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(09/2015)

**Deployment scenarios for point-to-point
systems in the fixed service**

F Series
Fixed service

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RECOMMENDATION ITU-R F.2086-0

Deployment scenarios for point-to-point systems in the fixed service

(Question ITU-R 252/5)

(2015)

Scope

This Recommendation contains information on deployment scenarios and related statistics for some point-to-point fixed wireless systems in the fixed service operating in the frequency range 1.4-86 GHz. This information can be used in sharing and interference studies between these systems in the fixed service and systems in other services. This Recommendation is intended to be used in conjunction with Recommendation ITU-R F.758.

Keywords

Deployment, point-to-point, sharing, elevation angle, link length, antenna height

The ITU Radiocommunication Assembly,

considering

- a) that it is often necessary to study sharing between point-to-point (P-P) systems in the fixed service (FS) and systems in other services in frequency bands which are allocated to both services with equal rights;
- b) that interference from other systems in services operating in the same band on a non-primary basis, unwanted emissions from other systems in services operating outside the band allocated to the fixed service, and emissions from sources other than radio services need also to be taken into account;
- c) that the deployment scenarios of systems in each service needs to be understood in order to establish the sharing models to be studied;
- d) that availability of basic information on FS point-to-point deployment is useful for sharing and interference studies involving FS and other services,

noting

- a) that Recommendation ITU-R F.758 provides information on the development of sharing criteria and assessment of interference conditions between the FS and other services and other sources of interference;
- b) that Recommendation ITU-R F.758 also provides guidance to the technical characteristics and typical system parameters of digital fixed wireless systems that need to be taken into account when developing criteria for sharing and compatibility with other services and radio applications;
- c) that Recommendations ITU-R F.699 and ITU-R F.1245 provide FS P-P antenna reference radiation patterns for peak side-lobe and average side-lobe, respectively,

recommends

that, when more specific information is not available, the information in Annex 1 should be used for FS point-to-point deployment scenarios in conjunction with statistical data in Annex 2 which may be used when studying sharing or interference between point-to-point systems in the FS and other systems/applications in the FS and other services.

Annex 1

Deployment scenarios for point-to-point systems in the fixed service

1 Introduction

As a default in the absence of more specific information, the parameters and assumptions in this Recommendation are recommended for use in technical studies on sharing or interference involving FS P-P systems in bands above approximately 1 GHz¹.

For simplicity, assumptions for the frequency bands in this Recommendation are shown for broad frequency ranges in some cases. This is done for simplicity and does not imply any allocation issues.

2 Deployment scenarios for FS point-to-point systems

The type of application for which an FS P-P system is used, and therefore the way the system is deployed, will broadly vary by frequency range and geographical environment in each administration.

- Lower microwave bands roughly below 11 GHz allow for long hops, but provide channel widths up to 28/40 MHz possibly doubled through dual channel aggregation. These characteristics are particularly well-suited to long intercity routes (e.g. along highways, railways, electrical transmission corridors and other rights-of-way). Systems in these bands may be used as an alternative to fibre or redundancy, in rugged terrain where it is difficult to deploy fibre or a case where low latency is desired. Links in these bands are less commonly (or less densely) deployed in urban cores and overall numbers of links in these bands are lower than at higher frequencies. It should be noted that radio links in these bands are likely to be deployed in star configuration converging to an FS station located in urban cores.
- Medium microwave bands roughly 11-23 GHz still allow for relatively long hops and provide wider channels compared to lower bands. These bands are often used for backhaul for mobile infrastructure within urban and suburban areas, often using ring or star configurations. Numbers of links as well as deployment density in these bands can be very high.
- High microwave bands roughly above 23 GHz, but below 30 GHz, are suitable for short hops but can provide large bandwidths. These bands are most popular in urban areas as an alternative to fibre, to link campuses or to provide backhaul for cell sites, especially small cells. Generally, systems will only extend to one or two hops. Numbers of links as well as deployment density in these bands can be very high in dense urban areas and use of these bands is increasing rapidly.
- Millimetric wave bands at frequencies above 30 GHz are suitable for short hops and are appealing for their high performance (very large bandwidths and high data rates). The propagation characteristics and antenna directivity are ideally suited for a high density architecture of short-range point-to-point links with a high level of frequency reuse. Millimetric wave fixed service links are capable of providing fibre-like multi-gigabit

¹ For the purposes of description, commonly used nomenclature refers to the frequency range of 300 MHz to 300 GHz as “microwaves”. In terms of frequency bands, according to RR No. 2.1, the frequency range of 30 GHz to 300 GHz is designated as “millimetric waves”.

capacity. Some of the links could be deployed in an uncoordinated manner. Potential applications of millimetric wave fixed service links include transport for: wireless local area networks (WLANs), wireless personal area networks (WPANs), mobile broadband (i.e. backhaul), high resolution nomadic multimedia services, and wireless video distribution systems. It is expected use of these bands will increase as technologies develop and mature.

These descriptions are broad generalizations and in practice there is considerable blurring and overlap between these general categories for frequency ranges and the corresponding applications.

It should be noted that for millimetric wave fixed service applications, several bands are not discussed further in this Recommendation. These include, in particular, the fixed service bands of 92-94 GHz and above. Therefore references in this Recommendation that refer to “above 23 GHz” do not include these higher frequency millimetric wave bands for fixed service allocations.

3 FS point-to-point parameters for use in technical studies

3.1 Interference criteria

Refer to Recommendation ITU-R F.758 for general information and guidance regarding interference criteria for technical studies.

3.2 FS point-to-point equipment parameters

The primary reference for assumptions regarding FS equipment parameters is Recommendation ITU-R F.758, Annex 2. If there is no information on the frequency range of interest, there is additional information in Recommendation ITU-R F.758, Annex 3.

In cases where there is no relevant information in either of these Annexes, and in case it is desired to analyse analogue systems, there is an archive of additional, though potentially outdated, equipment information in Report ITU-R F.2108.

3.3 Reference antenna patterns

The appropriate choice of reference antenna pattern for analyses involving FS point-to-point systems will depend on the scenario being studied:

- for cases where there is a single (or limited number of) interference source and static geometry, it is recommended to use a peak side-lobe pattern such as the one described in Recommendation ITU-R F.699;
- for statistical and time varying analyses as well as cases where there is an aggregation of interference from a large number of sources as well as for spatial statistical analyses, the use of a peak side-lobe pattern would tend to overestimate the level of interference. In these cases, it is recommended instead to use an average side-lobe pattern such as the one described in Recommendation ITU-R F.1245.

3.4 Propagation models

The appropriate P-series Recommendation(s) for analysing interference should be utilized.

3.5 Deployment-related parameters

In this Annex, the following deployment-related parameters are discussed as typical elements to be used for the sharing and interference studies involving P-P systems in the fixed service:

- link lengths;
- antenna elevation angles;
- antenna heights above ground level.

For these parameters, statistical data provided by some administrations are summarized in Annex 2.

When conducting the sharing studies with P-P systems in the fixed service operating in a certain frequency band, the guidance in Tables A1-1 to A1-4 may be useful, which show relations between the statistical data of deployment-related parameters in Annex 2 and the corresponding frequency bands identified in Recommendation ITU-R F.758.

For the frequency bands not included in any of the left column in the Tables, it is suggested to use the statistical data available in the close band.

TABLE A1-1

Statistical data of deployment-related parameters corresponding to the frequency bands identified in Recommendation ITU-R F.758 for below 6 GHz band

| Frequency band segment identified in Rec. ITU-R F.758 (GHz) | Statistical data of deployment-related parameters for use for the frequency bands in the left column | |
|---|--|----------------------------------|
| 1.350-1.530 | Tables A2-1A, A2-1B and A2-1C in Annex 2 | Band 1.375-1.400/1.427-1.452 GHz |
| 1.700-2.100/1.900-2.300 | | Band 2.025-2.110/2.200-2.285 GHz |
| 2.290-2.670 | | Band 2.025-2.110/2.200-2.285 GHz |
| 3.600-4.200 | | Band 3.7-4.2 GHz |
| 4.400-5.000 | | Note |

NOTE – The data is currently not available.

TABLE A1-2

Statistical data of deployment-related parameters corresponding to the frequency bands identified in Recommendation ITU-R F.758 for 6-10 GHz band

| Frequency band segment identified in Rec. ITU-R F.758 (GHz) | Statistical data of deployment-related parameters for use for the frequency bands in the left column | |
|---|--|--|
| 5.925-6.425 | Tables A2-2A, A2-2B and A2-2C in Annex 2 | Band 5.925-6.425 GHz Band 6 GHz |
| 6.425-7.125 | | Band 6.425-7.125 GHz Band 7 GHz |
| 7.110-7.900 | | Band 7 GHz Band 7.125-7.725 GHz Band 7.425-7.75 GHz |
| 7.725-8.500 | | Band 7.725-8.275 GHz Band 8.025-8.500 GHz Band 8 GHz |
| 10.5-10.68 | | Band 10 GHz |

TABLE A1-3

Statistical data of deployment-related parameters corresponding to the frequency bands identified in Recommendation ITU-R F.758 for 11-23 GHz band

| Frequency band segment identified in Rec. ITU-R F.758 (GHz) | Statistical data of deployment-related parameters for use for the frequency bands in the left column | |
|---|--|---|
| 10.7-11.7 | | Band 11 GHz Band 10.7-11.7 GHz |
| 12.75-13.25 | Tables A2-3A, A2-3B and A2-3C in Annex 2 | Band 13 GHz |
| 14.4-15.35 | | Band 14.25-14.5 GHz Band 15 GHz Band 14.4-15.23 GHz Band 14.5-15.35 GHz |
| 17.7-19.7 | | Band 17.7-19.7 GHz Band 18 GHz Band 17.8-18.3/19.3-19.7 GHz Band 17.82-18.72 GHz |
| 21.2-23.6 | | Band 23 GHz Band 22-23.6 GHz Band 22.4-22.6/23.0-23.2 GHz |

TABLE A1-4

Statistical data of deployment-related parameters corresponding to the frequency bands identified in Recommendation ITU-R F.758 for above 23 GHz band

| Frequency band segment identified in Rec. ITU-R F.758 (GHz) | Statistical data of deployment-related parameters for use for the frequency bands in the left column | |
|---|--|--|
| 24.25-29.50 | Tables A2-4A, A2-4B and A2-4C in Annex 2 | Band 26 GHz Band 25.053-25.431/ 26.061-26.439 GHz Band 28 GHz |
| 31.8-33.4 | | Band 32 GHz |
| 36.0-40.5 | | Band 38 GHz |
| 51.4-52.6 | | Note |
| 55.78-59.0 | | Note |
| 71-76/81-86 | | Band 75 GHz Band 71-76/81-86 GHz |

NOTE – The data is currently not available.

3.5.1 Link lengths

Link lengths of the fixed service could be determined, within the application for which an FS P-P system is used, taking into account the following factors (see also § 2 of this Annex: Deployment scenarios for FS point-to-point systems):

- required link performance (or availability)
- line-of-sight condition.

In case of backhaul for mobile infrastructure, the distance between mobile base stations or between mobile base stations and the high-level node (core network station) will become a basic factor.

3.5.2 Antenna pointing direction

In certain frequency bands shared with space services above 1 GHz, the direction of maximum radiation of any FS antenna exceeding certain e.i.r.p. limit is separated from geostationary-satellite orbit by 1.5 to 2 degrees in accordance with the relevant provision in RR Article **21** where it is practicable. In sharing studies between the fixed service and the space services, it would become an important factor whether the above arc avoidance has been (or is continue to be) applied to the FS deployment scenario in the frequency band in question.

3.5.2.1 Antenna azimuths

For general purpose sharing studies, it may be assumed that azimuth angles (in degrees clockwise from true north) will vary uniformly between zero and 360 degrees. Where possible, it is best to apply this on a link basis rather than a station basis but it may be acceptable to apply per station if limited by the constraints of the simulation or analysis approach used.

3.5.2.2 Antenna elevation angles

This parameter is an important factor in analysing interferences to and from space stations. For this parameter, it should be noted that a negative median elevation angle may be expected, particularly on longer links, as a result of the effect of atmospheric refraction around the curvature of the Earth (see Appendix to Annex 2).

3.5.3 Antenna heights above ground level

This parameter is an important factor in analysing clutter loss in urban environments, or in evaluating line-of-sight conditions or interferences to and from other terrestrial stations including earth stations in the space services.

3.5.4 Polarization

Fixed point-to-point systems use horizontal and/or vertical polarization. When studying impact to or from systems with circular polarization (such as satellite systems), it is not necessary to specify which specific polarization is used.

Where it is necessary to distinguish between horizontal and vertical polarizations, it will be necessary to specify the extent to which technologies such as co-channel, dual-polarization (CCDP) are used to increase system capacity. Traditional point-to-point systems will typically alternate between links with horizontal polarization and links with vertical polarization and would have a roughly even split between the two polarizations with each link using one or the other polarization. Systems using CCDP will use both horizontal and vertical on every link.

3.6 Dependency between parameters

It should be noted that link length, elevation angle and antenna height are dependent parameters. Given any two of these parameters, the third can be calculated. This needs to be taken into account when establishing sharing scenarios.

For example, for a particular scenario, a number of random links could be defined based on the specified statistical distributions of link lengths and antenna heights. In such a case, the relevant antenna elevation angles should be calculated for each such link rather than using the statistics specified in this Recommendation.

As another example, in setting up a scenario involving a number of randomly placed stations without establishing a link relationship, the link length statistics would be ignored and the antenna height and elevation angle distributions should be applied for each such station.

Annex 2

Summarization of statistical data of deployment-related parameters for P-P systems in the fixed service operating in the various frequency bands

1 Introduction

Based on the contributions from several administrations, this Annex provides summarization of statistical data of antenna elevation angles, link lengths and antenna heights above ground level, as typical deployment-related parameters for FS P-P systems, for use for sharing and interference studies involving the FS P-P systems.

2 Statistical data summarization

2.1 Frequency bands below 6 GHz

TABLE A2-1A
Elevation angle (degrees)

| | Band (GHz) | Number of records | Percentiles | | | Median ² | Standard deviation |
|--------|-----------------------------|----------------------|-------------|----------|----------|---------------------|-----------------------|
| | | | 5:95 | 10:90 | 25:75 | | |
| France | 1.375-1.400/ 1.427-1.452 | 1 614 | −3.8:4.4 | −1.9:2.2 | −0.4:0.4 | −0.01 | 3.37 |
| Canada | 2.025-2.110/ 2.200-2.285 | 6 350 | −0.9:0.3 | −0.6:0.1 | −0.3:0 | −0.2 | 0.9 |
| Canada | 3.7-4.2 | 1 580 | −1.4:0.7 | −0.7:0.4 | −0.3:0 | −0.2 | 0.8 |

² A negative median elevation angle is expected, particularly on longer links, as a result of the effect of atmospheric refraction around the curvature of the Earth (see Appendix to Annex 2).

TABLE A2-1B
Link length (km)

| | Band (GHz) | Number of records | Percentiles | | | Median | Standard deviation |
|--------|-----------------------------|-------------------|-------------|--------|--------|--------|--------------------|
| | | | 5:95 | 10:90 | 25:75 | | |
| France | 1.375-1.400/ 1.427-1.452 | 1 614 | 2.2:44 | 3.6:37 | 8.3:27 | 17.3 | 14.6 |
| Canada | 2.025-2.110/ 2.200-2.285 | 6 350 | 1:83 | 1:67 | 15:53 | 39 | 29 |
| Canada | 3.7-4.2 | 1 580 | 1:84 | 2:72 | 7:57 | 41 | 28 |

TABLE A2-1C
Antenna height (metres above ground level)³

| | Band (GHz) | Number of records | Percentiles | | | Median ³ | Standard deviation |
|--------|-----------------------------|-------------------|-------------|--------|-------|---------------------|--------------------|
| | | | 5:95 | 10:90 | 25:75 | | |
| France | 1.375-1.400/ 1.427-1.452 | 1 614 | 5:53 | 6:45 | 10:33 | 20 | 16.8 |
| Canada | 2.025-2.110/ 2.200-2.285 | 6 350 | 3:127 | 5:105 | 15:80 | 47 | 42 |
| Canada | 3.7-4.2 | 1 580 | 15:140 | 20:131 | 20:85 | 39 | 42 |

2.2 Frequency bands 6 to around 11 GHz

TABLE A2-2A
Elevation angle (degrees)

| | Band (GHz) | Number of records | Percentiles | | | Median ⁴ | Standard deviation |
|--------|-------------|-------------------|-------------|------------|-------------|---------------------|--------------------|
| | | | 5:95 | 10:90 | 25:75 | | |
| Canada | 5.925-6.425 | 31 423 | −0.8:0.5 | −0.5:0.1 | −0.3:0 | −0.2 | 1.4 |
| Canada | 6.425-6.930 | 21 126 | −0.7:0.5 | −0.5:0.2 | −0.2:0 | −0.1 | 1.1 |
| France | 5.925-6.425 | 1 937 | −1.5:1.6 | −0.7:0.9 | −0.1:0.2 | 0.03 | 1.13 |
| France | 6.425-7.125 | 2 756 | −2.3:2.3 | −1:1.3 | −0.2:0.2 | 0.01 | 1.5 |
| Poland | 6 | 1 262 | −0.62:0.42 | −0.35:0.13 | −0.19:−0.03 | −0.106 | 0.487 |
| Poland | 7 | 1 280 | −0.45:0.29 | −0.29:0.16 | −0.15:0.01 | −0.080 | 4.739 |
| Canada | 7.125-7.725 | 20 684 | −1.4:0.8 | −0.9:0.3 | −0.4:0 | −0.2 | 1.5 |
| Canada | 7.725-8.275 | 7 772 | −1.0:0.5 | −0.6:0.2 | −0.2:0 | −0.1 | 0.8 |

³ Height above ground level includes the antenna structure and any building on which the antenna is located.

⁴ A negative median elevation angle is expected, particularly on longer links, as a result of the effect of atmospheric refraction around the curvature of the Earth (see Appendix to Annex 2).

TABLE A2-2A (*end*)

| | Band (GHz) | | Number of records | Percentiles | | | Median ⁴ | Standard deviation |
|--------|-------------|----|-------------------|-------------|------------|-------------|---------------------|--------------------|
| | | | | 5:95 | 10:90 | 25:75 | | |
| Japan | 7.425-7.75 | | 16 380 | −7.29:7.26 | −4.50:4.45 | −1.41:1.32 | −0.119 | 6.472 |
| France | 8.025-8.500 | | 2 257 | −2.4:5.8 | −1.5:3.5 | −0.25:1.12 | 0.13 | 3.24 |
| Poland | 8 | | 1 856 | −0.37:0.20 | −0.27:0.06 | −0.18:−0.03 | −0.114 | .347 |
| Canada | 10.55-10.68 | | 1 272 | −1.0:0.86 | −0.56:0.43 | −0.22:0.11 | −0.05 | 0.87 |
| Canada | 10.7-11.7 | | 24 571 | −1.7:1.1 | −0.8:0.5 | −0.3:0.1 | −0.1 | 1.4 |
| France | 10.7-11.7 | | 2 491 | −2.7:3 | −1.45:1.5 | −0.35:0.42 | 0.0 | 1.92 |
| Japan | 10.7-11.7 | | 23 448 | −3.10:3.07 | −1.85:1.80 | −0.60:0.55 | −0.027 | 2.078 |
| Poland | 10 | Tx | 78 | −0.52:4.08 | −0.26:2.80 | −0.01:1.28 | 0.525 | 1.392 |
| | | Rx | 78 | −4.08:0.30 | −2.81:0.21 | −1.32:−0.17 | −0.579 | 1.373 |
| Poland | 11 | | 1 431 | −0.38:0.29 | −0.29:0.17 | −0.17:0.00 | −0.076 | 0.354 |

TABLE A2-2B

Link length (km)

| | Band (GHz) | | Number of records | Percentiles | | | Median | Standard deviation |
|--------|-------------|--|-------------------|-------------|------------|-----------|--------|--------------------|
| | | | | 5:95 | 10:90 | 25:75 | | |
| Canada | 5.925-6.425 | | 31 423 | 9:74 | 15:64 | 28:51 | 40 | 18 |
| Canada | 6.425-6.930 | | 21 126 | 5:68 | 8:59 | 17:45 | 30 | 20 |
| France | 5.925-6.425 | | 1 937 | 12:49 | 14:43 | 19:37 | 28 | 12.6 |
| France | 6.425-7.125 | | 2 756 | 8.2:46 | 10:42 | 15:30 | 21.7 | 12.5 |
| Poland | 6 | | 1 262 | 19.6:51.4 | 21.9:46.5 | 27.2:38.6 | 33.3 | 10.08 |
| Poland | 7 | | 1 280 | 11.7:41.1 | 14.4:34.0 | 17.1:26.8 | 21.2 | 9.06 |
| Canada | 7.125-7.725 | | 20 684 | 6:75 | 11:70 | 20:53 | 38 | 23 |
| Canada | 7.725-8.275 | | 7 772 | 5:59 | 6:47 | 13:35 | 22 | 17 |
| Japan | 7.425-7.75 | | 8 570 | 1.7:48.8 | 3.5:39.8 | 8.6:26.0 | 14.8 | 14.684 |
| France | 8.025-8.500 | | 2 257 | 2.7:50 | 4.8:41 | 10:28 | 17.43 | 14.9 |
| Poland | 8 | | 1 856 | 15.9:47.0 | 19.0:44.6 | 25.7:39.5 | 33.4 | 9.91 |
| Canada | 10.55-10.68 | | 1 272 | 6:27 | 7:22 | 10:17 | 13 | 6.41 |
| Canada | 10.7-11.7 | | 24 571 | 3:45 | 4:34 | 7:21 | 13 | 14 |
| France | 10.7-11.7 | | 2 491 | 4.8:26 | 6.4:22 | 9.2:17 | 12.51 | 6.71 |
| Japan | 10.7-11.7 | | 11 724 | 2.14:14.05 | 2.97:12.24 | 4.85:9.47 | 6.994 | 3.666 |
| Poland | 10 | | 78 | 1.1:39.2 | 1.7:20.5 | 3.6:12.6 | 6.9 | 10.97 |
| Poland | 11 | | 1 431 | 8.0:39.0 | 11.0:36.0 | 14.7:30.4 | 21.3 | 9.70 |

TABLE A2-2C
Antenna height (metres above ground level)⁵

| | Band (GHz) | | Number of records | Percentiles | | | Median ⁵ | Standard deviation |
|--------|-------------|----|-------------------|-------------|------------|------------|---------------------|--------------------|
| | | | | 5:95 | 10:90 | 25:75 | | |
| Canada | 5.925-6.425 | | 31 423 | 14:105 | 20:95 | 35:78 | 55 | 41 |
| Canada | 6.425-6.930 | | 21 126 | 15:115 | 20:102 | 36:81 | 54 | 32 |
| France | 5.925-6.425 | | 1 937 | 5:53 | 6:45 | 10:33 | 33 | 22.8 |
| France | 6.425-7.125 | | 2 756 | 8:64 | 10:55 | 17:43 | 30 | 19.6 |
| Poland | 6 | | 1 262 | 24.2:115.0 | 29.2:88.5 | 39.1:69.3 | 55.0 | 27.9 |
| Poland | 7 | | 1 280 | 23.0:89.9 | 33.5:75.0 | 41.2:62.0 | 52.0 | 22.7 |
| Canada | 7.125-7.725 | | 20 684 | 11:119 | 15:105 | 24:76 | 45 | 34 |
| Canada | 7.725-8.275 | | 7 772 | 19:110 | 23:89 | 37:73 | 52 | 27 |
| Japan | 7.425-7.75 | | 9 152 | 10.8:82.0 | 13.8:58.5 | 19.2:40.93 | 27.2 | 31.163 |
| France | 8.025-8.500 | | 2 257 | 5.5:72 | 8:58 | 12:36 | 21 | 25 |
| Poland | 8 | | 1 856 | 30.0:88.0 | 35.4:80.0 | 46.0:68.0 | 58.9 | 16.8 |
| Canada | 10.55-10.68 | | 1 272 | 15:82 | 20:66 | 30:50 | 40 | 24.1 |
| Canada | 10.7-11.7 | | 24 571 | 15:92 | 23:80 | 33:59 | 44 | 25 |
| France | 10.7-11.7 | | 2 491 | 8:55 | 10:48 | 17.5:39 | 29 | 17.11 |
| Japan | 10.7-11.7 | | 23 448 | 17.0:84.0 | 21.4:69.3 | 28.0:51.1 | 40.5 | 23.435 |
| Poland | 10 | Tx | 78 | 7.9:82.0 | 10.0:80.0 | 16.0:45.8 | 25.5 | 27.9 |
| | | Rx | 78 | 14.9:161.8 | 18.8:142.0 | 33.8:80.8 | 50.0 | 48.0 |
| Poland | 11 | | 1 431 | 27.6:105.0 | 35.0:86.0 | 44.0:69.6 | 58.0 | 23.8 |

2.3 Frequency bands 12 to 23 GHz

TABLE A2-3A
Elevation angle (degrees)

| | Band (GHz) | | Number of records | Percentiles | | | Median ⁶ | Standard deviation |
|--------|-------------|--|-------------------|-------------|------------|------------|---------------------|--------------------|
| | | | | 5:95 | 10:90 | 25:75 | | |
| France | 12.75-13.25 | | 8 323 | −2.7:2.8 | −1.4:1.4 | −0.35:0.33 | −0.01 | 2.31 |
| Poland | 13 | | 7 136 | −0.60:0.48 | −0.38:0.27 | −0.19:0.06 | −0.064 | 0.543 |
| France | 14.25-14.5 | | 186 | −7.35:12.9 | −3.02:7.32 | −0.41:2.6 | 0.14 | 6.61 |
| Canada | 14.5-15.35 | | 16 152 | −1.3:0.8 | −0.9:0.5 | −0.3:0.1 | −0.1 | 1.1 |
| Japan | 14.4-15.23 | | 10 316 | −3.30:3.27 | −1.92:1.89 | −0.60:0.60 | −0.018 | 2.123 |

⁵ Height above ground level includes the antenna structure and any building on which the antenna is located.

⁶ A negative median elevation angle is expected, particularly on longer links, as a result of the effect of atmospheric refraction around the curvature of the Earth (see Appendix to Annex 2).

TABLE A2-3A (*end*)

| | Band (GHz) | Number of records | Percentiles | | | Median ⁶ | Standard deviation |
|--------|-------------------------|----------------------|-------------|------------|------------|---------------------|-----------------------|
| | | | 5:95 | 10:90 | 25:75 | | |
| Poland | 15 | 5 836 | −0.55:0.47 | −0.35:0.25 | −0.18:0.08 | −0.049 | 0.446 |
| France | 17.7-19.7 | 7 127 | −3.3:3.37 | −1.57:1.79 | −0.38:0.48 | 0.02 | 2.69 |
| Canada | 17.8-18.3/ 19.3-19.7 | 19 448 | −1.9:1.0 | −1.1:0.6 | −0.5:0.2 | −0.1 | 2.2 |
| Japan | 17.82-18.72 | 15 892 | −9.22:9.22 | −5.04:5.02 | −1.35:1.34 | −0.040 | 6.563 |
| Poland | 18 | 9 137 | −0.79:0.73 | −0.44:0.38 | −0.18:0.10 | −0.041 | 1.226 |
| Canada | 21.6-22.4/ 23.0-23.6 | 13 345 | −1.95:1.92 | −1.19:1.27 | −0.46:0.43 | −0.01 | 2.07 |
| Japan | 22.4-22.6/ 23.0-23.2 | 1 148 | −20.7:20.7 | −13.7:13.7 | −3.69:3.68 | −0.098 | 11.864 |
| France | 22-23.6 | 13 303 | −3.2:3.1 | −1.55:1.53 | −0.42:0.41 | 0.0 | 2.78 |
| Poland | 23 | 24 344 | −1.09:1.06 | −0.65:0.61 | −0.24:0.19 | −0.030 | 1.064 |

TABLE A2-3B

Link length (km)

| | Band (GHz) | Number of records | Percentiles | | | Median | Standard deviation |
|--------|-------------------------|----------------------|-------------|-----------|-----------|--------|-----------------------|
| | | | 5:95 | 10:90 | 25:75 | | |
| France | 12.75-13.25 | 8 323 | 4:28 | 5.7:24 | 8.5:18 | 12.7 | 8.08 |
| Poland | 13 | 7 136 | 8.8:31.5 | 10.6:28.6 | 13.8:23.2 | 17.7 | 7.26 |
| France | 14.25-14.5 | 186 | 2:25 | 3.7:22 | 7:16 | 10.7 | 7.13 |
| Canada | 14.5-15.35 | 16 152 | 2:32 | 3:25 | 5:15 | 9 | 11 |
| Japan | 14.4-15.23 | 5 158 | 1.83:7.42 | 2.38:6.52 | 3.24:5.39 | 4.211 | 1.878 |
| Poland | 15 | 5 836 | 27.0:68.0 | 34.0:63.0 | 43.5:53.3 | 46.0 | 12.9 |
| France | 17.7-19.7 | 7 127 | 1.5:16 | 2.3:14 | 4.3:10 | 7.3 | 5.1 |
| Canada | 17.8-18.3/ 19.3-19.7 | 19 448 | 2:30 | 2:22 | 3:12 | 6 | 10 |
| Japan | 17.82-18.72 | 7 944 | 0.7:6.89 | 1.1:5.8 | 1.8:4.0 | 2.7 | 1.882 |
| Poland | 18 | 9 137 | 3.7:20.4 | 5.3:18.0 | 8.4:14.5 | 11.4 | 4.95 |
| Canada | 21.6-22.4/ 23.0-23.6 | 13 345 | 1:8 | 1:6 | 2:4 | 3 | 17.69 |
| Japan | 22.4-22.6/ 23.0-23.2 | 592 | 0.7:7.6 | 1.0:3.9 | 1.5:3.0 | 2.2 | 2.436 |
| France | 22.2-23.6 | 13 303 | 1.3:13 | 2.1:11 | 4.1:8.6 | 6.2 | 3.58 |
| Poland | 23 | 24 344 | 2.1:14.3 | 3.1:12.5 | 5.1:9.8 | 7.4 | 3.74 |

TABLE A2-3C
Antenna height (metres above ground level)⁷

| | Band (GHz) | Number of records | Percentiles | | | Median | Standard deviation |
|--------|-------------------------|----------------------|-------------|------------|------------|--------|-----------------------|
| | | | 5:95 | 10:90 | 25:75 | | |
| France | 12.75-13.25 | 8 323 | 7:52 | 10:45 | 17:37 | 27.7 | 16.61 |
| Poland | 13 | 7 136 | 17.0:104.1 | 25.0:80.0 | 37.0:58.0 | 46.0 | 28.8 |
| France | 14.25-14.5 | 186 352 | 6:52 | 8:45 | 12:34 | 20 | 16.67 |
| Canada | 14.5-15.35 | 16 152 | 22:94 | 26:82 | 34:58 | 43 | 24 |
| Japan | 14.4-15.23 | 10 316 | 19.78:91.83 | 22.4:74.4 | 31.2:52.0 | 41.20 | 26.073 |
| Poland | 15 | 5 836 | 27.0:68.0 | 34.0:63.0 | 43.5:53.3 | 46.0 | 12.9 |
| France | 177-19.7 | 7 127 | 8.6:55 | 11.7:47 | 20:38 | 29 | 17.84 |
| Canada | 17.8-18.3/ 19.3-19.7 | 19 448 | 18:91 | 23:75 | 30:52 | 40 | 24 |
| Japan | 17.82-18.72 | 10 232 | 11.7;71.89 | 15.0:52.59 | 22.38:41.0 | 32.0 | 30.939 |
| Poland | 18 | 9 137 | 20.0:84.1 | 27.0:69.3 | 38.0:58.0 | 45.0 | 22.8 |
| Canada | 21.6-22.4/ 23.0-23.6 | 13 345 | 11:74 | 15:60 | 25:44 | 33 | 23.7 |
| Japan | 22.4-22.6/ 23.0-23.2 | 538 | 5.0:68.5 | 6.0:51.29 | 12.3:35.4 | 24.0 | 21.885 |
| France | 22-23.6 | 13 303 | 9:50 | 12:44 | 20:36 | 28 | 15.26 |
| Poland | 23 | 24 344 | 15.0:82.0 | 21.5:65.0 | 33.5:52.0 | 42.0 | 24.1 |

2.4 Frequency bands above 23 GHz

TABLE A2-4A
Elevation angle (degrees)

| | Band (GHz) | Number of records | Percentiles | | | Median ⁸ | Standard deviation |
|--------|---------------------------------|----------------------|-------------|------------|------------|---------------------|-----------------------|
| | | | 5:95 | 10:90 | 25:75 | | |
| France | 25.053-25.431/ 26.061-26.439 | 3 582 | -3.03:3.35 | -1.6:2.09 | -0.5:0.6 | 0.03 | 2.68 |
| Poland | 26 | 626 | -2.46:2.44 | -1.40:1.38 | -0.53:0.50 | -0.017 | 2.366 |
| Poland | 28 | 8 | -:- | -:- | -0.38:0.34 | -0.041 | 0.378 |
| France | 31.871-32.543/ 32.683-33.355 | 122 | -0.83:4.3 | -0.31:3.24 | 0.05:1.27 | 0.5 | 1.90 |
| Poland | 32 | 7 587 | -2.13:2.12 | -1.36:1.34 | -0.56:0.54 | -0.005 | 2.177 |

⁷ Height above ground level includes the antenna structure and any building on which the antenna is located.

⁸ A negative median elevation angle is expected, particularly on longer links, as a result of the effect of atmospheric refraction around the curvature of the Earth (see Appendix to Annex 2).

TABLE A2-4A (*end*)

| | Band (GHz) | Number of records | Percentiles | | | Median ⁸ | Standard deviation |
|--------|---------------|----------------------|-------------|------------|------------|---------------------|-----------------------|
| | | | 5:95 | 10:90 | 25:75 | | |
| France | 38 | 7 554 | −3.8:4.3 | −2.09:2.36 | −0.73:0.71 | −0.04 | 3.13 |
| Poland | 38 | 30 437 | −3.59:3.59 | −2.17:2.17 | −0.85:0.83 | −0.004 | 3.600 |
| France | 71-76/81-86 | 61 | −1.7:4.3 | −0.9:2.6 | −0.2:1 | 0.34 | 2.15 |
| Poland | 75 | 176 | −3.12:3.11 | −2.54:2.54 | −1.01:1.00 | −0.004 | 2.366 |

TABLE A2-4B

Link length (km)

| | Band (GHz) | Number of records | Percentiles | | | Median | Standard deviation |
|--------|---------------------------------|----------------------|-------------|---------|----------|--------|-----------------------|
| | | | 5:95 | 10:90 | 25:75 | | |
| France | 25.053-25.431/ 26.061-26.439 | 3 582 | 0.7:8 | 1.07:6 | 1.85:5 | 3.06 | 2.12 |
| Poland | 26 | 626 | 0.8:9.0 | 1.0:7.6 | 2.0:5.8 | 3.3 | 2.63 |
| Poland | 28 | 8 | —:— | —:— | 4.9:11.3 | 7.1 | 3.08 |
| France | 31.871-32.543/ 32.683-33.355 | 122 | 0.72:5 | 1:4.4 | 1.5:4 | 2.5 | 1.43 |
| Poland | 32 | 7 587 | 0.5:7.2 | 0.7:6.2 | 1.1:3.7 | 2.0 | 2.15 |
| France | 38 | 7 554 | 0.5:5 | 0.8:4 | 1.3:3 | 2.29 | 1.38 |
| Poland | 38 | 30 437 | 0.4:4.6 | 0.5:3.9 | 1.0:2.7 | 1.7 | 1.35 |
| France | 71-76/81-86 | 61 | 0.5:2.8 | 0.7:2.7 | 1:2.3 | 1.87 | 0.95 |
| Poland | 75 | 176 | 0.3:2.0 | 0.5:1.9 | 0.7:1.8 | 1.0 | 0.66 |

TABLE A2-4C

Antenna height (metres above ground level)⁹

| | Band (GHz) | Number of records | Percentiles | | | Median | Standard deviation |
|--------|---------------------------------|----------------------|-------------|-----------|-----------|--------|-----------------------|
| | | | 5:95 | 10:90 | 25:75 | | |
| France | 25.053-25.431/ 26.061-26.439 | 3 582 | 10:56 | 14:48 | 21:38 | 29 | 18.13 |
| Poland | 26 | 626 | 14.4:110.3 | 18.0:79.5 | 26.0:55.0 | 38.3 | 29.2 |
| Poland | 28 | 8 | —:— | —:— | 33.5:99.8 | 50.0 | 32.2 |
| France | 31.871-32.543/ 32.683-33.355 | 122 | 13:63 | 17:52 | 24:43 | 33 | 19 |

⁹ Height above ground level includes the antenna structure and any building on which the antenna is located.

TABLE A2-4C (*end*)

| | Band (GHz) | Number of records | Percentiles | | | Median | Standard deviation |
|--------|---------------|----------------------|-------------|-----------|-----------|--------|-----------------------|
| | | | 5:95 | 10:90 | 25:75 | | |
| Poland | 32 | 7 587 | 13.0:98.0 | 16.0:68.2 | 21.4:40.0 | 28.0 | 29.5 |
| France | 38 | 7 554 | 10:53 | 14:46 | 20.5:36.5 | 28 | 16.88 |
| Poland | 38 | 30 437 | 12.0:85.0 | 15.0:64.0 | 22.0:44.5 | 33.5 | 26.5 |
| France | 71-76/81-86 | 61 | 12:50 | 16:46 | 21:36 | 29.05 | 11.59 |
| Poland | 75 | 176 | 11.0:68.2 | 13.6:49.0 | 17.0:38.9 | 26.3 | 21.4 |

Appendix to Annex 2

Guidance for the derivation of elevation angle data taking into account the effect of atmospheric refraction around the curvature of the Earth

For the all distances d the curvature of the Earth was taken into account and formulas present in Recommendation ITU-R P.1812-3 have been used:

$$\theta_{deg} = \theta_{rad} \cdot \frac{10^{-3} \cdot 180}{\pi} \quad \text{degrees}$$

where:

$$\theta_{id} = 1\,000 \arctan \left(\frac{h_{rs} - h_{ts}}{10^3 d} - \frac{d}{2 a_e} \right)$$

a_e : median effective Earth's radius appropriate to the path

h_{ts} : transmitter antenna height amsl (m)

h_{rs} : receiving antenna height amsl (m)

d : total great-circle path distance (km).

The median effective Earth radius factor k_{50} for the path is given by:

$$k_{50} = \frac{157}{157 - \Delta N}$$

ΔN : average radio-refractivity lapse-rate (N -units/km)

The median value of effective Earth radius a_e is given by:

$$a_e = 6\,371 \cdot k_{50} \quad \text{km.}$$