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**APT REPORT**

**on**

**STUDIES IN ADDRESSING THE INEFFICIENCY**

**ASSOCIATED WITH THE ASYMMETRY OF EXISTING UNPLANNED FSS UPLINK/DOWNLINK SPECTRUM**

**IN THE 10-15 GHZ BAND**

**No. APT/AWG/REP-45**Edition: March 2014

**Adopted by**

**16th Meeting of APT Wireless Group**

**18 – 21 March 2014
Pattaya, Thailand**

***(Source: AWG-16/OUT-05)***

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1. **Background**

In ITU Region 3 (Asia Pacific Region), there is only 750 MHz in the 10-15 GHz band for use by unplanned Fixed-Satellite Services (FSS) in the uplink (Earth-to-space) direction, while the downlink (space-to-Earth) direction enjoys 1.05 GHz of spectrum. Table 1 describes the asymmetry of existing unplanned FSS uplink/downlink spectrum in the 10-15 GHz band and indicates a spectrum shortfall in the uplink of 300 MHz in ITU Region 3.

**Table 1: The unplanned FSS bands in ITU Region 3 in the 10-15 GHz range**

|  |  |
| --- | --- |
| Frequency bands (GHz) | Bandwidth (MHz) |
| **Earth-to-space Direction (Uplink)** |
| 13.75-14.5 | 750 |
| **Total spectrum in the uplink** | **750** |
| **space-to-Earth Direction (Downlink)** |
| 10.95-11.2 | 250 |
| 11.45-11.7 | 250 |
| 12.2-12.75 | 550 |
| **Total spectrum in the downlink** | **1050** |
| **Uplink and downlink spectrum difference**  | **300** |

The existing unplanned FSS bands in the 10-15 GHz range are extensively used for a myriad of applications. Very small aperture terminal (VSAT) services, video distribution, broadband networks, internet services, satellite news gathering, and backhaul links have triggered the rapid rise in the demand curve for this frequency range. The industry norm is for satellites to employ frequency re-use by means of beam and/or polarization isolation, to optimally use the limited available spectrum and to reduce costs to end users. However, as indicated in Table 1, there is spectrum shortfall in the uplink of 300 MHz in ITU Region 3. This would translate to approximately 14 transponders, considering a transponder bandwidth of 36 MHz in both polarizations. Therefore, satellite manufacturers would have to design complicated payload configurations to compensate for the bandwidth limitation in the uplink, which in turn have cost implications to end users. Addressing the spectrum insufficiency issue would enable the satellite payload to be simplified, for example, through the reduction and simplification of satellite hardware, etc. which in turn would lead to reduction of satellite cost and launch weight that will enable the full frequency allocation to be implemented effectively and efficiently at each orbital location.

Moreover, the shortage in the uplink capacity hinders the rational, efficient and economical use of the limited frequency resource. Faced with the current congestion and insufficient use of spectrum, it is difficult for satellite operators to effectively expand their communication services to meet the growing market demands. Consequently, the digital divide is further widened as essential communication services are not attainable by rural areas and developing countries. Hence, to facilitate efficient spectrum utilization and accessibility to satellite services, it is necessary to resolve this spectrum insufficiency issue.

In order to provide a cost effective path for existing users to expand their services and to facilitate more widespread availability of services, additional uplink spectrum of 300 MHz in ITU Region 3 that is contiguous (or near contiguous) to the existing allocations is ideally required. This will minimise the necessity to invest in new ground terminals/equipment and reduce the cost of implementation on the satellite. Both of these measures will reduce the marginal cost for the end user to expand services.

1. **List of abbreviations**

WRC World Radiocommunication Conference

ITU-R International Telecommunication Union, Radiocommunication Sector

RR ITU Radio Regulations

FSS Fixed-satellite service

BSS Broadcasting-satellite service

MSS Mobile-satellite service

FS Fixed service

MS Mobile service

ALS Aircraft landing systems

ARNS Aeronautical radionavigation service

EESS Earth exploration-satellite service

SRS Space research service

VSAT Very small aperture terminal

e.i.r.p. Equivalent isotropic radiated power

pfd Power flux-density

TRMM Tropical rainfall measuring mission

GPM Global Precipitation Measurement

DPR Dual-frequency precipitation radar

1. **Frequency bands to be considered in sharing studies**

Some frequency bands, which could potentially improve the inefficiency associated with the asymmetry of existing unplanned FSS uplink/downlink spectrum in the 10-15 GHz band, are summarized in Table 2. To adequately take into account the compatibility with existing services, it is important to conduct sharing studies in the band 13-17 GHz either by considering potential new allocation for FSS (Earth-to-space) or by studying the possibility of removing or modifying regulatory restrictions on allocations to the FSS (Earth-to-space) in these bands.

1. Frequency bands with no FSS allocation

The possibility of additional allocations for unplanned FSS (Earth-to-space) in the bands of 13.25 – 13.4 GHz, 13.4 – 13.75 GHz, 14.8 – 15.35 GHz, 15.4 – 15.43 GHz, 15.63 – 15.7 GHz and 15.7 – 16.6 GHz should be examined.

1. Frequency bands with FSS allocation

The possibility of removing the current limitations in the bands of 14.5 – 14.8 GHz and 15.43 – 15.63 GHz, to facilitate its use for unplanned FSS (Earth-to-space) should be examined.

**Table 2: Summary of frequency bands for consideration of additional unplanned FSS uplink bands**

|  |  |  |
| --- | --- | --- |
| **Frequency bands (GHz)** | **Bandwidth (MHz)** | **Current allocation to FSS**  |
| 13.25-13.4 | 150 | No |
| 13.4-13.75 | 350 | No |
| 14.5-14.8 | 300 | Yes, but limited to feeder links for BSS, and for use outside of Europe (RR No. 5.510)  |
| 14.8-15.35 | 550 | No |
| 15.4-15.43 | 30 | No\* |
| 15.43-15.63 | 200 | Yes, but limited to feeder links of non-geostationary systems in the mobile-satellite service (RR No. 5.511A).  |
| 15.63-15.7 | 70 | No\* |
| 15.7-16.6 | 900 | No |

\*Allocated to FSS for which complete information for advance publication has been received by the BR by 21 November 1997.

In addition, following comments are addressed for consideration of additional FSS (uplink) allocation:

The 13.25-13.75 GHz band has been allocated to the Earth exploration-satellite service (active) (shortened form EESS) on a primary basis. The EESS (active) allocation in this band can be used for three types of active sensor: scatterometers, altimeters and precipitation radars.

Although EESS (active) satellites are currently operated by only a limited number of countries, measurements are performed worldwide and the remote sensing data and related analyses are distributed and used globally. For example, China shares their meteorological data which are explored by Chinese meteorological satellite to all countries of the Asia-Pacific region for weather forecast and climate prediction, prevention of and preparedness for meteorological disasters, and public meteorological service. The EESS (active) systems are crucial for the protection of human life and natural resources. It is necessary to ensure that the EESS (active) systems shall be protected without any undue constraints to their operations in the 13.25-13.75 GHz band.

1. **FSS earth stations characteristics to be used in study:**

The FSS characteristics as provided in Table 3-1, should be used to generate results based on the potential interference from one FSS Earth station while the FSS characteristics as provided in Table 3-2 should be used to generate results based on cumulative interference (static & dynamic analysis) from all FSS Earth stations.

There are three main types of transmissions (VSAT, Wideband, and Point-to-Point) currently active on fixed satellite systems and the relative frequency of use of these transmission types. For each of the transmission types, typical earth station characteristics are outlined. The characteristics in the tables below are taken from a statistical analysis of all the transmissions from 73 active satellites in 14.0-14.5 GHz band. There was an overall total of 25 937 transmissions which gives an average of 355 transmissions per satellite. The use of transmission types serves to provide an accurate description of FSS earth station operations and their transmissions.

Very small aperture terminals (VSATs) are earth stations with small diameter antennas that commonly transmit carriers with lower e.i.r.p. densities and smaller bandwidths. Transmissions were considered VSAT transmissions if the transmitting earth station was less than 3 m in diameter and the bandwidth was less than 3 MHz. Wideband transmissions are typically data or video carriers from hub stations. These stations transmit wideband carriers have large diameters and the ability to transmit higher e.i.r.p. densities. Any transmission in the sample with a bandwidth of 18 MHz or larger was classified as a wideband transmission. Point-to-point transmissions include all other transmissions that are not VSAT or wideband transmissions. The earth stations transmitting point-to-point links typically have diameters and e.i.r.p. densities larger than VSATs but smaller than hub stations transmitting wideband carriers.

* 1. **FSS characteristics for single entry analysis**

Table 3-1 contains some typical maximal characteristics for the FSS in the 10-17 GHz band. The impact of each type of antenna should be evaluated individually. It includes a sampling of transmitting earth station antenna patterns and characteristics for use in FSS networks. Recommendations ITU-R S.1855, ITU-R S.728 and ITU-R BO.1213 are used for the off-axis antenna pattern or off-axis e.i.r.p. density mask as appropriate. Recommendation ITU-R BO.1213 is considered primarily for modelling the main lobe characteristics of an FSS earth station antenna.

Table 3-1

 Single-Entry characteristics for the FSS in the 13-17 GHz band

|  |
| --- |
| **Satellite** |
| Transmissions per satellite[[1]](#footnote-1) | 355 |
| **Earth station** |
| Transmission type | VSAT | Wideband | Point-to-Point |
| Percentage of total satellite transmissions  | 69.3 | 4.9 | 25.8 |
| Range of peak antenna gains[[2]](#footnote-2) (dBi) | 37.2-50.5 | 51.7-60.8 | 43.9-57.2 |
| Range of antenna sizes (m) | 0.6-2.8 | 3.2-9.1 | 1.3-6.0 |
| 3 dB beamwidth at 14 GHz[[3]](#footnote-3) (°) | 1.15 | 0.85 | 0.74 |
| Maximum power spectral density at antenna port (dBW/Hz) | –42[[4]](#footnote-4) | –49 | –50[[5]](#footnote-5) |
| Alternative maximum power spectral density at antenna port (dBW/Hz) [[6]](#footnote-6) | –59 | –55 | –50 | –60 | –57 | –53 | –60 | –57 | –53 |
| Maximum e.i.r.p. density at the transmit antenna port (dBW/Hz)[[7]](#footnote-7) | 1.5 | 3.0 | 3.5 |
| Minimum elevation angle | 10° |
| Off-axis radiation pattern | S.1855 | S.580 | S.580 |
| Off-axis power limits | Rec. ITU-R S.728[[8]](#footnote-8) |
| Main lobe characteristics | Rec. ITU-R BO.1213 |

* 1. **FSS (Earth-to-space) characteristics for cumulative analysis**

Table 3-2 provides the antenna diameter sizes to be considered as well as the average bandwidths, the percentages of the total transponder bandwidth consumed by the global deployment, and average power density of the particular ES diameter. The total transponder bandwidth of the system operator was examined to determine how much of the total bandwidth was used by a certain size of Earth station. These numbers were provided by two FSS providers as being representative for their global networks. These numbers are subject to further review.

Table 3-2

Typical characteristics for the FSS (Earth-to-space) in the 13-17 GHz band

|  |  |  |  |
| --- | --- | --- | --- |
| **Transmission type** | **VSAT** | **Wideband** | **Point-to-Point** |
| Number of transmissions in the FSS model[[9]](#footnote-9) | 17 982 | 1 258 | 6 697 |
| Average bandwidth of transmission (MHz) | 0.58 | 30.84 | 2.94 |
| Total **s**pectrum usage(MHz) | 10 440 | 38 801 | 19 072 |
| Percentage of spectrum usage (%) | 15.28 | 56.80 | 27.92 |
| PSD@ antenna port (dBW/Hz) | Mean of peak envelope power density  | –54.19 | –56.43 | –57.52 |
| e.i.r.p. density (dBW/Hz) | Mean of peak envelope power density  | -9.23 | -3.40 | -5.62 |
| Bandwidth (MHz) | Average  | 0.6 | 30.8 | 2.9 |
| Standard deviation | 0.8 | 6.5 | 3.5 |
| Antenna size (m) | Average  | 1.73 | 6.13 | 3.62 |
| Standard deviation | 0.37 | 0.98 | 0.79 |

* 1. **GSO FSS satellite locations and distributions**

For the purpose of this study, 120 FSS satellites could be assumed at 3° spacing even if in some portions of the orbital arc less than or greater than 3 degree spacing is employed.

* 1. **FSS Earth station density**

In addition, if a frequency band is used by an Earth station in a specific beam towards a specific space station, no other Earth stations could use simultaneously this frequency in this specific beam towards this specific space station. Therefore, in order to have 2 Earth stations operating, in the same area, the same frequency simultaneously, we need to have 2 space stations and so on.

Depending on the parameters of the transmit Earth stations, we could assume to have a space station every 2-4° on the GSO arc with a minimum elevation angle of 10-20°. With such assumptions, as an example, Europe could only be potentially served from around 30 different space stations.

According to current surfaces on the majority of beams from space stations covering Europe, the average beam coverage surface is around 10 000 000 km2.

Therefore, considering these 30 maximum Earth stations operating simultaneously in Europe on the same frequency and same polarization at the same time on the same beam, the current density over Europe is around 3E-6 transmit (3-degree compliant) Earth stations per km2. This number can increase when dual polarization is taken into account and also depends on the victim receiver bandwidth considered.

Subject to further review, this deployment density could be used for the purpose of the sharing studies.

* 1. **Frequency reuse factor**

The use of spot beams on FSS GSO satellites could increase the effective amount of available amount of total global bandwidth at a geostationary orbital location. This effective increase of available spectrum is dependent upon sufficient isolation between beams. For instance, if there is a geographical overlap between two spot beams of the same frequency of one or more satellites in an orbital slot then a earth station to that orbital slot, at that same frequency, operating in the area of the geographical overlap would be seen by both spot beams and thereby reduce the amount of overall available bandwidth (for uplink and downlink transmission) by the bandwidth carrier of this earth station operating in that geographical overlap. With sufficient isolation between spot beams originating from a geostationary orbital location, two spot beams would double the available amount of total global bandwidth if all spectrum is implemented on-board the aircraft in each beam and three spot beams would triple the available amount of total global bandwidth if all spectrum is implemented on-board the aircraft in each beam. However, it should be recognized that, in practice, the use of multiple beams using the same frequencies in the Ku band is currently uncommon and the current frequency reuse, of about 1.2, introduced by the use of spot beams and dual polarization has been accounted for in the transmission data presented. However, this may not be representative of an FSS deployment based on future satellites, with multiple spot beams and increased frequency reuse and the frequency reuse factor should be re-evaluated as information on future satellite technologies and capacities becomes available.

1. **Initiation of band-by-band sharing studies:**
	1. **Frequency band: 13.25-13.75 GHz**

This band is currently allocated to the EESS (active) and SRS (active) on a primary basis. The band 13.25-13.4 GHz is also allocated to the ARNS on a primary basis, limited to use for Doppler navigation aids through RR No. 5.497.

The allocations in this band according to ITU Radio Regulations (RR) Article **5** are as shown below:

|  |
| --- |
| **13.25-13.4** EARTH EXPLORATION-SATELLITE (active) AERONAUTICAL RADIONAVIGATION 5.497 SPACE RESEARCH (active) 5.498A 5.499 |

|  |
| --- |
| **13.4-13.75** EARTH EXPLORATION-SATELLITE (active) RADIOLOCATION SPACE RESEARCH 5.501A Standard frequency and time signal-satellite (Earth-to-space) 5.499 5.500 5.501 5.5.01B  |

**5.497** The use of the band 13.25-13.4 GHz by the aeronautical radionavigation service is limited to Doppler navigation aids.

**5.498A** The Earth exploration-satellite (active) and space research (active) services operating in the band 13.25-13.4 GHz shall not cause harmful interference to, or constrain the use and development of, the aeronautical radionavigation service. (WRC-97)

**5.499** *Additional allocation*: in Bangladesh and India, the band 13.25-14 GHz is also allocated to the fixed service on a primary basis. In Pakistan, the band 13.25-13.75 GHz is allocated to the fixed service on a primary basis. (WRC-12)

**5.500** *Additional allocation*: in Algeria, Angola, Saudi Arabia, Bahrain, Brunei Darussalam,Cameroon, Egypt, the United Arab Emirates, Gabon, Indonesia, Iran (Islamic Republic of), Iraq, Israel, Jordan, Kuwait, Lebanon, Madagascar, Malaysia, Mali, Morocco, Mauritania, Niger, Nigeria, Oman, Qatar, the Syrian Arab Republic, Singapore, Sudan, South Sudan, Chad and Tunisia, the band 13.4-14 GHz is also allocated to the fixed and mobile services on a primary basis. In Pakistan, the band 13.4-13.75 GHz is also allocated to the fixed and mobile services on a primary basis. (WRC-12)

**5.501** *Additional allocation:* in Azerbaijan, Hungary, Japan, Kyrgyzstan, Romania and Turkmenistan, the band 13.4-14 GHz is also allocated to the radionavigation service on a primary basis. (WRC-12)

**5.501A** The allocation of the band 13.4-13.75 GHz to the space research service on a primary basis is limited to active spaceborne sensors. Other uses of the band by the space research service are on a secondary basis. (WRC-97)

**5.501B** In the band 13.4-13.75 GHz, the Earth exploration-satellite (active) and space research (active) services shall not cause harmful interference to, or constrain the use and development of, the radiolocation service. (WRC-97)

* + 1. **Review of studies performed in the band 13.25-13.75 GHz:**

**Remote active sensors**

EESS (active) satellites with three types of active sensor in 13.25-13.75 GHz –scatterometers, altimeters and precipitation radars – have been operating in this band for many years. The remote sensing systems of EESS (active) are used in backscatter echo mode to monitor weather, water and climate change and similar emergencies, with the aim of preventing natural disasters, which could suffer from interference resulting from FSS (uplink).

In the band 13.25-13.4 GHz, Report ITU-R RS.2068 describes the use of the band by the various types of EESS (active) sensors. The interference criteria of EESS active sensors can be found in Recommendation ITU-R RS.1166-4. The characteristics of current and planned systems can be found in Report ITU-R M.2221. Currently scatterometers only use the band 13.25-13.4 GHz.

Table 4

Summary of relevant Recommendations/Reports that may be useful for
sharing studies in the band 13.25-13.4 GHz

|  |  |
| --- | --- |
| Service | Relevant Recommendations/Reports |
| Fixed | Recommendation ITU-R F.699Recommendation ITU-R F.758Recommendation ITU-R F.1107Recommendation ITU-R F.1245Recommendation ITU-R F.1333Recommendation ITU-R F.1336Recommendation ITU-R F.1777Recommendation ITU-R F.746Recommendation ITU-R F.497 |
| Earth exploration-satellite (active) | Recommendation ITU-R RS.1166-4Report ITU-R RS.2068 |
| Aeronautical radionavigation  | Recommendation ITU-R M.2008Report ITU-R M.2230 |

As for the band 13.4-13.75 GHz, the relevant recommendations and report that may be useful for sharing studies are as shown:

Table 5

Summary of relevant Recommendations/Reports that may be useful for
sharing studies in the band 13.4-13.75 GHz

|  |  |
| --- | --- |
| Service | Relevant Recommendations/Reports |
| Fixed | Recommendation ITU-R F.699Recommendation ITU-R F.758 Recommendation ITU-R F.1107 Recommendation ITU-R F.1245Recommendation ITU-R F.1333Recommendation ITU-R F.1336 Recommendation ITU-R F.1777 |
| Earth exploration-satellite (active) | [Recommendation ITU-R RS.1281]Recommendation ITU-R RS.1166Report ITU-R RS.2068 |
| Radiolocation  | Recommendation ITU-R M.1644Recommendation ITU-R M.1461Recommendation ITU-R M.1851 |
| Space research | Recommendation ITU-R SA.609Recommendation ITU-R SA.510Recommendation ITU-R SA.1018Recommendation ITU-R SA.1019PDR Recommendation ITU-R SA.1414[[10]](#footnote-10)Recommendation ITU-R SA.1155 |

To obtain the information about the procedures for determining the potential for interference between radars operating in the radiodetermination service and systems in other services.

* Report ITU-R M.2221 (10/2011)
1. *Precipitation radars (i.e. tropical rain)*

These systems usually operate over bandwidths around 20 to 30 MHz: currently all systems operate in 13.4-13.75 GHz band such as Chinese meteorological satellites system (and some in 13.75-14 GHz). The Global Precipitation Mission (GPM) will use two channels at 13.593 and 13.603 GHz each channel being 3 MHz wide.

1. *Altimeters (measures oceans' currents): such as Jason, Envisat, Cryosat, Sentinel, HY-2*

These systems usually operate within a bandwidth of around 350 MHz and all current systems are centered on 13.575 GHz or 13.6 GHz, i.e. within 13.4-13.75 GHz. In addition, Report ITU-R RS.2068 provides a rationale for instruments having bandwidths of up to 600 MHz.

Considering future EESS systems of altimeters may operate in the band 13.25-13.4 GHz; sharing studies between FSS and EESS (altimeters) systems should be conducted in the whole band of 13.25-13.75 GHz.

*Scatterometers (measures winds at the surface of oceans)*

Current and planned systems: e.g. Seawinds on board the Quickscat satellite uses a bandwidth of a few MHz at the edge of 13.4 GHz, Scatterometers on board the HY-2 satellite and CFOSAT satellite uses a bandwidth of a few MHz at the edge of 13.25 GHz. Some systems are planned that would operate in the band 13.25-13.4 GHz. Typical bandwidths are around 1 MHz, the bandwidths of HY-2 satellite and CFOSAT satellite is 3-5 MHz, but higher bandwidths can be found.

**Aeronautical radionavigation service (ARNS)**

Doppler navigation aids in the band 13.25-13.4 GHz are operated in the ARNS on board aircraft. Such use is under RR No. 4.10.

* + - 1. **EESS (active) and FSS allocations**

At WARC-92, the band 13.75-14 GHz was allocated to FSS (Earth-to-space) on a primary basis. The EESS (active) was secondary within the 13.4-13.75 GHz band.

At WRC-97 the 500 MHz bandwidth 13.25-13.75 GHz was allocated to EESS (active) and space research (active) service on a primary basis. WRC-97 also saw the need to maintain the 13.75-14 GHz portion of the previous secondary allocation for use by several active sensor instruments that were currently in orbit or were planned and built as their characteristics could not be changed. However, in practice, the band 13.75‑14 GHz is no longer usable by scatterometers and altimeters, which moved to the band 13.25-13.75 GHz.

The 13.25-13.75 GHz frequency band allocated to EESS (active) is a key frequency band currently used by altimeters, scatterometers and precipitation radars.

* + - 1. **Previous compatibility studies between EESS (active) and FSS (Earth-to-Space)**

In the past WRC study cycles, such as WRC-95 and WRC-97, regarding the sharing issue between EESS (active) and FSS (Earth-to-Space) in the band 13.75-14 GHz, it was drawn that it was difficult to share the band based on the technical characteristics and assumptions of both systems considered during those study periods. After the year 2000, the band 13.75-14.0 GHz is no longer viable for use by active sensors because of its allocation to the fixed-satellite service (Earth-to-space) at WARC-92 (please refer to CPM WRC-95 Report under Agenda item 2.3 and CPM WRC‑97 Report under Agenda item 1.9.2).

* 1. **Frequency band: 14.5-14.8 GHz**

The allocations in this band according to RR Article 5 are as shown below:

|  |
| --- |
| 14.5-14.8 FIXED FIXED-SATELLITE (Earth-to-space) 5.510 MOBILE Space research |

5.510 The use of the band 14.5-14.8 GHz by the fixed-satellite service (Earth-to-space) is limited to feeder links for the broadcasting-satellite service. This use is reserved for countries outside Europe.

* + 1. **Possible studies:**

Studies to evaluate possible operational conditions (e.g. e.i.r.p. limitations, antenna size, orbital separation, conditional operation by means of geographical separation, etc.) for FSS in which the transmissions of FSS (Earth-to-space) do not cause more interference, or require more protection from interference, than the feeder links for the Broadcasting-Satellite Service (BSS) transmissions operating in conformity with the Plan or the List, as appropriate.

Studies for sharing in this band include studies with other allocated services, and studies within the FSS service.

* + - 1. **Sharing with fixed service and mobile service in the band 14.5-14.8 GHz:**

A list of relevant recommendations that may be useful for sharing studies is summarized in Table 6.

Table 6: Summary of relevant recommendations that may be useful for
sharing studies in the band 14.5-14.8 GHz

|  |  |
| --- | --- |
| Service: | Relevant Recommendation: |
| Fixed-Satellite Service (Earth-to-space) | Recommendation ITU-R S.1328-4Recommendation ITU-R S.1063 |
| Fixed Service | Recommendation ITU-R F.758-5Recommendation ITU-R F.636-4Recommendation ITU-R F.699-7Recommendation ITU-R F.1245-2Recommendation ITU-R F.1336-3Recommendation ITU-R F.1107Recommendation ITU-R F.1333Recommendation ITU-R F.1777 |
| Mobile Service | In the absence of specific characteristics for the mobile service in this band, mobile system characteristics are assumed to be similar to those for fixed systems. (Has to check with the relevant ITU Working Parties responsible for studies on mobile services on the validity of this assumption.) |
| Space research service | Recommendation ITU-R SA.609Recommendation ITU-R SA.1019Recommendation ITU-R SA.1155Recommendation ITU-R SA.1018PDR Recommendation ITU-R SA.1414 |
| Radio astronomy | Recommendation ITU-R RA.769 (adjacent band)Recommendation ITU-R RA.1031-2Recommendation ITU-R RA.1513-1 |

* + - * 1. **Sharing with fixed service in the band 14.5-14.8GHz:**

It is important to note that, stations operating in the fixed service have the following characteristics:

* Location and characteristics are known
* Not deployed in an ubiquitous manner (A radiocommunication service between specified fixed points)
* Operate under license

These three characteristics significantly ease the situation of sharing with FSS (Earth-to-space) as proper planning and mitigation techniques are possible and that could effectively reduce the interference from FSS terminal into FS terminal.

The following two subsections will discuss the coordination distance based on the worst case calculation method (RR AP7) and the actual required separation distance in reality. The first is used to identify coordination requirements while the second may be used by administrations in bilateral coordination.

**Maximum coordination distance identified by RR AP7**

This calculation is based on most unfavorable assumptions regarding system parameter values and interference path geometry. Assuming all the worst-case values will occur simultaneously.

In the case of sharing between FSS (Earth-to-space) and FS, this method is way too conservative since locations and characteristic of terminals are known. However, use of the AP7 can give an idea of the upper bound of the coordination distance, and through proper choice of the earth station locations, it maybe possible to avoid international coordination.

Assumptions:

|  |  |
| --- | --- |
| Frequency | 14.5-14.8 GHz |
| Maximum power density | -42dBW/Hz |
| Antenna gain | 43.8dBi (~ 1.2m antenna) |
| Satellite location  | 122E |
| Antenna Pattern | REC 580-6 |
| Chosen locations | Capital city of all APT member’s countries |

Calculation method (Worst case assumption): RR AP7

Description for this calculation method:

The determination of the coordination area is based on most unfavourable assumptions regarding system parameter values and interference path geometry. However, to assume that all the worst-case values will occur simultaneously will lead to unrealistically large distances to obtain the minimum required loss and hence unnecessarily large coordination areas. However, use of the AP7 can give an idea of the upper bound of the coordination distance.

The procedures allow the determination of a distance in all azimuthal directions around a transmitting or receiving earth station beyond which the predicted path loss would be expected to exceed a specified value for all but a specified percentage of the time. This distance is called the coordination distance. When the coordination distance is determined for each azimuth around the coordinating earth station it defines a distance contour, called the coordination contour, that encloses the coordination area.

It is important to note that, although the determination of the coordination area is based on technical criteria, it represents a regulatory concept. Its purpose is to identify the area within which detailed evaluations of the interference potential need to be performed in order to determine whether the coordinating earth station or any of the terrestrial stations, or in the case of a bidirectional allocation any of the receiving earth stations that are sharing the same frequency band, will really experience unacceptable levels of interference. Hence, the coordination area is not an exclusion zone within which the sharing of frequencies between the earth station and terrestrial stations or other earth stations is prohibited, but a means for determining the area within which more detailed calculations need to be performed. In most cases a more detailed analysis will show that sharing within the coordination area is possible since the procedure for the determination of the coordination area is based on unfavourable assumptions with regard to the interference potential.

Results based on the above assumptions and worst case calculation method:

The detail of the calculation results could be found in the end of this section, the result indicate that:

* More than 70% of APT member countries do not need to coordinate with another country if they place an FSS earth station in their capital city with horizontal elevation angle of 5deg or more.
* More than 60% of APT member countries do not need to coordinate with another country if they place an FSS earth station in their capital city regardless of the horizontal elevation angle.
* Coordination distance would be reduced significantly by having a minimum horizontal elevation angle of 5deg.

**Calculation results using the RR AP7 method:**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| No | Adm | Country | Capital City | Latitude andLongitude | RainClimateZone | Antenna Elevation(Deg) | Max coordination distancein all azimuthal directionswhen Horizontal elevation angle = 0deg (km) | Probably affected countries identified by RR AP7 software | Max coordination distancein all azimuthal directionswhen Horizontal elevation angle = 5deg (km) | Probably affected countries identified by RR AP7software |
| 1 | AFG | Afghanistan  | Kabul | [34°28'N 69°11'E](http://factacular.com/facts/34%C2%B028%27N_69%C2%B011%27E) | E | 21.82 | 197 | PAK | 105 | PAK |
| 2 | AUS | Australia  | Canberra | [35°15'S 149°08'E](http://factacular.com/facts/35%C2%B015%27S_149%C2%B008%27E) | K | 39.97 | 172 | - | 113 | - |
| 3 | BGD | Bangladesh (People's Republic of)  | Dhaka | [23°43'N 90°26'E](http://factacular.com/facts/23%C2%B043%27N_90%C2%B026%27E) | N | 45.15 | 235 | IND | 133 | IND |
| 4 | BTN | Bhutan (Kingdom of)  | Thimphu | [27°31'N 89°45'E](http://factacular.com/facts/27%C2%B031%27N_89%C2%B045%27E) | K | 42.17 | 174 | BGD CHN IND NPL | 113 | CHN IND |
| 5 | BRU | Brunei Darussalam  | Bandar Seri Begawan | [04°52'N 115°00'E](http://factacular.com/facts/04%C2%B052%27N_115%C2%B000%27E) | P | 79.97 | 193 | INS MLA | 131 | INS MLA |
| 6 | CBG | Cambodia (Kingdom of)  | Phnom Penh | [11°33'N 104°55'E](http://factacular.com/facts/11%C2%B033%27N_104%C2%B055%27E) | N | 65.95 | 173 | VTN | 131 | VTN |
| 7 | CHN | China (People's Republic of)  | Beijing | [39°55'N 116°20'E](http://factacular.com/facts/39%C2%B055%27N_116%C2%B020%27E) | H | 43.45 | 164 | - | 112 | - |
| 8 | FJI | Fiji (Republic of)  | Suva | [18°06'S 178°30'E](http://factacular.com/facts/18%C2%B006%27S_178%C2%B030%27E) | N | 23.69 | 227 | - | 136 | - |
| 9 | IND | India (Republic of)  | New Delhi | [28°37'N 77°13'E](http://factacular.com/facts/28%C2%B037%27N_77%C2%B013%27E) | K | 31.11 | 191 | - | 114 | - |
| 10 | INS | Indonesia (Republic of)  | Jakarta | [06°09'S 106°49'E](http://factacular.com/facts/06%C2%B009%27S_106%C2%B049%27E) | P | 70.8 | 189 | - | 131 | - |
| 11 | IRN | Iran (Islamic Republic of)  | Tehran | 35°44'N 51°30'E | K | 7.1 | 251 | - | 127 | - |
| 12 | J | Japan  | Tokyo | 35°40'N 139°45'E | K | 44.51 | 181 | - | 113 | - |
| 13 | KIR | Kiribati (Republic of)  | South Tarawa | 1°23'N, 173°09'E | N | 31.43 | 213 | - | 134 | - |
| 14 | KRE | Democratic People's Republic of Korea  | Pyongyang | 39°2′N 125°45′E | M | 44.65 | 176 | CHN KOR | 124 | - |
| 15 | KOR | Korea (Republic of)  | Seoul | 37°31'N 126°58'E | M | 46.2 | 178 | KRE | 124 | KRE |
| 16 | LAO | Lao People's Democratic Republic  | Vientiane | 17°58′N 102°36′E | N | 59.38 | 171 | THA | 132 | THA |
| 17 | MLA | Malaysia  | Kuala Lumpur | 03°09'N 101°41'E | P | 69.35 | 184 | INS | 131 | INS |
| 18 | MLD | Maldives (Republic of)  | Male | 04°00'N 73°28'E | N | 34.16 | 206 | - | 134 | - |
| 19 | MHL | Marshall Islands (Republic of the)  | Majuro | 07°05' N, 171°08'E | P | 33.23 | 201 | - | 134 | - |
| 20 | FSM | Micronesia (Federated States of)  | Palikir | 06°55'N 158°09'E | P | 47.42 | 195 | - | 132 | - |
| 21 | MNG | Mongolia  | Ulan Bator | 47°55′N 106°53′E | E | 33.04 | 174 | - | 99 | - |
| 22 | BRM | Myanmar (Union of)  | Yangon | 16°45'N 96°20'E | P | 54.65 | 190 | - | 132 | - |
| 23 | NRU | Nauru (Republic of)  | Yaren | 0° 32’S 166° 55’E  | N | 38.27 | 219 | - | 133 | - |
| 24 | NPL | Nepal (Federal Democratic Republic of)  | Kathmandu | 27°45'N 85°20'E | K | 38.43 | 179 | CHN IND | 113 | CHN IND |
| 25 | NZL | New Zealand  | Wellington | 41°19'S 174°46'E | K | 18.81 | 219 | - | 115 | - |
| 26 | PAK | Pakistan (Islamic Republic of)  | Islamabad | 33°40'N 73°10'E | E | 25.38 | 197 | IND | 104 | IND |
| 27 | PLW | Palau (Republic of)  | Koror | 07°20'N 134°28'E | P | 73.04 | 202 | - | 131 | - |
| 28 | PNG | Papua New Guinea  | Port Moresby | 09°24'S 147°08'E | P | 58.78 | 188 | - | 132 | - |
| 29 | PHL | Philippines (Republic of the)  | Manila | 14°40'N 121°03'E | N | 72.73 | 185 | - | 131 | - |
| 30 | SMO | Samoa (Independent State of)  | Apia | 13°50'S 171°50'W | D | 14.7 | 245 | SMA | 140 | - |
| 31 | SNG | Singapore (Republic of)  | Singapore | 01°14'N 103°55'E | P | 68.74 | 190 | INS MLA | 131 | INS MLA |
| 32 | SLM | Solomon Islands  | Honiara | 09°27'S 159°57'E | P | 44.92 | 195 | - | 133 | - |
| 33 | CLN | Sri Lanka (Democratic Socialist Republic of)  | Sri Jayawardenapura Kotte | 6°54′N 79°54′E | N | 40.89 | 190 | - | 133 | - |
| 34 | THA | Thailand  | Bangkok | 13°45'N 100°35'E | N | 60.45 | 184 | BRM | 132 | - |
| 35 | TON | Tonga (Kingdom of)  | Nuku'alofa | 21°10'S 174°00'W | N | 15.77 | 239 | - | 139 | - |
| 36 | TUV | Tuvalu  | Funafuti | 08°31'S 179°13'E | N | 24.48 | 238 | - | 135 | - |
| 37 | VUT | Vanuatu (Republic of)  | Port-Vila | 17°45'S 168°18'E | P | 33.95 | 217 | - | 134 | - |
| 38 | VTN | Viet Nam (Socialist Republic of)  | Hanoi | 21°01'N 105°50'E | N | 59.28 | 184 | CHN LAO | 132 | - |

**The sharing between FS and FSS in reality:**

FSS(Earth-to-space) and FS has long good sharing experience, many of the band allocated to FSS(Earth-to-space) are shared with FS. According to Recommendation ITU-R SF.1006, “experience has shown that, in many instances, separation distances as small as a few kilometres, when allowing for typical terrain and shielding, are achievable”. The actual required separation distance between the FS transmitter and the FSS station depends on the actual parameters of both systems, such as FS transmitter power density, minimum operational elevation angles of satellite systems, off-axis antenna gain of both systems, and the terrain topography.

Mitigation techniques as contained in section 5 of this document could be used to improve the required separation. On the conditions that the location of FS stations are known, the deployment of FS terminals are not ubiquitous and both FSS (Earth-to-space) and FS station are operated under license, with only as small as a few kilometers of separation distance in many instances, sharing between FS and FSS can be considered feasible. On the other hand, some Administrations deploy the FS stations in high density for domestic use without registering in the ITU database. In such a case, careful consideration of such usage would need to be taken into account like other frequency bands shared between the FS and the FSS.

FSS(Earth-to-space) and FS share well with each others. Experience has shown that, in many instances, separation distances as small as a few kilometres, when allowing for typical terrain and shielding, are achievable.

In terms of international coordination, even using the worst case calculation method RR AP7 using by the ITU, in many of the cases, coordination is not required.

In the case where international coordination is unavoidable, experience indicate that the actual required separation distances is significantly shorter than the coordination distance calculated using the RR AP7 method, it is therefore expected the coordination should not lead to a heavy burden to the administration.

* + - * 1. **Sharing with mobile service in the band 14.5-14.8GHz:**

There are no stations for the mobile service in ITU-R Region 3 as recorded in the ITU database as of 29.05.2012 (BR IFIC 2720). Also, according to APT Report on Information of Mobile Operator’s Frequencies, Technologies and License durations in Asia Pacific countries ([APT/AWG/Rep-15(Rev. 1)](http://www.apt.int/sites/default/files/Upload-files/AWG/APT-AWG-REP-15-R1-APT_Report_on_Mobile_Freq-Tech-License.docx)), the frequency range 14.5-14.8 GHz was not used for mobile service in Asia Pacific countries. However, the services covered in the APT Report are not fully inclusive and it is noted that the registration of terrestrial systems, including mobile systems in MIFR is voluntary on the part of the Administrations and some Administrations assign this frequency band to the mobile service for domestic use without registering on the ITU database. Therefore, careful consideration of such domestic use would be required.

* + - 1. **Sharing with fixed satellite service under footnote 5.510 in the band 14.5-14.8 GHz:**

Compatibility between BSS feeder links and other FSS in the 14.5-14.8 GHz would be obtained through regular coordination procedures for satellite networks. Today, such procedures are contained in Appendix 30A of the Radio Regulations in respect of coordination between BSS feederlinks. To obtain the same compatibility between BSS feederlinks and other FSS, similar criteria and coordination identification mechanisms could be included in Article 9 of the Radio Regulations.

According to Recommendation ITU-R S.1063, studies already show that coexistence of the FSS (Earth-to-space) and BSS feeder link assignments in the band 14.5-14.8GHz is feasible. Although the studies were done 20 years ago, there are some changes in the AP30A over this period and the sample characteristics used for studies may need to be reviewed, it is likely that the sharing between FSS (Earth-to-space) and the BSS feeder link in the band 14.5-14.8GHz is still feasible today.

Quote from section 4.2 of Recommendation ITU-R S.1063:

“

**Use of the 14.5-14.8 GHz frequency band**

WARC ORB-88 adopted a Plan for BSS feeder links in the 14.5-14.8 GHz band. This Plan, which appears in RR Appendix S30A contains assignments to 19 countries in Africa and Asia, uses 17 orbital locations between 37° W and 128° E and divides the band into 14 channels spaced 19.18 MHz apart.

The results of two studies into sharing between the FSS and BSS feeder links in this band are summarized in this section. These studies were carried out as part of the ex-CCIR preparation for WARC-92. Since that Conference decided that use of the band by the FSS should remain restricted to BSS feeder links, this section is included merely to illustrate the feasibility of 14/11 GHz band sharing.

BSS feeder link transmission parameters were taken as those published in RR Appendix S30A. Two types of FSS carriers were assumed, FM-TV and digital (IDR – 64 kbit/s and 8 448 kbit/s).

The interference analysis was based on the assumption of co-channel, co-coverage interference and no account was taken of polarization discrimination.

The key results showed that:

– an orbital separation of more than 2.5° is sufficient to protect the BSS feeder link assignments from the FSS under worst case co-coverage and co-frequency conditions;

– for smaller orbital separations between FSS and BSS satellites, FSS TV could use the bands with constraints on the uplink earth station locations within the BSS coverage area;

– the required orbital separations could be reduced if frequency separation is maintained between FSS TV and BSS assigned channel frequencies, and this appears to be possible;

– the FSS carriers with higher bit rates can use the band 14.5-14.8 GHz in a way similar to FSS TV;

– the sensitive carriers of the FSS can use the band by frequency planning the carriers around the BSS TV carriers and/or by avoiding certain contours of the BSS satellite antenna, depending on the orbital separation between the satellites.

To summarize, the studies show that coexistence of the FSS and WARC ORB-88 BSS feeder link assignments in the band 14.5-14.8 GHz is feasible. The constraints on FSS networks using this band are not onerous. For a new network to be positioned in most of the GSO, the constraints can be avoided altogether with appropriate choice of orbital location. For networks with limited orbital flexibility, the measures required are likely, in general, to be no greater in severity as compared to those experienced in normal coordination between FSS networks in current bands.”

There might be a need to revise the parameters on which the above conclusions are based, and the potential cumulative effect of FSS deployment in the 14.5-14.8 GHz band on the feeder-links should also be taken into account.

In examining the possibility for FSS Earth-to-space allocations in the 14.5-14.8 GHz band, the interference scenarios could be evaluated using Article 7 of Appendix 30A (AP 30A), which refers to the protection criteria of Annex 4 of AP 30A, and Article 6 of AP 30A.

**Consideration on sharing with the feeder link for the BSS Plan of AP 30A under footnote 5.510 in the band 14.5-14.8 GHz**

1) The band 14.5-14.8 GHz is part of the Regions 1 and 3 feeder link for the BSS Plan, contained in AP 30A, for countries outside Europe.

2) Additions to the Region 1 and 3 List of feeder link assignments for the BSS Plan can be made through the successful application of the Article 4 procedures of AP 30A.

3) The location of the transmitting earth stations of the above mentioned assignments in the Plan or in the List, could be at any point within the service area of its associated satellite network.

4) Considering that this band is already allocated to the fixed-satellite service in the Earth-to-space direction, sharing studies should include a review of regulatory procedures, taking into account sharing and compatibility studies, without placing undue constraints on the existing services in the band.

5) If consideration is given to the use of 14.5-14.8 GHz bands, appropriate measures need to be taken with regard to the AP 30A Plans and List to ensure the integrity and full protection of these bands, specifically taking into account:

a) required coordination procedures between AP 30A networks and any new fixed-satellite service utilization of the bands.

b) the need for transmitting earth stations in the AP 30A Plans and List to be able to be located anywhere within their respective service areas.

c) the need to appropriately protect assignments in the AP 30A Plans and List from any new fixed-satellite service utilization of the bands, including the accumulative aggregated interference levels from all other allotments and assignments from AP 30A in such a way that the level of interference (level of equivalent protection margin and/or C/I level) currently specified in AP 30A is not exceeded.

* 1. **Frequency band: 14.8-15.35 GHz**

The allocations in this band according to RR Article 5 are as shown below:

|  |
| --- |
| 14.8-15.35 FIXED MOBILE Space research 5.339 |

5.339 The bands 1 370-1 400 MHz, 2 640-2 655 MHz, 4 950-4 990 MHz and 15.20-15.35 GHz are also allocated to the space research (passive) and Earth exploration-satellite (passive) services on a secondary basis.

Table 7: Comparison of services allocation in the bands 14.5-14.8 GHz and 14.8-15.35 GHz

|  |  |
| --- | --- |
| 14.5-14.8  GHz | 14.8-15.35  GHz |
| FIXED*Identical*MOBILESpace researchFIXED-SATELLITE (Earth-to-space) 5.510 | FIXEDMOBILESpace research5.339 |

Table 7 shows a comparison of service allocation in the bands 14.5-14.8  GHz and 14.8-15.35 GHz. Noting the applications and technical characteristics of fixed service, mobile service and space research service in the bands 14.5-14.8  GHz and 14.8-15.35 GHz are very similar, the allocation to “FIXED-SATELLITE (Earth-to-space) 5.510” in the 14.5-14.8 GHz band demonstrates the possibility of co-existence of FSS (Earth-to-space) with existing services in the band of 14.8-15.35 GHz.

Although the allocation of FSS in the 14.5-14.8 GHz band is limited to feeder links for the broadcasting-satellite service (RR Appendix **30A**) and is reserved for countries outside Europe, the technical characteristics of planned and unplanned FSS are very similar following Recommendation ITU-R S.1328-4. Thus, the sharing of unplanned FSS (Earth-to-space) with existing services in the 14.8-15.35 GHz band may be feasible subject to the results of sharing studies. The operational limitations in the band of 14.8-15.35 GHz will depend on the results of sharing studies taking into account the compatibility with existing services in this band.

**Sharing with fixed service, mobile service and space research service in the band 14.8-15.35 GHz:**

A list of relevant recommendations that may be useful for sharing studies in the band of 14.8-15.35 GHz is summarized in Table 8.

Table 8: Summary of relevant recommendations that may be useful for
sharing studies in the band 14.8-15.35 GHz

|  |  |
| --- | --- |
| Service: | Relevant Recommendation: |
| Fixed Service | Recommendation ITU-R F.758-5Recommendation ITU-R F.636-4Recommendation ITU-R F.1107Recommendation ITU-R F.699-7Recommendation ITU-R F.1245-2Recommendation ITU-R F.1333Recommendation ITU-R F.1336-3Recommendation ITU-R F.1777  |
| Mobile Service | In the absence of specific characteristics for the mobile service in this band, mobile system characteristics are assumed to be similar to those for fixed systems. (Has to check with relevant ITU Working Parties responsible for studies on mobile services on the validity of this assumption.)Recommendation ITU-R M.1824 |
| Earth exploration-satellite (passive) | Recommendation ITU-R RS.515Recommendation ITU-R RS.2017 |
| Radio astronomy | Recommendation ITU-R RA.769 (adjacent band)Recommendation ITU-R RA.1513-1 |
| Space research | Recommendation ITU-R SA.1018Recommendation ITU-R SA.1155PDR Recommendation ITU-R SA.1414PDR Recommendation ITU-R SA.1626 |

* + 1. **Sharing with fixed service in the band 14.8-15.35GHz:**

The studies as contained in section 5.2.1.1.1 concerning the sharing between FSS (Earth-to-space) and FS in the band of 14.5-14.8GHz are equally applicable to the 14.8-15.35GHz band. The slightly higher frequency would lead to marginally shorter coordination distance and the required separation distance, a quick calculation indicate the improvement is in the order of less than 3km using RR AP7 method, therefore it is possible to assume the result is the same as those contained in section 5.2.1.1.1 The detail of the studies could be referred to section 5.2.1.1.1.

FSS(Earth-to-space) and FS share well with each other. Experience has shown that, in many instances, separation distances as small as a few kilometres, when allowing for typical terrain and shielding, are achievable.

On the conditions that the location of FS stations are known, the deployment of FS terminals are not ubiquitous and both FSS (Earth-to-space) and FS station are operated under license, with only as small as a few kilometres of separation distance in many instances, sharing between FS and FSS can be considered feasible. On the other hand, some Administrations deploy the FS stations in high density for domestic use without registering in the ITU database. In such a case, careful consideration of such usage would need to be taken into account like other frequency bands shared between the FS and the FSS.

In terms of international coordination, even using the worst case calculation method RR AP7 using by the ITU, in many of the cases, coordination is not required.

In the case where international coordination is unavoidable, experience indicate that the actual required separation distances is significantly shorter than the coordination distance calculated using the RR AP7 method, it is therefore expected the coordination should not lead to a heavy burden to the administration.

* + 1. **Sharing with mobile service in the band 14.8-15.35GHz:**

There are no earth stations for the mobile service in ITU-R Region 3 as recorded in the ITU database as of 29.05.2012 (BR IFIC 2720). Also, according to APT Report on Information of Mobile Operator’s Frequencies, Technologies and License durations in Asia Pacific countries ([APT/AWG/Rep-15(Rev. 1)](http://www.apt.int/sites/default/files/Upload-files/AWG/APT-AWG-REP-15-R1-APT_Report_on_Mobile_Freq-Tech-License.docx)), the frequency range 14.8-15.35 GHz was not used for mobile service in Asia Pacific countries. However, the services covered in the APT Report are not fully inclusive and it is noted that the registration of terrestrial systems, including mobile systems in MIFR is voluntary on the part of the Administrations and some Administrations assign this frequency band to the mobile service for domestic use without registering on the ITU database. Therefore, careful consideration of such domestic use would be required.

* 1. **Frequency band: 15.4-15.43 GHz**

The allocations in this band according to RR Article 5 are as shown below:

|  |
| --- |
| * + - 1. RADIOLOCATION 5.511E 5.511F

 AERONAUTICAL RADIONAVIGATION 5.511D |

**5.511E** In the frequency band 15.4-15.7 GHz, stations operating in the radiolocation service shall not cause harmful interference to, or claim protection from, stations operating in the aeronautical radionavigation service. (WRC-12)

**5.511F** In order to protect the radio astronomy service in the frequency band 15.35-15.4 GHz, radiolocation stations operating in the frequency band 15.4-15.7 GHz shall not exceed the power flux-density level of −156 dB(W/m2) in a 50 MHz bandwidth in the frequency band 15.35-15.4 GHz, at any radio astronomy observatory site for more than 2 per cent of the time. (WRC-12)

**5.511D** Fixed-satellite service systems for which complete information for advance publication has been received by the Bureau by 21 November 1997 may operate in the bands 15.4-15.43 GHz and 15.63-15.7 GHz in the space-to-Earth direction and 15.63-15.65 GHz in the Earth-to-space direction. In the bands 15.4-15.43 GHz and 15.65-15.7 GHz, emissions from a non-geostationary space station shall not exceed the power flux-density limits at the Earth’s surface of –146 dB(W/(m2.MHz)) for any angle of arrival. In the band 15.63-15.65 GHz, where an administration plans emissions from a non-geostationary space station that exceed –146 dB(W/(m2.MHz)) for any angle of arrival, it shall coordinate under No. **9.11A** with the affected administrations. Stations in the fixed-satellite service operating in the band 15.63‑15.65 GHz in the Earth-to-space direction shall not cause harmful interference to stations in the aeronautical radionavigation service (No. **4.10** applies). (WRC-97)

A list of relevant ITU-R Recommendations and Reports that may be useful for sharing studies is summarized in Table 9.

Table 9

Summary of relevant Recommendations/Reports that may be useful for
sharing studies in the band 15.4-15.43 GHz

|  |  |  |
| --- | --- | --- |
| Service: | Relevant Recommendation: | Relevant Report |
| Radiolocation | Recommendation ITU-R M.1730Recommendation ITU-R M.1461Recommendation ITU-R M.1851 | Report ITU-R М.2221Report ITU-R М.2170 |
| Aeronautical Radionavigation | Recommendation ITU-R S.1340 | Report ITU-R М.2221Report ITU-R M.2230 |
| Radioastronomy | Report ITU-R RA.769 | Report ITU-R М.2170Report ITU-R М.2221 |
| Fixed-satellite | Recommendation ITU-R S.1340 |  |

* 1. **Frequency band: 15.43-15.63 GHz**

The band is allocated to the aeronautical radionavigation service (ARNS) and radiolocation service on a primary basis. The band is also allocated to the FSS (Earth-to-space and space-to-Earth), limited to use for the feeder links of non-geostationary systems in the MSS through RR No. 5.511A.

The allocations in this band according to RR Article 5 are as shown below:

|  |
| --- |
| * + - 1. FIXED-SATELLITE (Earth-to-space) 5.511A

RADIOLOCATION 5.511E 5.511FAERONAUTICAL RADIONAVIGATION 5.511C |

**5.511A** The band 15.43-15.63 GHz is also allocated to the fixed-satellite service (space‑to‑Earth) on a primary basis. Use of the band 15.43-15.63 GHz by the fixed-satellite service (space-to-Earth and Earth-to-space) is limited to feeder links of non-geostationary systems in the mobile-satellite service, subject to coordination under No. **9.11A**. The use of the frequency band 15.43-15.63 GHz by the fixed-satellite service (space-to-Earth) is limited to feeder links of non‑geostationary systems in the mobile-satellite service for which advance publication information has been received by the Bureau prior to 2 June 2000. In the space-to-Earth direction, the minimum earth station elevation angle above and gain towards the local horizontal plane and the minimum coordination distances to protect an earth station from harmful interference shall be in accordance with Recommendation ITU-R S.1341. In order to protect the radio astronomy service in the band 15.35-15.4 GHz, the aggregate power flux-density radiated in the 15.35-15.4 GHz band by all the space stations within any feeder-link of a non-geostationary system in the mobile-satellite service (space-to-Earth) operating in the 15.43-15.63 GHz band shall not exceed the level of −156 dB(W/m2) in a 50 MHz bandwidth, into any radio astronomy observatory site for more than 2% of the time. (WRC-2000)

**5.511E** In the frequency band 15.4-15.7 GHz, stations operating in the radiolocation service shall not cause harmful interference to, or claim protection from, stations operating in the aeronautical radionavigation service. (WRC-12)

**5.511F** In order to protect the radio astronomy service in the frequency band 15.35-15.4 GHz, radiolocation stations operating in the frequency band 15.4-15.7 GHz shall not exceed the power flux-density level of −156 dB(W/m2) in a 50 MHz bandwidth in the frequency band 15.35-15.4 GHz, at any radio astronomy observatory site for more than 2 per cent of the time. (WRC-12)

**5.511C** Stations operating in the aeronautical radionavigation service shall limit the effective e.i.r.p. in accordance with Recommendation ITU-R S.1340. The minimum coordination distance required to protect the aeronautical radionavigation stations (No. **4.10** applies) from harmful interference from feeder-link earth stations and the maximum e.i.r.p. transmitted towards the local horizontal plane by a feeder-link earth station shall be in accordance with Recommendation ITU-R S.1340. (WRC-97)

A list of relevant ITU-R Recommendations and Reports that may be useful for sharing studies is summarized in Table 10.

Table 10

Summary of relevant Recommendations/Reports that may be useful for
sharing studies in the band 15.43-15.63 GHz

|  |  |  |
| --- | --- | --- |
| Service: | Relevant Recommendation: | Relevant Report |
| Radiolocation | Recommendation ITU-R M.1730Recommendation ITU-R M.1461Recommendation ITU-R M.1851 | Report ITU-R М.2221Report ITU-R М.2170 |
| Aeronautical Radionavigation | Recommendation ITU-R S.1340 | Report ITU-R М.2221Report ITU-R M.2230 |
| Radioastronomy | Report ITU-R RA.769 | Report ITU-R М.2170Report ITU-R М.2221 |
| Fixed-satellite | Recommendation ITU-R S.1340 |  |

* + 1. **Review of studies performed in the band 15.43-15.63 GHz:**

**Aeronautical radionavigation service (ARNS)**

This band is allocated to the ARNS on a primary basis and provision RR No. 4.10 (addressing safety-related services) applies. The entire 15.43-15.63 GHz band is used in several countries for aircraft landing systems (ALS). The characteristics of aeronautical radionavigation systems (including ALS) which operate in the band 15.4-15.7 GHz are contained in Annex 1 of Recommendation ITU‑R S.1340 as well as in Report ITU-R M.2170.

* 1. **Frequency band: 15.63-15.7 GHz**

The allocations in this band according to RR Article 5 are as shown below:

|  |
| --- |
| **15.63-15.7** RADIOLOCATION 5.511E 5.511FAERONAUTICAL RADIONAVIGATION 5.511D |

**5.511E** In the frequency band 15.4-15.7 GHz, stations operating in the radiolocation service shall not cause harmful interference to, or claim protection from, stations operating in the aeronautical radionavigation service. (WRC-12)

**5.511F** In order to protect the radio astronomy service in the frequency band 15.35-15.4 GHz, radiolocation stations operating in the frequency band 15.4-15.7 GHz shall not exceed the power flux-density level of −156 dB(W/m2) in a 50 MHz bandwidth in the frequency band 15.35-15.4 GHz, at any radio astronomy observatory site for more than 2 per cent of the time. (WRC-12)

**5.511D** Fixed-satellite service systems for which complete information for advance publication has been received by the Bureau by 21 November 1997 may operate in the bands 15.4-15.43 GHz and 15.63-15.7 GHz in the space-to-Earth direction and 15.63-15.65 GHz in the Earth-to-space direction. In the bands 15.4-15.43 GHz and 15.65-15.7 GHz, emissions from a non-geostationary space station shall not exceed the power flux-density limits at the Earth’s surface of –146 dB(W/(m2.MHz)) for any angle of arrival. In the band 15.63-15.65 GHz, where an administration plans emissions from a non-geostationary space station that exceed –146 dB(W/(m2.MHz)) for any angle of arrival, it shall coordinate under No. **9.11A** with the affected administrations. Stations in the fixed-satellite service operating in the band 15.63‑15.65 GHz in the Earth-to-space direction shall not cause harmful interference to stations in the aeronautical radionavigation service (No. **4.10** applies). (WRC-97)

A list of relevant ITU-R Recommendations and Reports that may be useful for sharing studies is summarized in Table 11.

Table 11

Summary of relevant Recommendations/Reports that may be useful for
sharing studies in the band 15.63-15.7 GHz

|  |  |  |
| --- | --- | --- |
| Service: | Relevant Recommendation: | Relevant Report |
| Radiolocation | Recommendation ITU-R M.1730Recommendation ITU-R M.1461Recommendation ITU-R M.1851 | Report ITU-R М.2221Report ITU-R М.2170 |
| Aeronautical Radionavigation | Recommendation ITU-R S.1340 | Report ITU-R М.2221Report ITU-R M.2230 |
| Radioastronomy | Report ITU-R RA.769 | Report ITU-R М.2170Report ITU-R М.2221 |
| Fixed-satellite | Recommendation ITU-R S.1340 |  |

* 1. **Frequency band: 15.7-16.6 GHz**

The allocations in this band according to RR Article **5** are as shown below:

|  |
| --- |
| **15.7-16.6** RADIOLOCATION 5.512 5.513 |

**5.512** *Additional allocation:* in Algeria, Angola, Saudi Arabia, Austria, Bahrain, Bangladesh, Brunei Darussalam, Cameroon, Congo (Rep. of the), Costa Rica, Egypt, El Salvador, the United Arab Emirates, Eritrea, Finland, Guatemala, India, Indonesia, Iran (Islamic Republic of), Jordan, Kenya, Kuwait, Lebanon, Libya, Malaysia, Mali, Morocco, Mauritania, Montenegro, Nepal, Nicaragua, Niger, Oman, Pakistan, Qatar, Syrian Arab Republic, the Dem. Rep. of the Congo, Serbia, Singapore, Somalia, Sudan, South Sudan, Tanzania, Chad, Togo and Yemen, the band 15.7-17.3 GHz is also allocated to the fixed and mobile services on a primary basis. (WRC-12)

**5.513** *Additional allocation:* in Israel, the band 15.7-17.3 GHz is also allocated to the fixed and mobile services on a primary basis. These services shall not claim protection from or cause harmful interference to services operating in accordance with the Table in countries other than those included in No. **5.512**.

* + 1. **Review of studies performed in the band 15.7-16.6 GHz:**

A list of relevant recommendations that may be useful for sharing studies in the band 15.7-16.6 GHz is summarized in Table 12.

Table 12: Summary of relevant recommendations that may be useful for
sharing studies in the band 15.7-16.6 GHz

|  |  |
| --- | --- |
| Service | Relevant Recommendations/Reports |
| Radiolocation | Recommendation ITU-R M.1730Recommendation ITU-R M.1461Recommendation ITU-R M.1851Report ITU-R M.2170 |
| Fixed | Recommendation ITU-R F.699Recommendation ITU-R F.758 Recommendation ITU-R F.1107 Recommendation ITU-R F.1245Recommendation ITU-R F.1333Recommendation ITU-R F.1336 Recommendation ITU-R F.1777 |
| Mobile | Recommendation ITU-R M.1824 |

Sharing studies for additional allocation to FSS (Earth-to-space) could be conducted in the band of 15.7-16.6 GHz taking into consideration the current allocations of radiolocation, fixed and mobile services in this band. This proposal is grounded on the fact that it is possible to have allocations for FSS (Earth-to-space), radiolocation, fixed and mobile (additional allocations via footnotes) services as indicated in the frequency band of 13.75-14 GHz. In this band, it is noted that there are antenna size and power flux-density limits imposed on the operation of FSS in order to protect the radiolocation services through RR No. **5.502**. In addition, the FSS Earth stations in this band are also subject to the off-axis e.i.r.p. limits in RR Nos. **22.26**, **22.27** and **22.28** as mentioned in RR No. **22.29**.

|  |
| --- |
| **13.75-14** FIXED-SATELLITE (Earth-to-space) 5.484A RADIOLOCATION Earth exploration-satellite Standard frequency and time signal-satellite (Earth-to-space) Space research 5.499 5.500 5.501 5.502 5.503 |

**5.484A** The use of the bands 10.95-11.2 GHz (space-to-Earth), 11.45-11.7 GHz (space-to-Earth), 11.7-12.2 GHz (space-to-Earth) in Region 2, 12.2-12.75 GHz (space-to-Earth) in Region 3, 12.5-12.75 GHz (space-to-Earth) in Region 1, 13.75-14.5 GHz (Earth-to-space), 17.8-18.6 GHz (space-to-Earth), 19.7-20.2 GHz (space-to-Earth), 27.5-28.6 GHz (Earth-to-space), 29.5-30 GHz (Earth-to-space) by a non-geostationary-satellite system in the fixed-satellite service is subject to application of the provisions of No. **9.12** for coordination with other non-geostationary satellite systems in the fixed-satellite service. Non-geostationary-satellite systems in the fixed-satellite service shall not claim protection from geostationary-satellite networks in the fixed-satellite service operating in accordance with the Radio Regulations, irrespective of the dates of receipt by the Bureau of the complete coordination or notification information, as appropriate, for the non-geostationary-satellite systems in the fixed satellite service and of the complete coordination or notification information, as appropriate, for the geostationary satellite networks, and No. **5.43A** does not apply. Non-geostationary-satellite systems in the fixed-satellite service in the above bands shall be operated in such a way that any unacceptable interference that may occur during their operation shall be rapidly eliminated. (WRC-2000)

**5.499** *Additional allocation:* in Bangladesh and India, the band 13.25-14 GHz is also allocated to the fixed service on a primary basis. In Pakistan, the band 13.25-13.75 GHz is allocated to the fixed service on a primary basis. (WRC-12)

**5.500** *Additional allocation:* in Algeria, Angola, Saudi Arabia, Bahrain, Brunei Darussalam, Cameroon, Egypt, the United Arab Emirates, Gabon, Indonesia, Iran (Islamic Republic of), Iraq, Israel, Jordan, Kuwait, Lebanon, Madagascar, Malaysia, Mali, Morocco, Mauritania, Niger, Nigeria, Oman, Qatar, the Syrian Arab Republic, Singapore, Sudan, South Sudan, Chad and Tunisia, the band 13.4-14 GHz is also allocated to the fixed and mobile services on a primary basis. In Pakistan, the band 13.4-13.75 GHz is also allocated to the fixed and mobile services on a primary basis. (WRC-12)

**5.501** *Additional allocation:* in Azerbaijan, Hungary, Japan, Kyrgyzstan, Romania and Turkmenistan, the band 13.4-14 GHz is also allocated to the radionavigation service on a primary basis. (WRC-12)

**5.502** In the band 13.75-14 GHz, an earth station of a geostationary fixed-satellite service network shall have a minimum antenna diameter of 1.2 m and an earth station of a non-geostationary fixed-satellite service system shall have a minimum antenna diameter of 4.5 m. In addition, the e.i.r.p., averaged over one second, radiated by a station in the radiolocation or radionavigation services shall not exceed 59 dBW for elevation angles above 2° and 65 dBW at lower angles. Before an administration brings into use an earth station in a geostationary-satellite network in the fixed-satellite service in this band with an antenna diameter smaller than 4.5 m, it shall ensure that the power flux-density produced by this earth station does not exceed:

* -115 dB(W/(m2 · 10 MHz)) for more than 1% of the time produced at 36 m above sea level at the low water mark, as officially recognized by the coastal State;
* -115 dB(W/(m2 · 10 MHz)) for more than 1% of the time produced 3 m above ground at the border of the territory of an administration deploying or planning to deploy land mobile radars in this band, unless prior agreement has been obtained.

For earth stations within the fixed-satellite service having an antenna diameter greater than or equal to 4.5 m, the e.i.r.p. of any emission should be at least 68 dBW and should not exceed 85 dBW. (WRC-03)

**5.503** In the band 13.75-14 GHz, geostationary space stations in the space research service for which information for advance publication has been received by the Bureau prior to 31 January 1992 shall operate on an equal basis with stations in the fixed-satellite service; after that date, new geostationary space stations in the space research service will operate on a secondary basis. Until those geostationary space stations in the space research service for which information for advance publication has been received by the Bureau prior to 31 January 1992 cease to operate in this band:

* in the band 13.77-13.78 GHz, the e.i.r.p. density of emissions from any earth station in the fixed-satellite service operating with a space station in geostationary-satellite orbit shall not exceed:
1. 4.7*D* 28 dB(W/40 kHz), where *D* is the fixed-satellite service earth station antenna diameter (m) for antenna diameters equal to or greater than 1.2 m and less than 4.5 m;
2. 49.2 20 log(*D*/4.5) dB(W/40 kHz), where *D* is the fixed-satellite service earth station antenna diameter (m) for antenna diameters equal to or greater than 4.5 m and less than 31.9 m;
3. 66.2 dB(W/40 kHz) for any fixed-satellite service earth station for antenna diameters (m) equal to or greater than 31.9 m;
4. 56.2 dB(W/4 kHz) for narrow-band (less than 40 kHz of necessary bandwidth) fixed satellite service earth station emissions from any fixed-satellite service earth station having an antenna diameter of 4.5 m or greater;
* the e.i.r.p. density of emissions from any earth station in the fixed-satellite service operating with a space station in non-geostationary-satellite orbit shall not exceed 51 dBW in the 6 MHz band from 13.772 to 13.778 GHz.

Automatic power control may be used to increase the e.i.r.p. density in these frequency ranges to compensate for rain attenuation, to the extent that the power flux-density at the fixed-satellite service space station does not exceed the value resulting from use by an earth station of an e.i.r.p. meeting the above limits in clear-sky conditions. (WRC-03)

There is possibility that protection could also be accorded to the affected services in the band 15.7-16.6 GHz through similar mechanisms as used in the band 13.75-14 GHz. However, this proposal would be subject to further technical studies and regulatory considerations, to ensure compatibility with the existing services and allocations in the band 15.7-16.6 GHz.

1. **Applicable Interference Mitigation Techniques**

When a certain frequency band which is already allocated to an existing service is considered allocated to the new service, compatibility of this new service with the existing services normally needs to be considered. To reduce interference and enhance compatibility to allow frequency sharing, interference mitigation techniques have been studied. Interference mitigation techniques and their effectiveness would depend on several factors such as local usage of the band, system characteristics, geographical situation and operating scheme of the systems.

As the deployment of FSS (Earth-to-space) stations is subject to licensing by the country on whose territory they are located and as the deployment is at the discretion of the licensing administration, mitigation technique could be applied effectively to reduce the required separation distance with the stations of other services.

This section shows some typical interference mitigation techniques applicable for the satellite communication systems in frequency sharing situation with other radio systems. These techniques can be applied individually or in combination.

* 1. **Adaptive power control**

Adaptive power control means that the transmitted power is limited to the level necessary to obtain the required service quality. Studies have shown that the use of adaptive uplink power control will ease overall coordination between FSS and other radio networks.

Adaptive uplink power control may be used by;

* terrestrial networks to maintain system performance during times of increased levels of interference by increasing the power and;
* by Earth stations to reduce the power and correspondingly the interference by decreasing the transmit power to the lowest possible level to meet the performance objectives. This could also include uplink power control to allow operation at low power levels during non-faded conditions.

* 1. **Use of low side lobe antennas**

When the Earth station transmits power to the space station, the terrestrial stations may receive interference from the Earth station. In this case, the e.i.r.p towards the local horizon of the Earth station will be dominant in determining the level of interference encountered by the terrestrial receivers. An antenna with low off-axis antenna gain (sidelobes) would reduce the interference towards the horizon and would reduce the interference into terrestrial receivers for the same levels of e.i.r.p. towards the space station (on-axis e.i.r.p.). This would be very helpful to obtain compatibility between an Earth station and terrestrial receivers.

* 1. **Minimum operational elevation angle**

This could offer significant signal discrimination and therefore reduce the interference to the terrestrial station. This technique could be implemented relatively easily by an administration in controlling the orbital arc or satellites to which uplinks are licensed in their country.

* 1. **Geographic isolation and separation distance**

Various studies have showed that geographic isolation of earth station is an effective interference mitigation method, especially in respect of FS. The number of the FSS Earth stations as well as those of terrestrial stations is normally relatively small and confined to fixed known locations or geographical areas. This allows for administrations ensuring sufficient separation between transmitting earth stations and receiving terrestrial stations to avoid harmful interference. In many cases the Earth station and/or terrestrial stations is surrounded by mountains or buildings which blocks the line of sight to the terrestrial stations. This will lead to significantly shorter separation distances.

In adopting this method, the estimation of the minimum separation distance is very important to increase the possibility of this method and the minimum separation distance would be determined by the acceptable interference level of the interfered stations and the path loss in the region.

* 1. **Natural or man-made site shielding**

This method is very effective in adding additional diffraction or other losses in the vicinity of the transmitting earth station and/or the receiving terrestrial station to reduce the received interference signal by the terrestrial station.

The additional diffraction loss could be calculated in accordance with Recommendation ITU-R P.526. The required separation distance of the FSS(Earth-to-space) stations and terrestrial stations could therefore be reduced significantly by applying this mitigation technique.

* 1. **Reduction of antenna height**

Reduction of antenna height of the transmitting earth station and/or the receiving terrestrial station could lead to addition diffraction loss between the stations.

The additional diffraction loss could be calculated in accordance with Recommendation ITU-R P.526. This could reduce the required separation distance of the FSS(Earth-to-space) stations and terrestrial stations.

* 1. **Adaptive channel assignment**

This section is addressing techniques:

• wherein transmitting earth stations and receiving terrestrial stations are operated in identified, separated areas;

• wherein transmitting earth stations and receiving terrestrial stations operate in the same geographical area at the same time and use different portions of the frequency band,
or

• where transmitting earth stations and receiving terrestrial stations use the band at different times in the same geographical area.

Adaptive channel assignment is currently receiving a lot of interest from the research community as it allows high flexibility for two services to co-exist by exploiting spectrum holes and non-utilized capacity. The distribution of radio resources could either be static and/or dynamic depending on the local situation.

The application of dynamic adaptive channel assignment assumes one “primary” service and one “secondary” service based upon pre-defined criteria (e.g. national preferences, geographical location or operational frequency) and consists of two main functions.

* Spectrum opportunity identification:

It is necessary to identify available frequency bands that can be used by a transmitter at a given location and how it can be used.

For a band to be available at a given location, knowledge about the usage of that band by other users in this location and the impact on this, is required.

* Spectrum opportunity exploitation:

Once spectrum opportunities are detected, prospective users can decide whether and how to exploit them within the specified limitations and if service objective can be met.

1. **Conclusions**

In ITU-R Region 3, the spectrum allocated to the unplanned FSS in the Earth-to-space and space-to-Earth directions in the 10-15 GHz is 750 MHz and 1 050 MHz, respectively. The difference of capacity may create bandwidth limitation in the Earth-to-space direction and it may restrict satellite operators from fully utilizing the limited frequency resource. If additional frequency bands are considered in order to resolve the difficulties, the studies on compatibility with incumbent services and development of frequency sharing criteria should be required.

The frequency band 13.25 – 17 GHz is significant for both satellite and terrestrial radio communication services because some radio communication and/or broadcasting systems have already been operated commercially in the band and EESS/ARNS systems are very sensitive to radio interference. Additionally, it is noted that the BSS feeder links in the 14.5 – 14.8 GHz pursuant to Appendix 30A of Radio Regulations (Planned Bands) is very important especially to developing countries.

Therefore, the studies on additional frequency for FSS in the Unplanned Ku band should be conducted based on the relevant ITU-R recommendations and reports listed in previous sections, including the consideration of bands within the range and taking into account appropriate protection for the existing and planned systems under current frequency allocations.

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1. Accounts for current frequency reuse involving spot beams. Current frequency reuse is on the order of 1.2. [↑](#footnote-ref-1)
2. The peak antenna gain is estimated at the center of the band (14.25 GHz) and 65% efficiency. [↑](#footnote-ref-2)
3. The 3 dB beamwidth was calculated assuming non-uniform illumination using 70° as the coefficient relating the ratio λ/D to the beamwidth (θ3dB=70λ/D). [↑](#footnote-ref-3)
4. This level is derived based on Recommendation ITU-R S.728 and is 8 dB higher than one known administration’s domestic rules for routine licensing of VSAT earth stations. Currently, there are a small number of ESs operating at this power level. [↑](#footnote-ref-4)
5. This level is equivalent to one known administration’s domestic rules for routine licensing of FSS earth stations. [↑](#footnote-ref-5)
6. Sharing studies could be conducted with a value as low as PSD of -60 dBW/Hz. Should studies show that sharing is only possible at this lower PSD level, regulatory considerations would need to be developed to match these values for all antenna sizes. [↑](#footnote-ref-6)
7. The maximum e.i.r.p. density at the antenna port is the actual maximum e.i.r.p. seen in operation. It corresponds to gains values of 43.5 dBi (1.2 m), 52 dBi (3.3 m), and 53.5 dBi (3.9 m) for VSAT, wideband, and point-to-point respectively, transmitting the maximum PSD quoted in the table. [↑](#footnote-ref-7)
8. Recommendation ITU-R S.728-1, “*Maximum permissible level of off-axis e.i.r.p. density from very small aperture terminals (VSATs)*”. [↑](#footnote-ref-8)
9. 500 MHz, dual polarization [↑](#footnote-ref-9)
10. See draft revision Recommendation ITU-R SA.1414. [↑](#footnote-ref-10)