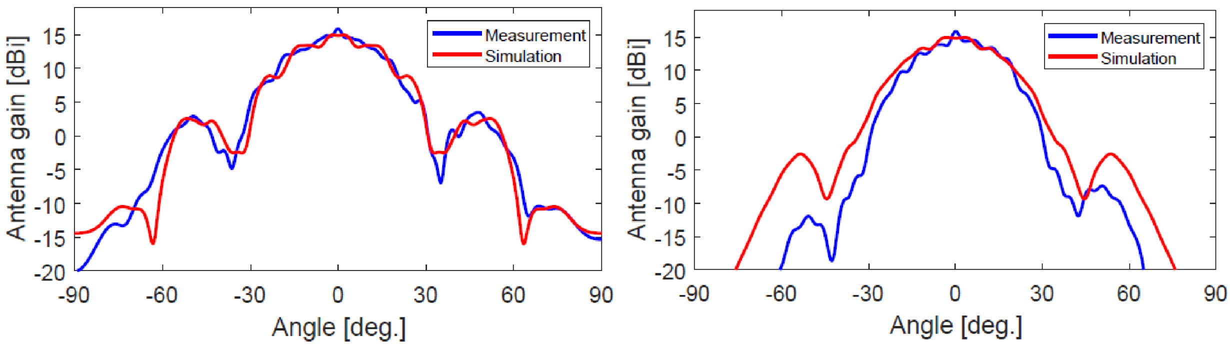


Figure 7-5
Dielectric cuboid antenna structure embedded in smartphone.



(a) E-plane antenna pattern (b) H-plane antenna pattern

Figure 7-6
Measured and simulated antenna pattern of dielectric cuboid antenna at 300 GHz.

7.4.2 Conventional structure of antennas

Four different antenna structures i.e. offset parabola, cassegrain, standard gain horn and corrugate horn, as shown in Table 7-2, are measured at 300 GHz. The size of each antenna is also summarized in Table 7-2.

Table 7-2
External view and physical dimensions of each antenna.

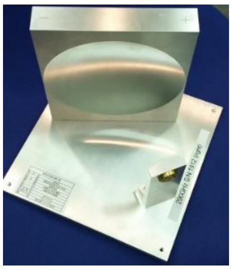
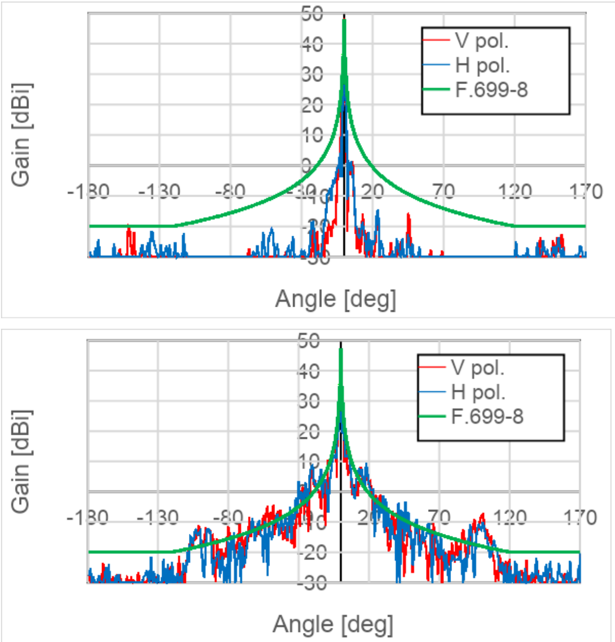
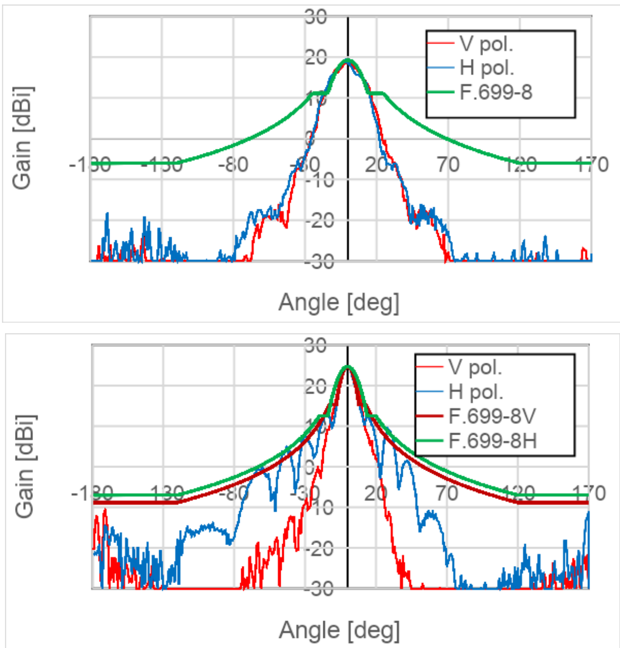
Type of antenna	External view	Size
Offset parabola		φ 150 mm
Cassegrain		φ 152 mm
Standard gain horn		8.36 mm x 5.5 mm
Corrugated horn		φ 4.4 mm

Figure 7-7 shows measurements at 275 GHz and calculation results using Recommendation F.699-8. Each antenna should be selected by their requirements from system characteristics. High-gain antenna such as offset parabola and cassegrain antennas could be used for point-to-point long distance applications above 100 m and the other two antennas may be used for short distance applications less than 100 m.



(a) Offset parabola antenna (b) Cassegrain antenna



(c) Corrugate horn antenna (d) Standard horn antenna

Figure 7-7

Measurements at 275 GHz and calculated results based on Recommendation F.699-8 of each antenna.

8. Summary

The bandwidth of 44 GHz in the frequency range 252-296 GHz could be utilized for point-to-point high capacity radiocommunication systems using the current device and antenna technologies. It should be emphasized that the single chip transceivers using CMOS technologies enable THz systems to be operated and utilized in consumer markets. It should be also noted that the performance of the single chip transceivers could be improved by connecting HPA and LNA made of compound semiconductor devices.

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[3] Y. Samura, K. Horio, V. B. Antipov, S. E. Shipilov, A. I. Eremeev, O. V. Minin, I. V. Minin, and S. Hisatake, “Characterization of mesoscopic dielectric cuboid antenna at millimeter-wave band,” IEEE Antenna and Wireless Propagation Letters, Vol. 18, No. 9, pp. 1828-1832, Sept. 2019.

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Annex 1

THz PHY Channelization in the frequency range 252-296 GHz

CHNL_ID	Bandwidth (GHz)	Start frequency (GHz)	Center frequency (GHz)	Stop frequency (GHz)
1	2.16	252.72	253.8	254.88
2	2.16	254.88	255.96	257.04
3	2.16	257.04	258.12	259.2
4	2.16	259.2	260.28	261.36
5	2.16	261.36	262.44	263.52
6	2.16	263.52	264.6	265.68
7	2.16	265.68	266.76	267.84
8	2.16	267.84	268.92	270.0
9	2.16	270.0	271.08	272.16
10	2.16	272.16	273.24	274.32
11	2.16	274.32	275.4	276.48
12	2.16	276.48	277.56	278.64
13	2.16	278.64	279.72	280.8
14	2.16	280.8	281.88	282.96
15	2.16	282.96	284.04	285.12
16	2.16	285.12	286.2	287.28
17	2.16	287.28	288.36	289.44
18	2.16	289.44	290.52	291.6
19	2.16	291.6	292.68	293.76
20	2.16	293.76	294.84	295.92
33	4.32	252.72	254.88	257.04
34	4.32	257.04	259.2	261.36
35	4.32	261.36	263.52	265.68
36	4.32	265.68	267.84	270.0
37	4.32	270.0	272.16	274.32
38	4.32	274.32	276.48	278.64
39	4.32	278.64	280.8	282.96
40	4.32	282.96	285.12	287.28
41	4.32	287.28	289.44	291.6
42	4.32	291.6	293.76	295.92
49	8.64	252.72	257.04	261.36
50	8.64	261.36	265.68	270.0
51	8.64	270.0	274.32	278.64
52	8.64	278.64	282.96	287.28
53	8.64	287.28	291.6	295.92

57	12.96	252.72	259.2	265.68
58	12.96	265.68	272.16	278.64
59	12.96	278.64	285.12	291.6
62	17.28	252.72	261.36	270.0
63	17.28	270.0	278.64	287.28
66	25.92	252.72	265.68	278.64