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Operation of earth stations in motion communicating with geostationary space stations in the fixed-satellite service allocations at 17.7-19.7 GHz and 27.5-29.5 GHz

S Series

Fixed-satellite service

Foreword

The role of the Radiocommunication Sector is to ensure the rational, equitable, efficient and economical use of the radio-frequency spectrum by all radiocommunication services, including satellite services, and carry out studies without limit of frequency range on the basis of which Recommendations are adopted.

The regulatory and policy functions of the Radiocommunication Sector are performed by World and Regional Radiocommunication Conferences and Radiocommunication Assemblies supported by Study Groups.

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

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REPORT ITU-R S.2464-0

Operation of earth stations in motion communicating with geostationary space stations in the fixed-satellite service allocations at 17.7-19.7 GHz and 27.5-29.5 GHz

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NOTE – In this Report, there are several areas with several options on which agreement was not reached.

1 Introduction

In *resolves* 1.5 of Resolution **809 (WRC-15)**, the 2015 World Radiocommunication Conference (WRC-15) resolved "to consider the use of the frequency bands 17.7-19.7 GHz (space-to-Earth) and 27.5-29.5 GHz (Earth-to-space) by earth stations in motion communicating with geostationary space stations in the fixed-satellite service and take appropriate action, in accordance with Resolution **158**" as part of the agenda for WRC-19.

Resolution **158 (WRC-15)**, in its *resolves to invite ITU-R* 1 and 2, invites the ITU-R:

– "to study the technical and operational characteristics and user requirements of different types of earth stations in motion that operate or plan to operate within geostationary FSS allocations in the frequency bands 17.7-19.7 GHz and 27.5-29.5 GHz, including the use of spectrum to provide the envisioned services to various types of earth station in motion and the degree to which flexible access to spectrum can facilitate sharing with services identified in recognizing further *a)* to *n)*";

– "to study sharing and compatibility between earth stations in motion operating with geostationary FSS networks and current and planned stations of existing services allocated in the frequency bands 17.7-19.7 GHz and 27.5-29.5 GHz to ensure protection of, and not impose undue constraints on, services allocated in those frequency bands, and taking into account recognizing further *a)* to *n)*".

Resolution **158 (WRC-15)**, in its *resolves to invite ITU-R* 3, invites the ITU-R to consider the above studies "to develop, for different types of earth stations in motion and different portions of the frequency bands studied, technical conditions and regulatory provisions for their operation".

The earth station in motion (ESIM) addressed in this Report are similar in function and concept to the ESIM addressed in Resolution **156 (WRC-15)** for the frequency bands 19.7-20.2 GHz and 29.5-30 GHz and, for the maritime ESIM case, the earth stations on board vessels (ESV) that were addressed in Resolution **902 (Rev.WRC-15)** by WRC-03 and WRC-15. However, the allocation, sharing and interference environments of the C-band, the Ku-band, and the frequency bands 19.7-20.2 GHz and 29.5-30 GHz are different from those in the 17.7-19.7 GHz/27.5-29.5 GHz frequency bands, and must be addressed accordingly. In particular, it needs to be noted that the frequency bands 19.7-20.2 GHz and 29.5-30 GHz are not allocated to terrestrial services on a primary basis. As background, for ESVs in the 6 GHz and 14 GHz frequency bands, WRC-03, recognizing difficulties in the use of the coordination procedure in Appendix **7** to the Radio Regulations, decided to use the concept of fixed distance and specific antenna diameters for the protection of terrestrial systems. For the frequency bands 19.7-20.2 GHz and 29.5-30 GHz, WRC-15 adjusted some of the criteria but retained the initial concept. ESIM in the frequency bands 17.7-19.7 GHz and 27.5-29.5 GHz are under consideration in accordance with Resolution **158 (WRC-15)**.

As further background, WRC-15 adopted RR No. **5.527A** and Resolution **156 (WRC-15)** specifying the conditions for the use of the 19.7-20.2 GHz and 29.5-30.0 GHz frequency bands by ESIM with some GSO FSS space stations. These conditions include: operating ESIM within the envelope of the

coordination agreement with which the ESIM is associated or in the absence of such agreement to meet the off-axis e.i.r.p. density levels specified in Annex of Resolution **156 (WRC-15)**; that ESIM be subject to permanent monitoring and control by a Network Control and Monitoring Centre (NCMC) or equivalent facility and be capable of receiving and acting upon at least "enable transmission" and "disable transmission" commands; use of techniques to track the associated GSO FSS satellite; and that the satellite network communicating with the ESIM have the capability to limit operations of such earth stations to the territory or territories of administrations having authorized those earth stations.

ESIM that would potentially operate in the 27.5-29.5 GHz and 17.7-19.7 GHz frequency bands are the same as those that operate under RR No. **5.527A** in the frequency bands 19.7-20.2 GHz and 29.5-30.0 GHz. In addressing ESIMs in the 27.5-29.5 GHz and 17.7-19.7 GHz frequency bands, due account is taken of available ITU-R materials such as those included in the CPM Reports to previous WRC's on ESIM and ESV in other FSS bands.

2 ESIM user needs

The user needs addressed by ESIM in the 27.5-29.5 GHz and 17.7-19.7 GHz frequency bands are principally the provision of broadband communications on mobile platforms (e.g. ships, aircraft, land vehicles). The provision of communication service to mobile platforms has traditionally been accomplished by MSS satellite systems using relatively low frequency bands (such as the 1.5 GHz, 1.6 GHz, 2.1 GHz, and 2.4 GHz frequency bands). The frequency bandwidths available to an individual user in these frequency ranges are relatively low, typically a few kHz to a few hundred kHz. The small frequency bandwidths available consequently limit the data rates that can be provided, current capabilities in these frequency bands range from a few kbit/s to around 700 kbit/s in a single channel.

Over the last ten years or so, there has been very high growth in broadband connectivity provided to homes and businesses. The growth has been in both the number of connections and in the data throughput per connection.

For some users requiring high-speed data, terrestrial connectivity solutions are limited or unavailable, particularly for users on ships at sea and aircraft in flight. For aircraft on long-distance routes, an ESIM system can provide continuous broadband connectivity for passengers and crew.

There may be some growth in the number of aircraft connected to broadband networks by ESIM. ESIM operating within the 27.5-29.5 GHz and 17.7-19.7 GHz frequency bands will help satisfy the requirements triggered by this growth.

A similar user need exists for passenger ships, the largest of which can accommodate several thousands of passengers. For ships there is additionally a broadband communication requirement separate to passenger requirements for managing the ship's operation (for example for transmission of engine diagnostics and for access to the corporate network) and for crew communications. A similar growth as for aircraft connectivity can also be witnessed in new and better options for vessels. The number of maritime vessels in service grew by almost 25% between 2012 and 2013. In 2014 over 20 000 vessels were satellite connected and this number is expected to increase to around 50 000 vessels over the next few years only.[1]

Land vehicles with broadband connectivity needs that can be met by ESIM include trains, coaches, vans, trucks and motorhomes. Land ESIM can provide connectivity throughout countries, and may be particularly useful in areas without coverage by terrestrial networks.

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[1] The Comsys Maritime VSAT Report, 4th edition.

In addition to the above, there are ESIM applications for government users and aid organizations which have broadband communication needs for land vehicles, ships and aircraft.

For some ESIM users, especially those onboard ships and aircraft, the desired geographic coverage may virtually be the entire Earth, since the ships operate on almost any sea and aircraft operate over almost any location over land and sea. This leads to a need for ESIM systems to provide continuous and consistent service with very wide or global geographic coverage.

The typical data-rates currently provided by terminals operating in networks serving ESIM are around 100 Mbit/s. Data rates may increase to support higher broadband demand or be lower for some applications that use smaller antennas (but still be higher than what has been available from existing MSS systems).

2.1 ESIM system needs

The growing demand for broadband satellite communications to mobile platforms has led several satellite operators to develop systems to address the need. There are some services provided in C-band (ESVs) and Ku-band (ESVs and AMSS), but the Ka-band frequencies have been identified by several systems focused on the provision of ESIM services and some of the Ka-band frequencies are the subject of WRC-19 agenda item 1.5 (in particular the frequency bands 17.7-19.7 GHz and 27.5-29.5 GHz).

There are several factors which have led to the Ka-band frequencies being a primary focus for new systems:

– new Ka-band systems are capable of providing high capacity per satellite (known as "High Throughput Satellite" (HTS) systems. HTS systems typically use multiple small spot beams to allow the reuse of frequencies many times on the same satellite;

– the large bandwidths available in Ka-band for service links – potentially large bandwidth in each direction – allow for the larger frequency bandwidths to be available to individual terminals.

2.2 Flexible access to spectrum

The frequency bands 19.7-20.2 GHz and 29.5-30.0 GHz may be used by ESIM operating in accordance with Resolution **156 (WRC-15)**. Terrestrial services operate on a primary or secondary basis in a limited number of countries (see RR No. **5.524** and RR No. **5.542**) and therefore the abovementioned frequency bands may accommodate ESIM operations with relatively limited technical and operational constraints.

The frequency bands 17.7-19.7 GHz and 27.5-29.5 GHz are allocated to a number of different services and parts of these bands are used by non-GSO FSS satellite systems, including feeder links for non-GSO MSS systems. The necessary sharing constraints are more complex than in the frequency bands 19.7-20.2 GHz and 29.5-30.0 GHz and consequently, the use of ESIM in some parts of the frequency bands 17.7-19.7 GHz and 27.5-29.5 GHz may not be feasible in some geographic locations due to use by other services, the current use and future availability of which needs to be protected.

For example, the frequency bands 27.8285-28.4445 GHz and 28.8365-29.4525 GHz are used by the fixed service in various countries in Europe on the basis of a harmonized channel plan, and ESIM are not able to transmit on those same frequencies when operated in the national territory of some countries.[2] When ESIM operate in international water and airspace, the responsible operators need to take the necessary steps, such as complying with appropriate technical limits, so as to protect the abovementioned fixed services from harmful interference.

[2] For further details, see CEPT ECC Decision (13)01.

It should be noted that, in order to protect other services sharing the 27.5-29.5 GHz frequency band, different constraints could apply to different types of ESIM, as the interference scenarios with respect to some other services will be different for maritime, aeronautical and land-based ESIM.

Considering the above described restrictions, as ESIM move from one location to another or from one country to another, the operating frequencies used might therefore need to change. To ensure continuity of service and meet user requirements, ESIM operators deem it critical to have the ability to operate within different parts of the frequency bands 17.7-19.7 GHz and 27.5-29.5 GHz, so that they can access the spectrum they need to provide the intended service.

3 Characteristics and spectrum use of ESIM

This section provides characteristics for ESIM for the three scenarios where these terminals are planned to operate with transmissions in the 27.5-29.5 GHz range and reception in the 17.7-19.7 GHz frequency bands. ESIM may operate in three environments:

a) land (receive/transmit),

b) vessel (receive/transmit),

c) aircraft (receive/transmit).

In these three environments, ESIM can operate while stationary and while in motion, under the terms and conditions specified in the Radio Regulations and as authorized by the national authority, and are capable of operating in closely spaced GSO FSS environment. Generally, ESIM consist of a stabilized antenna and associated electronics. The antenna orientation is controlled by an Antenna Control Unit (ACU), which controls the pointing direction of the terminal based on two mechanisms. The first is a stabilized platform that detects the pitch, roll and yaw angles of the platform on which the antenna is installed, and adjusts the azimuth and elevation of the antenna to cancel out the movement of the platform. The second is RF closed-loop tracking[3], which employs an algorithm that minimizes the pointing error by analyzing a pre-determined signal received from the intended satellite. The RF closed-loop automatic tracking technique consists of adjusting the antenna pointing at successive steps by maximizing the received signal strength of a reference or a carrier transmitted by the intended satellite. This signal also ensures that an ESIM will not track an unintended satellite.

Furthermore, such earth stations are designed to inhibit transmissions if the reference signal is not correctly received and decoded. The result of employing these mechanisms is that a very high pointing accuracy in the direction of the intended satellite can be maintained, which results in pointing error of less than ±0.2 degrees. Report ITU-R S.2357-0, "Technical and operational guidelines for earth stations on mobile platforms communicating with geostationary space stations in the fixed-satellite service in the frequency bands 19.7-20.2 GHz and 29.5-30.0 GHz" provides more detail on the methods for satellite tracking and pointing accuracy by ESIM.

In addition to these capabilities, ESIM are subject to permanent monitoring and control by a Network Control and Monitoring Center (NCMC) or equivalent networking facility that will monitor the ESIM to ensure that operations are within the prescribed operational parameters. ESIM are also designed to be capable of receiving and acting upon at least an "enable transmission" and "disable transmission" command from the NCMC, as well as any similar facilities in the country/countries authorizing the ESIM operation. Operators of ESIM should have the ability to immediately reduce or cease transmission if the terminal's antenna mis-pointing may result in interference to other users of the band. Moreover, the notifying administration of the satellite network with which the ESIM communicate and satellite operators of ESIM will maintain a point of contact available 24/7 with the authority and ability to cease transmissions from any operating ESIM through a suitable network control centre.

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[3] Open loop tracking algorithms may also be used that comply with the pointing requirements.

The following sections provide typical parameters for ESIM that will operate on vessels, aircraft and land. Some of the technical characteristics which have an impact on interference to other services may need to be reflected in the regulations for ESIM.

3.1 ESIM characteristics for interference studies

All ESIM, regardless of the platform, can conform to the Resolution **156 (WRC-15)** e.i.r.p. off-axis spectral density mask, which was used for the studies in the frequency range 27.5-29.5 GHz. It should be noted that the mask defined in this Resolution only applied within 3 degrees of the GSO orbit and as such may not be sufficient to protect non-GSO FSS systems. In addition, this mask cannot provide protection for closely spaced GSO FSS satellite networks with an orbital separation of less than 2 degrees, where this mask is not defined.

In the 17.7-19.7 GHz range, the ITU-R BR APL antenna pattern APEREC015V01[4] (based on Recommendation ITU-R S.580-6) can be used for the studies together with a system noise temperature of 189 K.

It should be noted that the pattern APEREC015V01 and terminal system noise temperature of 189 K reflect the average values for stationary FSS earth station operations in the band 17.7-19.7 GHz. These values are also applicable for ESIM studies in the 17.7-19.7 GHz band since ESIM are expected to operate within the same envelope as stationary FSS earth stations.

3.2 Maritime ESIM (M-ESIM)

Delivery of broadband services on vessels can provide maritime users (commercial shipping, energy providers and cruise/ferry operators) with improved communication capabilities for actual information such as access to real-time weather as well as the ability for improved communications similar to those available to land base users.

Maritime ESIM (M-ESIM) consist of a stabilized antenna and relevant electronics enclosed in a protective radome designed for operation aboard vessels. Typically, these earth stations range in diameter from 0.65 m to 1.2 m. Figure 1 shows an example of an M-ESIM.

FIGURE 1

M-ESIM (antenna and radome)

[4] Corresponds to the Antenna Pattern Library used by BR software (see http://www.itu.int/en/ITU-R/software/Pages/ant-pattern.aspx).

Several companies are specialized in the provision of maritime communications equipment manufacture such earth stations. Table 1 provides transmit and receive characteristics of M-ESIM.

TABLE 1

Typical M-ESIM receive and transmit characteristics

Antenna dimensions (cm)	65 to 100
Receive frequency range (GHz)	17.7-19.7
Receive gain (dBi)	40 to 44
Transmit frequency range (GHz)	27.5-29.5
Transmit gain (dBi)	44 to 47.5
Input power (W)	5

3.3 Aeronautical ESIM (A-ESIM)

Delivery of broadband services on aircraft can allow passengers on commercial, business, and general aviation flights to connect to the Internet with their smartphones, tablets and laptops or other RLAN-enabled device.

Aeronautical ESIM (A-ESIM) are of two types depending on how the A-ESIM is mounted on an aircraft. A tail mount A-ESIM is a two-axis stabilized earth station employing a 30 cm or larger aperture diameter antenna. The antenna is a typically a circular aperture with a symmetrical centre-fed design.

The fuselage mounted A-ESIM is a two-axis stabilized earth station employing an asymmetrical rectangular array antenna with typical dimensions of around 65 cm by 19.5 cm. A larger aperture antenna may also be used. This type of A-ESIM is mounted on the top of the aircraft fuselage.

Both types consist of the stabilized antenna and relevant electronics enclosed in a protective radome designed for operation aboard aircraft. Figures 2 and 3 below provide an example of a tail mounted A-ESIM terminal and a fuselage mounted A-ESIM terminal respectively.

FIGURE 2

Tail Mounted A-ESIM

FIGURE 3

Fuselage Mounted A-ESIM (antenna and radome)

The following Tables provides transmit and receive characteristics of A-ESIM stations.

TABLE 2

Typical A-ESIM tail mount receive and transmit characteristics

Antenna dimensions (cm)	30 or larger
Receive frequency range (GHz)	17.7-19.7
Receive gain (dBi)	32.7
Transmit frequency range (GHz)	27.5-29.5
Transmit gain (dBi)	> 37
Input power (W)	5

TABLE 3

Typical A-ESIM fuselage mount receive and transmit characteristics*

Antenna dimensions (cm)	65 by 19.5, or larger
Receive frequency range (GHz)	17.7-19.7
Receive gain (dBi)	36.8
Transmit frequency range (GHz)	27.5-29.5
Transmit gain (dBi)	> 39.8
Input power (W)	5

* The fuselage mounted low-profile aeronautical ESIM have antenna radiation patterns that are not rotationally symmetric about their main beam axis. This factor should be taken into account when estimating the off-axis e.i.r.p. density limits for aeronautical ESIM in the frequency band 27.5-28.6 GHz to protect non-GSO FSS systems.

3.4 Land ESIM (L-ESIM)

Land ESIM can provide broadband communication services to individual subscribers as well as to a wide range of users such as emergency services, public transportation (bus, train), hydrocarbon exploration, mining and construction. L-ESIM use small, lightweight, high-efficiency antennas such as parabolic, low-profile, or phased-arrays. The antenna system includes mechanical or electronic tracking systems to maintain accurate pointing to the target satellite while the vehicle is in motion.

The terminal type is generally chosen based on operational requirements and speed of the land vehicles. For example, off-road vehicles that generally move slower and operate in demanding environments can use small dish antennas, whereas this may not be possible for high-speed vehicles (e.g. trains) due to aerodynamic limitations. Fast moving land vehicles tend to use low-profile array antennas instead.

4 Consideration of ESIM compatibility with other services and applications

In this section, it should be noted that any coordination agreement involving GSO FSS networks with which ESIM operate does not change the regulatory status of those ESIM.

The sharing and compatibility between earth stations in motion operating with geostationary FSS networks and current and planned stations of existing services allocated with services in the frequency bands 17.7-19.7 GHz and 27.5-29.5 GHz need to be assessed to ensure protection of, and not impose undue constraints on, services allocated in those frequency bands. These frequency ranges include allocations for fixed service, fixed-satellite service (GSO and non-GSO), mobile service, feeder links for the broadcasting-satellite service, non-GSO feeder links of the mobile satellite service, and the earth exploration-satellite service.

Table 4 provides information with regard to the services allocated in the 27.5-29.5 GHz frequency band.

In the ITU RR, the frequency band 27.5-29.5 GHz is allocated globally on a primary basis to the fixed-satellite service (FSS) (Earth-to-space) and also to the fixed service (FS) and mobile service (MS) which are used for a variety of different systems by many administrations. These existing services and their future development should be protected without undue constraints.

A portion of this frequency band, the band 28.5-29.5 GHz, is also allocated to the Earth exploration-satellite service (Earth-to-space) on a secondary basis, see RR No. **5.541**. Conditions for using the frequency band 27.5-29.5 GHz are defined in relevant RR footnotes: Nos. **5.484A**, **5.516B**, **5.523A**, **5.523C**, **5.523E**, **5.535A**, **5.537A**, **5.538**, **5.539**, **5.540**, **5.541** and **5.541A** (see Table 4).

TABLE 4

27.5–28.5	FIXED 5.537A FIXED-SATELLITE (Earth-to-space) 5.484A 5.516B 5.539 MOBILE 5.538 5.540
28.5–29.1	FIXED FIXED-SATELLITE (Earth-to-space) 5.484A 5.516B 5.523A 5.539 MOBILE Earth exploration-satellite service (Earth-to-space) 5.541 5.540
29.1–29.5	FIXED FIXED-SATELLITE (Earth-to-space) 5.516B 5.523C 5.523E 5.535A 5.539 5.541A MOBILE Earth exploration-satellite service (Earth-to-space) 5.541 5.540

According to RR No. **5.516B**, Ka-band frequency bands 27.5-27.82 GHz in Region 1, 28.35-28.45 GHz in Region 2, 28.45-28.94 GHz in all Regions, 28.94-29.1 GHz in Regions 2 and 3, 29.25-29.46 GHz in Region 2 and 29.46-30 GHz in all Regions are identified for use by high-density applications in the fixed-satellite service (HDFSS) (Earth-to-space). The HDFSS systems are characterized by ubiquitous deployment of multiple receiving/transmitting earth stations with small antennas which operation is regulated according to a simplified procedure without individual frequency licensing.

Frequency bands 27.5-27.82 GHz, 28.45-28.94 GHz and 29.46-29.5 GHz are identified in Region 1 for HDFSS (Earth-to-space) applications. Frequency bands 17.3-17.7 GHz and 19.7-20.2 GHz identified in Region 1 for HDFSS (space-to-Earth) applications are not considered.

The FSS allocations in the bands 18.8-19.3/28.6-29.1 GHz are also available for non-GSO FSS systems subject to RR No. **5.523A**. In accordance with this regulation, GSO FSS networks and non-GSO FSS systems coordinate on an equal status under RR No. **9.11A**, and RR No. **22.2** does not apply (with the exception of certain legacy GSO FSS systems).

The FSS allocations in the bands 19.3-19.7/29.1-29.5 GHz were identified by WRC-95 and WRC-97 for feeder link use for non-GSO MSS systems. The use of the bands 19.3-19.7/29.1-29.5 GHz is subject to footnotes Nos. **5.523B**, **5.523C**, **5.523D**, **5.523E** and **5.535A** of the Radio Regulations. In accordance with these footnotes, GSO FSS and non-GSO MSS feeder links operating in the FSS coordinate subject to the application of the provision of RR No. **9.11A** (i.e. on an equal status), and RR No. **22.2** does not apply (with the exception of certain legacy GSO FSS systems). Use of the 19.3-19.7 GHz (space-to-Earth) band by non-GSO FSS applications other than non-GSO MSS feeder links is subject to RR No. **22.2** (and is not subject to RR No. **9.11A**). However, RR No. **5.535A** limits the FSS (Earth-to-space) allocation in the band 29.1-29.5 GHz to geostationary-satellite systems and feeder links to non-geostationary-satellite systems in the mobile-satellite service.

The Table of Allocations for the bands 19.3-19.7 GHz (space-to-Earth) and 29.1-29.5 GHz (Earth-to-space) is provided below.

TABLE 5

Allocation to services		
Region 1	**Region 2**	**Region 3**
19.3-19.7 FIXED FIXED-SATELLITE (space-to-Earth) (Earth-to-space) 5.523B 5.523C 5.523D 5.523E MOBILE		
…		
29.1-29.5 FIXED FIXED-SATELLITE (Earth-to-space) 5.516B 5.523C 5.523E 5.535A 5.539 5.541A MOBILE Earth exploration-satellite (Earth-to-space) 5.541 5.540		

Specific elements addressing sharing, compatibility, and protection between ESIM operating with geostationary FSS networks and current and planned stations of existing services allocated with services in the frequency bands 17.7-19.7 GHz and 27.5-29.5 GHz are given in §§ 4.1 through 4.7 below.

ESIM do not transmit at all in the 17.7-19.7 GHz bands, with the transmissions coming from GSO FSS space stations operating without any special considerations for transmissions to ESIM. In other words, the transmissions from GSO FSS spacecraft to ESIM in the 17.7-19.7 GHz bands are identical to transmissions from GSO FSS spacecraft to FSS earth stations. Table 6 shows the allocations in this range.

TABLE 6

Allocation to services		
Region 1	**Region 2**	**Region 3**
17.7-18.1 FIXED FIXED-SATELLITE (space-to-Earth) 5.484A (Earth-to-space) 5.516 MOBILE	**17.7-17.8** FIXED FIXED-SATELLITE (space-to-Earth) 5.517 (Earth-to-space) 5.516 BROADCASTING-SATELLITE Mobile 5.515	**17.7-18.1** FIXED FIXED-SATELLITE (space-to-Earth) 5.484A (Earth-to-space) 5.516 MOBILE
	17.8-18.1 FIXED FIXED-SATELLITE (space-to-Earth) 5.484A (Earth-to-space) 5.516 MOBILE 5.519	
18.1-18.4 FIXED FIXED-SATELLITE (space-to-Earth) 5.484A 5.516B (Earth-to-space) 5.520 MOBILE 5.519 5.521		

Allocation to services		
Region 1	**Region 2**	**Region 3**
18.4-18.6 **FIXED** **FIXED-SATELLITE (space-to-Earth)** 5.484A 5.516B **MOBILE**		
18.6-18.8 EARTH EXPLORATION-SATELLITE (passive) FIXED FIXED-SATELLITE (space-to-Earth) 5.522B MOBILE except aeronautical mobile Space research (passive) 5.522A 5.522C	**18.6-18.8** EARTH EXPLORATION-SATELLITE (passive) FIXED FIXED-SATELLITE (space-to-Earth) 5.516B 5.522B MOBILE except aeronautical mobile SPACE RESEARCH (passive) 5.522A	**18.6-18.8** EARTH EXPLORATION-SATELLITE (passive) FIXED FIXED-SATELLITE (space-to-Earth) 5.522B MOBILE except aeronautical mobile Space research (passive) 5.522A
18.8-19.3 FIXED FIXED-SATELLITE (space-to-Earth) 5.516B 5.523A MOBILE		
19.3-19.7 FIXED FIXED-SATELLITE (space-to-Earth) (Earth-to-space) 5.523B 5.523C 5.523D 5.523E MOBILE		

4.1 ESIM compatibility with the mobile and fixed services

4.1.1 Frequency band 17.7-19.7 GHz

This band is allocated to the mobile and fixed service on a primary basis in all three Regions (with the exception of the band 17.7-17.8 GHz in Region 2, where the mobile service is allocated on a secondary basis). No characteristics or protection criteria for mobile service systems in this band have been identified and no sharing studies have been carried out, taking also into account that in this band ESIM receive.

There are pfd limits in RR Article **21** to protect terrestrial services from FSS space station emissions in the band 17.7-19.7 GHz and provided that these limits are unchanged, the interference environment with respect to receiving mobile and fixed service stations would be unchanged.

If this band was to be used for mobile systems, there would be potential for interference from mobile service transmitters to ESIM receivers. There is also potential for interference from fixed service transmitters to ESIM receivers. However, it is anticipated that ESIM would operate on condition of not claiming protection from any interference caused by terrestrial services.

4.1.2 Frequency band 27.5-29.5 GHz

The question was raised on how an A-ESIM would be coordinated with terrestrial services, as currently there is no established procedure in the Radio Regulations for coordination of an A-ESIM. However, the pfd concept is taken from RR Article **21** which deals with the protection of the service area of the terrestrial services from the fixed-satellite service. It was also noted that, there is a need to achieve the same objectives as those achieved by RR Nos. **9.17** and **9.18** to protect the assignments of the terrestrial services. In the absence of the latter provisions, the pfd concept may assist administrations to be assured that their terrestrial services would not receive unacceptable interference.

The applicability of the pfd concept for the protection of the terrestrial services from A-ESIM needs to be carefully examined to verify its validity and agreed upon for such protection due to the moving feature of the earth stations on board the aircraft.

4.1.2.1 Maritime ESIM

ITU-R studies concluded that an M-ESIM can protect stations in the mobile and fixed service by complying with the both following conditions when communicating within a GSO FSS network in the 27.5-29.5 GHz band:

a) The minimum distances from the low-water mark as officially recognized by the coastal State beyond which M-ESIM can operate without the prior agreement of any administration is 60 to 120 km, with preference to 60 to 70 km, depending on the results of studies. Any transmissions from maritime ESIM within the minimum distance would be subject to the prior agreement of the concerned coastal State;

and

b) The maximum M-ESIM e.i.r.p. spectral density towards the territory of any coastal State would not exceed 12.98 dBW in reference bandwidth of 1 MHz. Transmissions from M-ESIM with higher e.i.r.p. spectral density levels towards the territory of any coastal state would be subject to the prior agreement of the concerned coastal State together with the mechanism by which this level is to be maintained.

In particular, it should be noted that, with regard to condition a) above, for the protection of the mobile service:

1) 60 km was derived using the methodology used in Recommendation ITU-R SF.1650 using 20% of time in the propagation model and maximum 10 MHz ESIM bandwidth with 100% duty cycle. Results are comparable to the case where 10% duty cycle is used for satellite architectures with ESIMs that are capable of operating with the minimum 100 MHz bandwidth of the mobile service receiver;

2) 120 km was derived from a snapshot of an M-ESIM while sailing in the main beam of the mobile service receiver, 1% of time in the propagation model and 100 MHz bandwidth for ESIM.

It should also be noted that the separation distance of 70km was derived to protect the fixed service.

4.1.2.2 Aeronautical ESIM

ITU-R studies concluded that an A-ESIM can protect stations in the fixed service by complying with the following pfd mask on the Earth surface when within the line of sight of a territory of an administration:

a)

$\text{pfd}(\delta) = -124.7$	(dB(W/(m^2 · 14 MHz)))	for	$0° \le \delta \le 0.01°$
$\text{pfd}(\delta) = -120.9 + 1.9 \cdot \log10(\delta)$	(dB(W/(m^2 · 14 MHz)))	for	$0.01° \le \delta \le 0.3°$
$\text{pfd}(\delta) = -116.2 + 11 \cdot \log10(\delta)$	(dB(W/(m^2 · 14 MHz)))	for	$0.3° < \delta \le 1°$
$\text{pfd}(\delta) = -116.2 + 18 \cdot \log10(\delta)$	(dB(W/(m^2 · 14 MHz)))	for	$1° < \delta \le 2°$
$\text{pfd}(\delta) = -117.9 + 23.7 \cdot \log10(\delta)$	(dB(W/(m^2 · 14 MHz)))	for	$2° < \delta \le 8°$
$\text{pfd}(\delta) = -96.5$	(dB(W/(m^2 · 14 MHz)))	for	$8° < \delta \le 90.0°$

where δ is the angle of arrival of the radio-frequency wave (degrees above the horizon).

b) Higher pfd levels produced by A-ESIM at the Earth surface than provided in a) above shall be subject to the prior agreement of the administration within line-of-sight of the A-ESIM.

NOTE – The pfd levels provided above relate to the pfd and angles of arrival that would be obtained using free-space propagation, atmospheric absorption and any attenuation due to the aircraft fuselage.

Regarding the protection of the mobile service, and the interpretation of ITU-R studies, two views were expressed to ensure that an aeronautical ESIM (A-ESIM) can protect stations in the mobile service: one view requires compliance with a maximum pfd limit at the surface of the Earth within line-of-sight of the territory of an administration without a minimum altitude while the other view requires compliance with a maximum pfd limit at the surface of the Earth within line-of-sight of the territory of an administration and a minimum altitude.

The values needed for the pfd mask and, for the second view above, the value of the minimum altitude were not agreed.

In this context, two pfd masks were proposed.

Some studies showed that A-ESIM can protect stations in the mobile service by complying with the following conditions when communicating within a GSO FSS network in the 27.5-29.5 GHz band:

a) Within line-of-sight of the territory of an administration, the maximum pfd produced (in a reference bandwidth of 14 MHz) at the surface of the Earth by emissions from a single A-ESIM shall not exceed:

$$\text{pfd}(\delta) = -124.7 \quad (\text{dB}(\text{W}/(\text{m}^2 \cdot 14\ \text{MHz}))) \quad \text{for} \quad 0° \le \delta \le 0.01°$$

$$\text{pfd}(\delta) = -120.9 + 1.9 \cdot \log10(\delta) \quad (\text{dB}(\text{W}/(\text{m}^2 \cdot 14\ \text{MHz}))) \quad \text{for} \quad 0.01° \le \delta \le 0.3°$$

$$\text{pfd}(\delta) = -116.2 + 11 \cdot \log10(\delta) \quad (\text{dB}(\text{W}/(\text{m}^2 \cdot 14\ \text{MHz}))) \quad \text{for} \quad 0.3° < \delta \le 1°$$

$$\text{pfd}(\delta) = -116.2 + 18 \cdot \log10(\delta) \quad (\text{dB}(\text{W}/(\text{m}^2 \cdot 14\ \text{MHz}))) \quad \text{for} \quad 1° < \delta \le 2°$$

$$\text{pfd}(\delta) = -117.9 + 23.7 \cdot \log10(\delta) \quad (\text{dB}(\text{W}/(\text{m}^2 \cdot 14\ \text{MHz}))) \quad \text{for} \quad 2° < \delta \le 8°$$

$$\text{pfd}(\delta) = -96.5 \quad (\text{dB}(\text{W}/(\text{m}^2 \cdot 14\ \text{MHz}))) \quad \text{for} \quad 8° < \delta \le 90.0°$$

where δ is the angle of arrival of the radio-frequency wave (degrees above the horizon).

b) Higher pfd levels produced by aeronautical ESIM at the Earth surface than provided in a) above shall be subject to the prior agreement of the administration within line-of-sight of the A-ESIM.

NOTE – The pfd levels provided above relate to the pfd and angles of arrival that would be obtained using free-space propagation, atmospheric absorption and any attenuation due to the aircraft fuselage.

These ITU-R studies showed that protection of the mobile service was possible without the need for a minimum altitude.

Some ITU-R studies showed that the above pfd mask adequately protects the mobile service when taking into consideration the probability and duration of interference between the two services. Simulations modelling interference using actual aircraft flight paths and electronic beam-steering of the mobile station antennas show that the maximum level of interference in the mobile service receivers is $I/N = -8$ dB (exceeded for 0.0034% of time) in a worst-case scenario. When taking into consideration polarization loss (due to polarization mismatch between ESIM and MS systems), clutter loss, maximum ESIM bandwidth of 10 MHz (equates to 10% duty cycle for satellite architectures capable of 100 MHz bandwidth) and user terminal body loss, the maximum level of interference received by the mobile service receiver is reduced to $I/N = -31.8$ dB (exceeded for 0.0012% of time).

The same ITU-R studies also showed the above pfd mask also meets the protection requirements of the mobile service using studies solely based on the characteristics of the mobile service receivers and a static interference methodology that assumes worst-case alignment between A-ESIM and MS antenna beams at all time. A study based on this approach also took into consideration body loss and polarization mismatch between the A-ESIM and MS. When additional assumptions regarding time

or location variability of A-ESIM interference are taken into account (i.e. A-ESIM duty cycle and clutter loss), the Option 1 pfd mask offers 20 dB more protection than the mobile service protection requirements.

Views were expressed that if the off-axis e.i.r.p. density specified in Annex of Resolution **156 (WRC-15)** is applied to A-ESIM, under the certain altitude pfd values at the surface of the Earth may not meet the pfd values above. For some cases, with low elevation angle and low angle of arrival, the pfd value at the surface of the Earth cannot meet even at an altitude of 10km. In addition, the same views were expressed that in the study above, it was not confirmed and shown how to achieve the pfd values at the surface of the Earth from off-axis e.i.r.p. density of A-ESIM. Moreover, the pfd values at the surface of the Earth with reference bandwidth of 14 MHz cause worse interference situation to mobile service from A-ESIM with smaller bandwidth than 14 MHz, than those with reference bandwidth of 1 MHz.

Other ITU-R studies showed that A-ESIM can protect stations in the mobile service by complying with the following conditions when communicating within a GSO FSS network in the 27.5-29.5 GHz band:

a) Within line-of-sight of the territory of an administration, the maximum pfd produced (in a reference bandwidth of 14 MHz) at the surface of the Earth by emissions from a single A-ESIM shall not exceed:

$pfd(\delta) = -122.7$	$(dB(W/(m^2 \cdot 1\ MHz)))$	for	$0° \leq \delta \leq 2°$	
$pfd(\delta) = -122.7 + 2 * (\delta - 2)$	$(dB(W/(m^2 \cdot 1\ MHz)))$	for	$2° < \delta \leq 2.3°$	
$pfd(\delta) = -122.6 + 1.5 * (\delta - 2)$	$(dB(W/(m^2 \cdot 1\ MHz)))$	for	$2.3° < \delta \leq 7.9°$	
$pfd(\delta) = -113.9$	$(dB(W/(m^2 \cdot 1\ MHz)))$	for	$7.9° < \delta \leq 90°$	

where δ is the angle of arrival of the radio-frequency wave (degrees above the horizontal).

b) Higher pfd levels produced by aeronautical ESIM on surface of the Earth than provided in a) above shall be subject to the prior agreement of the administration within line-of-sight of the A-ESIM.

NOTE – The pfd levels provided above relate to the pfd and angles of arrival that would be obtained using free-space propagation, atmospheric absorption and any attenuation due to the aircraft fuselage.

c) Based on the above pfd mask, it is shown that protection of the mobile service was possible, provided that the minimum required altitude limit for A-ESIM communication of 6 km is complied with, under the assumption of 50% probability of location in clutter loss and off-axis e.i.r.p. density performance of the A-ESIM with the same levels as those indicated in the Annex of Resolution **156 (WRC-15)**.

Some views were expressed that ITU-R studies show that the Option 2 pfd mask adequately protects the mobile service and is derived solely using the characteristics of mobile service receivers and a static interference methodology that assumes worst-case alignment between A-ESIM and MS antenna beams at all times. The protection requirements for 0 to 7.9 degrees are driven by the base station characteristics and assume that the MS base stations are pointing towards the horizon. Depending on the base station height and system specifications indicated in the draft new Recommendation ITU-R M.[MS-RXCHAR-28][5], MS base station beams are electronically steered at least between 2 to 6 degrees below the horizon.

While both pfd masks would protect the mobile service, the majority of Option 2 pfd mask has lower pfd levels than Option 1 and is therefore more constraining to A-ESIM operation.

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5 As of the date of publication of this Report, this draft new Recommendation has been adopted and will be considered for approval at the Radiocommunication Assembly 2019 (RA-19).

Views were expressed that, in addition, limiting transmissions below a specific altitude is one of the possible techniques an A-ESIM operator can use to meet a pfd level on the ground; mandating how an administration should meet the pfd limit is not necessary. Views were also expressed that a minimum altitude is totally unnecessary.

Views were expressed that the pfd is a mechanism or procedure to protect the terrestrial service from the fixed-satellite service. The extension of this mechanism to protect the terrestrial service by A-ESIM is a matter to be verified and validated by the Bureau as a neutral entity.

Some other views were expressed that ITU-R studies provided the Option 2 pfd mask to protect all systems of mobile services defined in Recommendation ITU-R M.[MS-RXCHAR-28]. This pfd mask is based on Recommendation ITU-R M.[MS-RXCHAR-28], i.e. it is derived for all elevation angles and utilize the wavelength, the receiver antenna gain pattern, and the receiver noise figure for all systems of mobile service systems and applies to all azimuth angles as described in Recommendation ITU-R M.[MS-RXCHAR-28].

Some views were expressed that the protection of terrestrial services from unacceptable interference from A-ESIM should be considered in conjunction with the draft new Resolution **[A15] (WRC-19)** (see CPM Report to WRC-19).

Some other views were expressed that the above course of action does not release the notifying administration of A-ESIM from the obligation that such an ESIM of not causing unacceptable interference to nor claiming protection from terrestrial services and such A-ESIM should comply with the course of action described in the draft new Resolution **[A15] (WRC-19)** (see CPM Report to WRC-19).

4.1.2.3 Land ESIM (L-ESIM)

Studies were also performed between mobile service and L-ESIM. Although operation of L-ESIM within a country is a national matter, it is expected that land ESIM in the 27.5-29.5 GHz frequency band shall operate on the basis of not causing unacceptable interference to terrestrial services in neighbouring countries.

The ITU-R is developing methodologies that can be used to limit the potential interference from L-ESIM into MS and FS receivers to an acceptable level. Two interference scenarios are considered, one where the specific locations of the MS base-stations, or FS, stations are known, and the other where these locations are unknown but contained within a known region.

Until the time that such methodologies are developed and agreed upon, in the absence of bi-lateral or multilateral agreements between the concerned administrations, the notion of unacceptable interference caused by L-ESIM to terrestrial service may/would not be achieved.

Studies were also performed between mobile service and L-ESIM. Although operation of L-ESIM within a country is a national matter, it is expected that land ESIM in the 27.5-29.5 GHz frequency band shall operate on the basis of not causing unacceptable interference to terrestrial services in neighbouring countries. This interference situation is addressed through bilateral or multilateral agreements.

4.2 ESIM compatibility with the Earth exploration-satellite service

4.2.1 Frequency band 18.6-18.8 GHz

The frequency band 18.6-18.8 GHz is used by the Earth exploration-satellite service (EESS) (passive) for remote sensing by Earth exploration and meteorological satellites. The use of this band by FSS networks communicating with ESIM would not change the interference environment with respect to the EESS (passive) remote sensing operations.

4.2.2 Frequency band 28.5-29.5 GHz

The band 28.5-29.5 GHz is allocated to the EESS (space-to-Earth) on a secondary basis. The ITU-R was unable to identify 28.5-29.5 GHz band EESS (space-to-Earth) operational scenarios to be studied. Thus, the use of this band by FSS networks communicating with ESIM would not change the interference environment with respect to the EESS under any identified scenarios.

4.3 ESIM compatibility with non-geostationary FSS systems (including HDFSS, where applicable)

4.3.1 Frequency band 17.7-18.6 GHz

Through RR No. **5.484A**, non-GSO FSS systems operating in the band 17.8-18.6 GHz are not entitled to protection from GSO FSS networks. epfd limits for the protection of GSO FSS receive earth stations in this band are found in Table 22-1b of the Radio Regulations. The epfd limits are applicable to GSO FSS receive earth stations with antenna diameters of 1 m, 2 m and 5 m, and as such may not provide full protection of ESIM stations, especially when such ESIM antennas are not rotationally symmetric about their main beam axis.

In the band 17.8-18.6 GHz, ESIM are receiving and GSO FSS satellites that support ESIM are no different from GSO FSS satellites that operate stationary FSS earth stations. Therefore, the interference into non-GSO FSS receiving earth stations remains unchanged with the introduction of ESIM in the band.

GSO FSS networks that support ESIM would receive some protection from the downlinks of non-GSO FSS systems through the application of the current epfd↓ limits and hence would receive the same protection provided to GSO FSS earth stations with similar receive antenna characteristics.

4.3.2 Frequency band 18.8-19.3 GHz

Through RR No. **5.523A**, the band 18.8-19.3 GHz is subject to the provisions of RR No. **9.11A**, and No. **22.2** does not apply.

In the band 18.8-19.3 GHz, ESIM are receiving and GSO FSS satellites that support ESIM are no different from GSO FSS satellites that operate stationary FSS earth stations. Therefore, the interference into non-GSO FSS receive earth stations remains unchanged with the introduction of ESIM in the band.

The operation of GSO FSS networks that support ESIM can be taken into consideration during coordination with the non-GSO network operators in a similar manner to coordination of GSO FSS networks operating stationary FSS earth stations. It should be noted that any coordination agreement does not change the regulatory status of ESIM.

4.3.3 Frequency band 27.5-28.6 GHz

Through RR No. **5.484A**, non-GSO FSS systems operating in the band 27.5-28.6 GHz are not entitled to protection from GSO FSS networks. However, WRC-2000 did not adopt earth station off-axis EIRP limits for the protection of non-GSO FSS in this band, as it did for the Ku-band and the 29.5-30 GHz band. Potential ESIM in the 27.5-28.6 GHz band would operate within the envelope of stationary FSS earth stations in the general direction of the GSO arc. However, such ESIM antennas are not rotationally symmetric about their main beam axis, so the interference environment into non-GSO FSS systems was assessed for the introduction of ESIM in the band and it is proposed that ESIM should meet the following limits for any off-axis angle φ which is 3 degrees or more off the main-lobe axis of an ESIM antenna and outside 3 degrees of the GSO:

Off-axis angle	Maximum e.i.r.p. density
$3° \leq \varphi \leq 7°$	$28 - 25 \log \varphi$ dB(W/40 kHz)
$7° < \varphi \leq 9.2°$	7 dB(W/40 kHz)
$9.2° < \varphi \leq 48°$	$31 - 25 \log \varphi$ dB(W/40 kHz)
$48° < \varphi \leq 180°$	−1 dB(W/40 kHz)

Some ITU-R studies also concluded that for any ESIM that do not meet the condition above, outside of 3 degrees of the GSO arc, the maximum ESIM on-axis e.i.r.p. not to be exceeded is 55 dBW for emission bandwidths up to and including 100 MHz. For emission bandwidths larger than 100 MHz, the maximum ESIM on-axis e.i.r.p. need to be increased proportionately.

Some other ITU-R studies also concluded that for any ESIM that do not meet the condition above, outside of 3 degrees of the GSO arc, the maximum ESIM on-axis e.i.r.p. not to be exceeded is 55 dBW for emission bandwidths of 100 MHz. For emission bandwidths smaller or larger than 100 MHz, the maximum ESIM on-axis e.i.r.p. need to be decreased or increased proportionately, as appropriate.

GSO FSS satellites that support ESIM are protected from interference from non-GSO FSS systems through the epfd↑ limits (see RR No. **22.5D**) and hence receive the same protection as other GSO FSS satellites.

4.3.4 Frequency band 28.6-29.1 GHz

The introduction of ESIM in the 28.6-29.1 GHz band will be coordinated with non-GSO FSS systems under the current coordination requirements of Article **9** of the Radio Regulations in a similar manner to coordination of GSO FSS networks operating with stationary FSS earth stations. During the coordination the specific characteristics of the ESIM and the non-GSO FSS network can be taken into account to ensure operations are compatible.

Potential ESIM in the 28.6-29.1 GHz band would operate within the envelope of stationary FSS earth stations, at least in the general direction of the GSO arc, however, ESIMs can have antennas that perform more poorly in other directions away from the GSO arc, so the interference environment into non-GSO FSS systems required assessment for the introduction of ESIM in the band.

4.4 ESIM compatibility with non-geostationary MSS feeder links

Non-GSO MSS feeder links stations, which operate at defined locations, have been operating for almost 20 years in portions of the 19.3-19.7 GHz (space-to-Earth) and 29.1-29.5 GHz (Earth-to-space) frequency bands with GSO FSS links. Through bilateral coordination under RR No. **9.11A** between administrations operating GSO FSS networks and non-GSO MSS feeder link systems, compatibility is maintained. Administrations will agree on specifics regarding protection criteria and methodology on a bilateral basis while taking into account relevant ITU-R Recommendations regarding protection criteria, methodologies and mitigation techniques.

During the bi-lateral coordination process, analysis is conducted to define operational constraints that will allow compatible operations between the GSO FSS and non-GSO MSS feeder link systems. The analysis uses short-term and long-term interference criteria applicable to non-GSO MSS feeder links and interference criteria for GSO FSS stations as agreed to between the administrations. In coordination, to ensure protection of the operations of non-GSO MSS feeder links based on long term and short term I/N values and their corresponding percentages of times, boundaries need to be defined where operational constraints are required. Such a boundary would consist of geographical points at which a hypothetical interfering ESIM just meets the single-entry protection criteria. During coordination, administrations may also take into account various interference mitigation techniques that can be employed to improve compatibility, such as adaptive power control, the use of high gain antennas, geographical isolation between earth stations, satellite diversity, frequency diversity and

site diversity as appropriate. Under the existing or future regulatory framework this coordination may include ESIM based on the outcome of studies under this agenda item.

Since ESIMs will operate while moving, this will require that the operator of the ESIM has the capability to control some of the ESIM characteristics (e.g. transmit power, frequency, location) to ensure that any relevant regulatory restrictions developed are maintained. These requirements should align with those adopted by WRC-15 for ESIM operations in the 29.5-30.0 GHz/19.7-20.2 GHz bands (see Resolution **156 (WRC-15)**).

4.4.1 Frequency band 19.3-19.7 GHz

In the band 19.3-19.7 GHz, ESIM are receiving and GSO FSS satellites that support ESIM are no different from GSO FSS satellites that operate stationary FSS earth stations. Downlink transmissions from GSO satellites that serve fixed earth stations also support ESIMs. Therefore, the interference environment for non-GSO MSS feeder links remains unchanged with the introduction of ESIM in the band. Moreover, this band is subject to coordination under RR No. **9.11A** and GSO FSS satellite will operate consistent with those coordination agreements. As no changes to GSO downlink transmissions are necessary to support ESIM operations, no ESIM-specific measures are needed in coordination of GSO networks.

4.4.2 Frequency band 29.1-29.5 GHz

Some sharing and compatibility studies conducted in the ITU-R show that for some assumptions regarding ESIM characteristics and operations, the coordination procedures of Article **9** of the Radio Regulations may be used to address potential interference between ESIM operating with GSO FSS stations and non-GSO MSS feeder links in the 29.1-29.5 GHz (Earth-to-space) FSS band. The sharing and compatibility studies also show that for other assumptions regarding ESIM characteristics and operations, defined technical and operational restrictions may be needed to resolve potential interference.

From these studies, it was possible to derive a set of technical and operating parameters for ESIM, and ranges for the values of those parameters, that can be used to identify which types of L-ESIM, M-ESIM, and A-ESIM may be successfully coordinated with non-GSO MSS feeder link systems in the 29.1-29.5 GHz band (which may, in some cases, require defined technical and operational constraints). If an ESIM operates at a level that meets each of the parameters or operating conditions listed in Table 7 below, there is an expectation that the ESIM may be successfully coordinated with non-GSO MSS feeder link systems in the 29.1-29.5 GHz band.

TABLE 7

ESIM operational characteristics and parameter[NOTE]

e.i.r.p density per carrier (single per ES)	≤ 35.5 dBW/MHz or ≤ 50 dBW/MHz
Off-axis e.i.r.p density	per Resolution **156**, Annex or per RR No. **22.32**
Average carrier burst duty cycle	≤ 10% (averaged over 30 seconds) or 100% (per ESIM, averaged over 4 hours)
Number of transmitting ESIM in a single satellite beam in a 15 MHz channel	≤ 6 or ≤ 12
For TDMA systems, is there a possibility of co-frequency, co-time bursts within a beam?	No

Note to Table 7: Depending on the values of these parameters and characteristics in combination, there may need to be an exclusion zone or other constraint(s) on ESIM developed during coordination. Where two values are stated for an element, an ESIM operating at or under only the second value is likely to lead to the imposition of a further constraint on ESIM operation.

For cases where coordination is considered to be an acceptable mechanism for assuring protection by GSO networks employing ESIM of non-GSO MSS feeder link systems in the 19.3-19.7 GHz (space-to-Earth) and 29.1-29.5 GHz (Earth-to-space) band under the existing coordination procedures of RR No. **9.11A**, the material in this Report can be used by Administrations during frequency coordination and will allow Administrations to take into account specific parameters of ESIM deployments in adopting suitable technical and operational constraints on ESIM operations to ensure that non-GSO MSS feeder links are protected.

For cases where coordination is not feasible due to the characteristics of contemplated ESIM deployments and operations, this report also may serve as a basis for developing and adopting suitable regulatory, technical and/or operational constraints on ESIM operations to ensure that non-GSO MSS feeder links are protected.

Under both frameworks it will be necessary for the ESIM operator to have the capability to control the ESIM characteristics based on its location (e.g. transmit power, frequency) to ensure that constraints agreed to in coordination or otherwise required are met and that non-GSO MSS feeder links are protected.

Other sharing and compatibility studies showed that the introduction of ESIM in the 29.1-29.5 GHz band will be coordinated with non-GSO MSS feeder link systems under the current coordination requirements of RR Article **9** in a similar manner to coordination of GSO FSS networks operating with stationary FSS earth stations. During the coordination the specific characteristics of the ESIM and the non-GSO MSS feeder link system can be taken into account to ensure operations are compatible. The maritime and land ESIMs operate on the surface of the earth therefore any constraints agreed to for the fixed terminal will apply equally to these types of ESIMs.

Under one simulation study for analysing compatibility between airborne ESIM and non-GSO MSS feeder links in the 29.1-29.5 GHz band, the long term aggregate I/N of −12.2 dB for 10% of the time is never exceeded. The long term single entry I/N of −18.2 dB for four GSO systems is also never exceeded, even with no isolation zone over the gateway.

Given that the simulation reports an I/N of approximately −37.5 dB 10% of the time even with no isolation zone with the aggregate transmissions of four GSO ESIM networks, which is 25.3 dB less than the target goal, it is obvious that no isolation is needed to meet the long term criteria for the four GSO networks used in this example simulation.

For short term I/N and % time criteria, the study included a sensitivity analysis of impact of size of circular isolation zones on received interference. The curves in the study represent results based on the characteristics of one GSO operator, and entirely different sets of curves could be obtained by changing ESIM transmission characteristics, the number of ESIMs, as well as the operational flight patterns, altitudes and frequency of flights for these ESIMs. The range, variation and limits of these parameters are areas for additional studies to help provide a basis for determining an accurate zone where operational controls may be required.

In coordination, to resolve potential interference between ESIM operating with GSO FSS stations and non-GSO MSS feeder links, Administrations will need to take into account specific parameters of the type of ESIM deployments in adopting suitable regulatory, technical and operational constraints on ESIM operations to ensure that non-GSO MSS feeder links are protected. Under this framework it will be necessary for the ESIM operator to have the capability to control the ESIM characteristics (e.g. transmit power, frequency, location) to ensure that any relevant regulatory restrictions developed are maintained.

4.5 ESIM compatibility with the GSO FSS (including HDFSS, where applicable)

The characteristics of GSO FSS satellites that support ESIM operation do not differ in any significant way from GSO FSS satellites operating stationary earth stations. In fact, in most cases the same satellite supports both types of earth stations. The e.i.r.p. of GSO FSS satellites operating stationary FSS earth stations does not change with the operation of ESIM and hence there is no change in the interference environment for other satellite services in the downlink band. Further, GSO FSS systems have similar spot beams and frequency reuse capability irrespective of whether they support ESIM operations. GSO FSS satellites that support ESIM operation are indistinguishable from GSO FSS satellites that operate stationary FSS earth stations and therefore create no additional interference or impose constraints on other satellite services.

4.5.1 Frequency band 17.7-19.7 GHz

In the band 17.7-19.7 GHz, ESIM are receiving and GSO FSS satellites that support ESIM are no different from GSO FSS satellites that operate stationary FSS earth stations. Therefore, the interference environment for GSO FSS systems remains unchanged with the introduction of ESIM in the band.

Specifically, there is no potential of interference from ESIM into other services. There are also no technical requirements on stationary GSO FSS earth stations in this band, so the same should apply for the operation of ESIM.

In terms of coordination with other satellite networks, characteristics of ESIM in 17.7-19.7 GHz are comparable to stationary FSS earth stations of the same size. ESIM are neither more sensitive to interference nor require more protection than stationary GSO FSS terminals of similar size, and studies have been conducted using noise temperature and antenna patterns for ESIM that are typical values for stationary earth stations.

The operation of GSO FSS networks that support ESIM can be taken into consideration during coordination with other GSO FSS network operators in a similar manner to coordination of GSO FSS networks operating stationary FSS earth stations. There is no need for additional studies on this matter.

4.5.2 Frequency band 27.5-29.5 GHz

ESIM would always remain in the envelope of stationary GSO FSS earth stations, as they respect the limits of coordination agreements with other satellite networks. Further information on this, including how these requirements are met in practice, is provided in Reports ITU-R S.2357-0 and ITU-R S.2223-1. In addition, Annex 1 of Report ITU-R S.2223-1 also establishes that the risk of mis-pointing from ESIM is negligible compared to stationary earth stations (e.g. VSATs).

The only difference between ESIM operation and stationary GSO FSS earth station operation from the perspective of another satellite network is that the location of the ESIM changes dynamically within the service area of the satellite whereas stationary earth stations operates from a fixed location, anywhere in the service area. GSO FSS networks operating stationary earth station networks evolve as earth stations are deployed in new locations and possibly removed from other locations. It is also noted that some ‘stationary’ earth stations are transportable. In both cases, the precise location of the earth stations is normally unknown at the time of coordination and an ESIM that moves within a certain service area can be treated in the same way as stationary earth station which may be located anywhere within the same service area. Additional interference entries, such as from other satellite beams, from earth stations operating on a different polarisation or for multiple earth stations using CDMA, can be added as appropriate. The process for adding multiple interference entries is the same whether these entries come from stationary earth stations or ESIMs, and in some cases will be a mixture of both.

One study assessed the potential interference from ESIM to the Next Generation GSO FSS networks using High-Throughput Satellites (HTS) with higher gain-to-noise temperature ratios (G/T ≈ 15 – 30 dB/K) at the satellite receiving systems and spot multi-beam antenna systems in 27.5-29.5 GHz band. Based on the methodology of Recommendation ITU-R S.1323 and Report ITU-R S.2409, this study showed that the use of the maximum off-axis e.i.r.p. spectral density levels adopted for ESIM in Resolution **156 (WRC-15)** with regard to other GSO FSS networks would not ensure uplink interference protection with orbital separation of 2 and more degrees for the HTS networks with higher sensitivity to uplink interference. As a result, coordination of the satellite network with ESIM with other GSO FSS networks will be needed to ensure their compatibility.[6]

The operation of GSO FSS networks that support ESIM can be taken into consideration during coordination with the GSO FSS network operators in a similar manner to coordination of GSO FSS networks operating stationary FSS earth stations.

4.6 ESIM compatibility with BSS feeder uplinks

4.6.1 Frequency band 17.7-18.4 GHz

The band 17.7-18.4 GHz is allocated to the FSS (Earth-to-space) and is used for BSS feeder uplinks under the conditions given in RR Nos. **5.516** and **5.520**.

In the band 17.7-18.4 GHz, ESIM are receiving and GSO FSS satellites that support ESIM are no different from GSO FSS satellites that operate stationary FSS earth stations. Therefore, the interference environment for BSS feeder links remains unchanged with the introduction of ESIM in the band.

Receiving FSS earth stations could receive interference from BSS feeder link earth stations. For a stationary FSS earth station such potential interference is managed by coordination of the earth stations, through RR No. **9.17A**. In the case of ESIM, it is anticipated that they would not claim protection from BSS feeder uplinks, so there is no need for additional studies.

4.6.2 Frequency band 27.5-29.5 GHz

The band 27.5-29.5 GHz is allocated to the FSS (Earth-to-space). RR No. **5.529** states that this band may also be used for feeder links for the broadcasting-satellite service. As this band is in any case use for GSO FSS uplinks, the use of the band for feeder links for the BSS does not introduce any additional interference situation.

ESIM in the 27.5-29.5 GHz band would operate within the envelope of stationary FSS earth stations so the interference environment for BSS feeder uplinks remains unchanged with the introduction of ESIM in the band.

The operation of GSO FSS networks that support ESIM can be taken into consideration during coordination with the FSS networks that support BSS feeder uplink operations in a similar manner to coordination of GSO FSS networks operating stationary FSS earth stations. There is no need for additional studies on this matter.

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[6] It is important to note that establishment of adequate limits for off-axis emissions of earth stations to protect GSO FSS networks from uplink interference refers to the general issue of FSS regulation, and affects both typical FSS earth stations and ESIM, see Report ITU-R S.2409. The general solution to this issue relates to matters of FSS intra-service spectrum sharing. However, the matter of ESIM off-axis emission limits is an integral part of this general issue.

5 Regulatory issues

This section addresses any regulatory issues related to the operation of ESIM in the 17.7-19.7 GHz and 27.5-29.5 GHz frequency bands. WRC-19 is expected to address these issues.

Notwithstanding the material contained in the CPM Report to WRC-19, a possible example that may be relevant to this task is included in the Annex to this Report for information purpose only.

6 Summary

The foregoing sections of this Report describe ESIM operation (M-ESIM, A-ESIM, and L-ESIM) in the frequency bands 17.7-19.7 GHz and 27.5-29.5 GHz, and capture the results of studies called with existing services in those bands

Annex

A possible example that may be helpful to address regulatory issues related to ESIM

A1.1 Technical, operational, regulatory and administrative responsibility and obligations

The obligations of administrations and entities responsible for the operation, authorization and management of interference from ESIM (land, maritime and aeronautical) are contained in the draft new Resolution [**A15**] (**WRC-19**) (see Method B in the CPM Report to WRC-19). The general provisions for using of all the above types of ESIM are as follows:

1) The notifying administration of the satellite network, with which the ESIM (land, maritime and aeronautical) communicate, shall send to the Bureau the relevant information on the transmit / receive characteristics of the ESIM intended to communicate with the satellite network, together with the commitment that ESIM operation are in conformity with the Radio Regulations and Resolution [**A15**] (**WRC-19)**;

2) Any vehicle equipped and operating ESIM (maritime, aeronautical or land) shall be licensed (authorized) for radio communication using ESIM, provided by the administration[7] of the country in which the vehicle is registered;

3) The operation of the ESIM (land, maritime and aeronautical) within the territory(-ies), territorial waters and airspace under the jurisdiction of an administration, shall be carried out only if authorized by the administration. To this effect, a satellite operator using the ESIM, in addition to the license for radio communication using ESIM, see point 2) above, shall obtain permission to use the frequencies for ESIM operation, which shall be provided by the relevant administration before the vehicle equipped and operating ESIM enters the territory (s), territorial waters or airspace under the jurisdiction of that administration;

4) In case of unacceptable interference caused by any type of ESIM:

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[7] In points 2) and 4) above, the administration authorizing ESIM is the administration providing the licence for radio communication using ESIM to the vehicle (aircraft, vessel or land vehicle) on which the ESIM operate.

- the administration[6] of the country in which the ESIM is authorized and the notifying administration of the satellite network with which the ESIM communicate shall, jointly or individually, as appropriate, upon receipt of a report of interference, ascertain the facts and take required action to eliminate or reduce interference to an acceptable level;
- the administration[6] of the country in which the ESIM is authorized shall cooperate with an investigation into the matter and provide, where possible, any required information on the operation of ESIM and a point of contact to provide such information;

5) ESIM shall not be used or relied upon for safety-of-life applications.

The following are the obligations of administrations and entities in the operation of specific types of ESIM:

a) Aeronautical ESIM

The notifying administration of the satellite network with which the aeronautical ESIM communicate and the satellite operator of ESIM on board a aircraft are responsible to implement and respect all actions relating to the technical, operational, regulatory and administrative measures to protect radiocommunication services of the administration the airspace of which aeronautical ESIM operate.

To that effect, the notifying administration of the satellite network with which ESIM communicate shall ensure that any aeronautical ESIM complies with the pfd limits produced at the Earth surface on the territory of an administration by emissions from single aeronautical ESIM (see §§ 4.1.2 and 4.2.2), which shall be established in the Radio Regulations, see Resolution [**A15**] (**WRC-19**). Higher pfd levels produced by emissions from a single aeronautical ESIM at the Earth surface shall be subject to prior agreement with this administration.

Such responsibility may be contained in the licence agreement (permission to use the frequencies for aeronautical ESIM operation, see point 3) above), in addition to the licence for radio communication using ESIM to the aircraft on which the ESIM operate (see point 2) above), to be sought from that administration well before the aircraft equipped and operating ESIM flies over the airspace of that administration.

With respect to the compatibility of aeronautical ESIM with the services of other administrations, the concepts (non-interference and non-protection with respect to terrestrial services operating in accordance with the Radio Regulations) would apply.

Any aeronautical ESIM operating in the frequency band 27.5-29.5 GHz and complying with all the provisions of the Resolution [**A15**] (**WRC-19**) should be considered as creating acceptable interference (see RR No. **1.168**) to terrestrial services, operating in accordance with the Radio Regulations.

b) Land ESIM

The administration authorising the operation of an ESIM on board a land vehicle on the territory under its jurisdiction (see point 3) above) is responsible for implementing the required technical, operational, regulatory and administrative measures to protect the terrestrial radiocommunication services on its territory as well as the terrestrial radiocommunication services on the territories of other administrations, operating in accordance with the Radio Regulations.

To that effect, such responsibility may be contained in the licence agreement (permission to use the frequencies for land ESIM operation, see point 3) above), in addition to the licence for radio communication using ESIM to the land vehicle on board which the ESIM operate (see point 2) above), to be sought from that administration well before the land vehicle equipped and operating land ESIM enters the territory of that administration.

With respect to the compatibility of land ESIM with the terrestrial services of other administrations, the land ESIM in the frequency band 27.5-29.5 GHz shall not cause unacceptable interference to fixed

and mobile terrestrial services in neighbouring countries in this frequency band, operating in accordance with the Radio Regulations. The land ESIM in the frequency band 17.7-19.7 GHz shall not claim protection from fixed and mobile terrestrial services of the neighbouring countries in this frequency band, operating in accordance with the Radio Regulations.

c) ESIM on board vessels/maritime ESIM

The notifying administration of the satellite network with which the maritime ESIM communicate and the satellite operator of maritime ESIM are responsible to implement and respect all actions relating to the technical, operational, regulatory and administrative measures to protect radiocommunication services of the administration responsible for terrestrial stations which could be impacted by maritime ESIM. The notifying administration of the satellite network with which maritime ESIM communicates shall ensure that the maritime ESIM complies with the minimum distance (70 km from the low-water mark) beyond which the maritime ESIM can operate without prior agreement of administrations, as well as the e.i.r.p. spectral density limits towards the horizon, (see §§ 4.1.2 and 4.2.2), which shall be established in the Radio Regulations, see Resolution [**A15**] (**WRC-19**).

Any transmissions from maritime ESIM on board vessels within the minimum distance or with higher e.i.r.p. spectral density levels shall be subject to prior agreement with the concerned coastal administration. This obligation takes effect when the vessel operating the marine ESIM is located in international waters, as the minimum distance (70 km) exceeds the boundaries of territorial waters (12 nautical miles (22.2 km) established by the 1982 United Nations Convention on the Law of the Sea) under the sovereignty of coastal states.

To that effect, such responsibility may be contained in the licence agreement (permission to use the frequencies for maritime ESIM operation, see point 3) above), in addition to the licence for radio communication using ESIM to the vessels on board which the maritime ESIM operate (see point 2) above), to be sought from that administration well before the vessel equipped and operating maritime ESIM cross the minimum distance (70 km) established in the Radio Regulations.

With respect to the compatibility of maritime ESIM with the services of other administrations, the concepts (non-interference and non-protection with respect to terrestrial services, operating in accordance with the Radio Regulations) would apply.

Any maritime ESIM operating in the frequency band 27.5-29.5 GHz and complying with all the provisions of the Resolution [**A15**] (**WRC-19**) should be considered as creating acceptable interference (see RR No. **1.168**) to terrestrial services, operating in accordance with the Radio Regulations.

A1.2 Additional obligations of the notifying Administration of the satellite network with which the ESIM communicate

The notifying Administration of the satellite network with which the ESIM communicate also shall ensure that:

1) ESIM operation is permitted only in the satellite networks in which frequency assignments of typical earth stations are (coordinated and notified)/recorded in the MIFR. In other cases, ESIM operation shall not be permitted;

2) with respect to satellite networks of other administrations, ESIM remained within the framework of coordination agreements for frequency assignments of typical earth stations of a satellite network with which ESIM communicate;

3) in case of interference, the ESIM shall, upon receipt of a report of harmful interference with respect to any terrestrial systems immediately cease or reduce the interference to the acceptable level;

4) ESIM have the capability to limit operations to the territory or territories of administrations having authorized those earth stations and to comply with Article **18**.

With respect to other services allocated in the frequency bands 17.7-19.7 GHz and 27.5-29.5 GHz, Resolution **[A15] (WRC-19)** defines the relevant technical, operational and regulatory provisions for ESIM operation based on the results of ITU-R studies The result of these activities may form the basis of new provisions (e.g. in the Radio Regulations) to address ESIM in these bands.