



Recommendation ITU-R SA.364-6
(12/2018)

**Preferred frequencies and bandwidths for
manned and unmanned near-Earth satellites
of the space research service**

SA Series
Space applications and meteorology

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.

Policy on Intellectual Property Right (IPR)

ITU-R policy on IPR is described in the Common Patent Policy for ITU-T/ITU-R/ISO/IEC referenced in Annex 1 of Resolution ITU-R 1. Forms to be used for the submission of patent statements and licensing declarations by patent holders are available from <http://www.itu.int/ITU-R/go/patents/en> where the Guidelines for Implementation of the Common Patent Policy for ITU-T/ITU-R/ISO/IEC and the ITU-R patent information database can also be found.

Series of ITU-R Recommendations

(Also available online at <http://www.itu.int/pub/R-REC/en>)

Series	Title
BO	Satellite delivery
BR	Recording for production, archival and play-out; film for television
BS	Broadcasting service (sound)
BT	Broadcasting service (television)
F	Fixed service
M	Mobile, radiodetermination, amateur and related satellite services
P	Radiowave propagation
RA	Radio astronomy
RS	Remote sensing systems
S	Fixed-satellite service
SA	Space applications and meteorology
SF	Frequency sharing and coordination between fixed-satellite and fixed service systems
SM	Spectrum management
SNG	Satellite news gathering
TF	Time signals and frequency standards emissions
V	Vocabulary and related subjects

Note: This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.

Electronic Publication
Geneva, 2018

© ITU 2018

All rights reserved. No part of this publication may be reproduced, by any means whatsoever, without written permission of ITU.

RECOMMENDATION ITU-R SA.364-6

Preferred frequencies and bandwidths for manned and unmanned near-Earth satellites of the space research service

(1963-1966-1970-1978-1986-1992-218)

Scope

This Recommendation provides guidance for the selection of frequencies and bandwidths for manned and unmanned near-Earth satellites of the space research service from a preferred list of frequencies and bandwidths.

Keywords

Preferred frequencies and bandwidth, the space research service (SRS), near-Earth, manned, unmanned

Related Recommendations and Reports

Recommendations ITU-R SA.363, ITU-R SA.1019, ITU-R SA.1863

The ITU Radiocommunication Assembly,

considering

- a) that suitable frequencies and required radio-frequency bandwidths for near-Earth space research missions are determined by radiowave propagation factors and technical requirements;
- b) that two-way communication is required for many near-Earth missions, and is vital for manned missions;
- c) that it is necessary to satisfy requirements for radiocommunication reliability during periods of adverse atmospheric conditions;
- d) that it is practical and desirable to effect radiocommunication functions on a single link;
- e) that to effect precision tracking, a pair of coherently related Earth-to-space and space-to-Earth links' frequencies is desirable;
- f) that for simultaneous transmit/receive operations involving a single antenna, the paired Earth-to-space and space-to-Earth links' frequencies should be separated by at least 6%;
- g) that space-to-space and Earth-to-space relay satellite radiocommunication links are necessary to accommodate the growth and development of near-Earth explorations in the space research service;
- h) that particular modulation and channel coding techniques may be required for some links in order to comply with power flux-density (pfd) limits or to guard against multipath and/or interference effects,

recommends

- 1 that frequency bands for near-Earth missions in the space research service be selected, with due regard to the purpose of the link and to the feasibility of sharing, in the preferred frequency ranges listed in Table 1;

2 that information concerning typical individual link bandwidths and their uses listed in Table 2 of the Annex be employed in order to provide for present and future near-Earth telecommunications in multi-spacecraft, multi-mission systems, within the space research service;

3 that the frequency bands allocated to the space research service, corresponding pfd limits, and typical use of these frequency bands as provided in the Attachment to the Annex be taken into account in designing space research systems.

Annex

Preferred frequencies and bandwidths for manned and unmanned near-Earth satellites of the space research service

1 Introduction

This Recommendation provides information on the preferred frequencies and bandwidths for manned and unmanned near-Earth satellites operating in the space research service (SRS). Section 2 explores the various functions of SRS communications, including command, telemetry, and tracking. Section 3 discusses the frequency bands for SRS missions, including mission and equipment requirements, propagation and radiation effects, link performance considerations, and related ITU-R Recommendations. Section 4 contains tables of preferred frequency bands and their uses and typical individual links bandwidths and their uses.

2 Space research communication and tracking functions and their technical requirements

The three primary spacecraft functions discussed below, command, telemetry and tracking, are space operation functions. Space research missions use frequency bands allocated to the SRS to provide the space operation functions as well as the mission telemetry within a single radio system. This allows for more efficient use of the radio-frequency spectrum, as well as less stringent requirements for spacecraft power, component space, and weight.

2.1 Functions

2.1.1 Command transmissions

Commands provide control of a spacecraft, activate various mission functions or modify the operation of a spacecraft or its payloads, and counter operational anomalies. During launch operations, most commands are recorded and delivered by an on-board sequencer. Earth-to-space commands are transmitted for execution in real time or may be stored for later sequencing. Critical commands are often sent as two stage commands; the first command configures the operation to be taken, and the second command executes the operation. Both commands in a two-stage set must be successfully received for the operation to be implemented.

2.1.2 Spacecraft telemetry transmissions

The spacecraft telemetry subsystem reports the condition of the spacecraft systems, its payloads, and provides measured data from spacecraft instrumentation to a designated earth station. This system also gives the status of the reception and execution of commands. Telemetry data may be

stored for subsequent transmission or require real time transmission, as in the case for launch and contingency operations.

2.1.3 Mission telemetry transmissions

The mission telemetry subsystem is responsible for the transmission to the Earth of scientific and technical data accumulated through experimentation, active and passive sensing, and data generated by spacecraft and payloads such as probes and landers. For manned missions the telemetry subsystem is also required to transmit audio and video.

2.1.4 Tracking

Tracking is a basic requirement of any space research mission. In addition to providing information necessary to determine the location and velocity of the spacecraft, tracking is also required for evaluation of launch and orbit performance, for trajectory corrections, for determining the precise timing for critical functions such as retrorocket firing, and forecasting spacecraft visibility and antenna pointing angles required by spacecraft and earth stations.

3 Frequency bands for space research missions

Factors that determine the suitability of specific frequencies for space research missions include mission requirements, equipment availability and cost, radiowave propagation and radiation effects, link performance and existing SRS frequency allocations. Evolving mission requirements and physical effects are used to define requirements for new space research allocations.

3.1 Mission requirements

Space research missions require a variety of data types to support command, telemetry, and tracking functions. Real time audio and video are required for manned missions. These requirements are usually multiplexed onto a single frequency carrier to implement an efficient spectrum usage.

Higher frequency allocations generally allow the use of wider bandwidths. Wider bandwidth provides the ability to support higher data rate requirements, video communications, and the use of more complex coding schemes to effectively reduce error rates and susceptibility to interference.

Frequencies may be reused among spacecraft if their orbital characteristics and transmission requirements are such as could avoid excessive levels of interference. However, different frequencies are required for spacecraft if their orbital characteristics and transmission requirements are such as could lead to excessive levels of interference.

Precision tracking requires that the frequencies for Earth-to-space and space-to-Earth tracking signals be coherently related by a suitable turn-around ratio. This requirement is provided by ensuring that the forward and return frequency separation ranges between 6-10% of the higher frequency.

Frequency bands for active and passive sensing depend on the particular information being sought with respect to the characteristics of the object, the space environment, and/or the particular phenomenon in space being studied. The frequency bands chosen are those identified by the physics as optimum for the scientific investigation. Bandwidths determine the resolution and precision that is obtainable.

3.2 Equipment requirements

Frequency dependent equipment factors either directly influence link performance, such as antenna gain, efficiency and pointing accuracy, or do not directly affect link performance but nevertheless require consideration in the selection of frequencies. For simultaneous transmit and receive

operations involving a single antenna, the paired Earth-to-space and space-to-Earth frequency bands need to be separated by 6-7% of the high frequency for near-Earth and 8-20% of the high frequency for deep-space missions.

Spacecraft antenna size is limited by space and weight limitations, technology development for large unfurlable antennas, and the capability of the satellite to point the antenna with the required precision. The 100 MHz to 1 GHz frequency range is suitable for spacecraft with widebeam or omnidirectional antenna and narrow bandwidth requirements and for simple earth stations without facilities for antenna tracking. In the 1-10 GHz frequency range, spacecraft antennas have gains compatible with attitude stabilization and beam steering requirements. Surface and pointing accuracy required for large earth stations can also be met in this range, which is also suitable for wide band precision tracking and communication systems.

The availability of space qualified hardware could be a limiting factor in the use of higher frequencies. Currently, the most mature space research hardware has been developed for the 2 GHz and the 7/8 GHz frequency bands, which are essential for providing weather tolerant links. This equipment is also attractive and readily available for small project/missions with low data rate requirements and budget constraints. Hardware is becoming mature for the 27/32/34 GHz frequency bands that provide the advantage of wider available bandwidths for near-Earth and deep-space spacecraft.

3.3 Propagation and radiation effects

Radiocommunication links between earth stations and space research satellites pass through the Earth's atmosphere where absorption, precipitation and scattering affect the propagation of radio signals and limit the use of a number of frequency bands. Precipitation, especially rain, causes absorption and scattering of radio waves that can lead to severe signal attenuation. For all rainfall rates, the specific attenuation increases rapidly with increase of the used frequency up to about 100 GHz, after which the rate of attenuation does not increase appreciably as a function of frequency. For countries located in regions of high rain rate, the choice of suitable frequencies is critical if they are to maintain a high quality of performance despite adverse weather conditions.

Molecular absorption is primarily due to atmospheric water vapour and oxygen. Trace gases, in the absence of water vapour, can also contribute significant attenuation for frequencies greater than 70 GHz. Water vapour has absorption lines centred at 22.235 GHz, at 183.3 GHz and around 325 GHz. Oxygen has a series of absorption lines extending from 53.5 to 65.2 GHz, and an isolated line centred at 118.74 GHz. In the future it may be desirable to employ geostationary relay stations operating at frequencies which are relatively opaque to the transmission of radio signals through the Earth's atmosphere, thereby limiting interference between the relay stations and spacecraft from terrestrial stations.

Sky noise temperature as seen by an earth station antenna is a function of frequency, antenna elevation angle, and atmospheric conditions. Above about 4 GHz, precipitation can result in an increase in sky noise that is several times larger than the receiver noise temperature. The sky noise temperature seen by a spacecraft is determined primarily by celestial bodies such as the moons and the planets that provide the backdrop for most space research missions. The Sun with blackbody radiation temperature of 6000 K, would greatly increase the system noise temperature and therefore transmissions that require a receiving antenna to point at or near the Sun are usually avoided. The blackbody radiation temperatures of the moon and planets range from about 50-700 K (the Earth temperature is 290 K). For many near-Earth missions, the Earth will generally be within the main lobe of a spacecraft or DRS antenna and contribute to the overall noise temperature of the receiving system. System noise temperature of typical spacecraft range from 600 to 1500 K.

Radio-frequency spectrum below 100 MHz is generally not considered for space research because ionospheric effects, cosmic and man-made noise mitigate against the use of frequencies in that range. In the range between 100 MHz and 1 GHz, atmospheric absorption is low and weather has very little effect on signal propagation. Background noise, however, is relatively high, increasing as $1/f^2$, and therefore the use of low-noise receivers do not provide significant improvement in performance in this range of frequencies. In the 1 to 10 GHz frequency range, weather effects are very small particularly at the lower end of the range permitting essentially weather independent communications. Both galactic and atmospheric noise are low permitting the use of low-noise receivers. Above 10 GHz and up to 275 GHz, the propagation of signals through the atmosphere is subject to high attenuation primarily due to precipitation and gaseous absorption. Both of these conditions can have a significant effect on Earth-to-space communication paths.

3.4 Link performance

Link reliability is an important mission requirement. Critical operations such as launch and contingency operations when the orientation of the spacecraft cannot be guaranteed require highly reliable links. Reliability is of paramount importance for all manned missions. The 2 GHz allocations to the SRS are employed to provide a reliable, weather independent link for space research missions and are used for these critical functions.

The identification of frequency bands which provide the best performance for space research communication and tracking links is done in the link performance analysis and depends on radiowave propagation parameters and equipment characteristics. A convenient index of link performance is the ratio of received signal power to noise power spectral density ratio (P_r/N_0). Information curves derived from link performance analysis assist in identifying frequency ranges that provide optimum performance for the proposed mission conditions. Different assumptions about communication distance, antenna characteristics and transmitter power alter the absolute values of P_r/N_0 but do not change the shape of the curves. The frequency band which provides the highest value of P_r/N_0 for a particular system and set of propagation conditions is defined as the preferred frequency band.

3.5 Recommendations related to space research service allocations

Frequency band allocations for space research were initiated during the 1959 Ordinary Administrative Radio Conference in Geneva when provisional allocations to transmissions between the Earth and artificial Earth satellites were made in the frequency bands 136-137 MHz and 2290-2300 MHz. In 1963 the Extraordinary Administrative Radio Conference fortified these two space research allocations making them primary, co-equal with other services, and exclusive in Region 2. That time advances in the space research technology and communications and demands to meet ever increasing data requirements have necessitated the allocation of additional bands to meet the growing needs of the space research service.

Preferred frequency bands for the space research service can be found in the following ITU-R Recommendations:

- Recommendation ITU-R SA.363 – Space operation systems
- Recommendation ITU-R SA.1019 – Preferred frequency bands and transmission directions for data relay satellite systems
- Recommendation ITU-R SA.1863 – Radiocommunications used for emergencies in manned space flight.

A comprehensive table of SRS allocations, their use by SRS systems and corresponding pfd limits is presented in the Attachment to this Annex.

4 Preferred frequency bands, their uses by SRS systems and typical individual links bandwidths and their uses

Maximum data rate capability is obtained by using frequency bands where P_r/N_0 is a maximum for the weather conditions and space-station antenna limitations considered. Table 1 summarizes the frequency bands preferred for various applications. A high rain rate was assumed when determining the width of all-weather frequency bands in order that the results be applicable worldwide. Frequency bands outside this range may be suitable for areas of lower rain rates.

Space-to-space links are best located in the frequency ranges of high atmospheric attenuation as this virtually eliminates any problem of interference to and from terrestrial sources.

Above about 150 GHz, trans-atmospheric communications are subject to a high level of signal attenuation when the elevation angle is low. However, the range of frequencies above 150 GHz may be considered for links through the atmosphere, where the elevation angle of operation is not low.

The list of frequency bands given in Table 1 is intended to identify those frequency ranges which are preferred from a technical standpoint. The inclusion of a frequency band in the table is not intended to indicate that there will be sufficient available link margin or bandwidth and does not mean that these frequencies have been allocated. Also, exclusion of other frequencies from the table does not necessarily preclude operations in these frequency bands where frequency sharing considerations and state of the art equipment limitations dictate their use.

TABLE 1
Preferred frequency ranges and their uses*

Frequency ranges (GHz)	Direction s-E = space-to-Earth E-s = Earth-to-space s-s = space-to-space	Comments
0.1-2.5 0.1-3.0	s-E E-s	An all-weather link, optimum also when communications must be established regardless of spacecraft orientation
0.1-10 0.1-10	s-E E-s	A clear-weather link, optimum when a broad or fixed beamwidth antenna is required on the spacecraft
0.02-6 0.02-6	s-E E-s	An all-weather link for use with directive antennas
0.02-6 13.4-27.5 31-36	s-s s-s s-s	Frequency bands necessary to provide space-to-space communications with existing and proven space equipment and technology. Also necessary to provide continuity of service until other frequency bands show practical and technical usability
10-26 14-23 31-36 40-41 31-36 37-38 74-84 85-100 127-137	s-E E-s E-s E-s s-E s-E s-E E-s and s-E E-s and s-E	A clear-weather link, optimum for a high or medium gain antenna on the spacecraft
65-66 117-120 178-188 318-328	s-s s-s s-s s-s	Frequency bands affording maximum clear-sky interference protection to space-to-space links from terrestrial applications, optimum for high to medium gain spacecraft antennas

* Specific frequency bands for SRS systems need to be used in accordance with existing SRS allocations (see Attachment to the Annex).

The list of typical individual link bandwidths given in Table 2 contains information on link bandwidths which can be supported with the current technology. The inclusion of a link bandwidth in the table is not intended to indicate the frequency band in which the individual link may be required to operate nor to limit the numbers of such links that may be required to support any particular spacecraft or mission systems.

TABLE 2
Typical individual link bandwidths and their uses

Type of the use	Direction	Typical bandwidth	Comments
Telecommand	E-s	10-500 kHz	
Maintenance telemetry	s-E	5-500 kHz	
Telemetry	s-E (direct)	100 kHz-100 MHz	Direct satellite transmission to the Earth
Telemetry	s-E (relay)	225-650 MHz	Relay satellite link to an earth station, data from one or more user satellites
Telemetry	s-s	5-225 MHz	User satellite link to relay satellite
Telemetry	s-s	> 1 GHz	Relay satellite link to relay satellite
Tracking	s-E	500 Hz-500 kHz	Interferometry
Tracking	E-s	1-3 MHz	Range and range rate systems
Tracking	E-s	1-10 MHz	Radar
Tracking	E-s	5-6 MHz	Bilateration ranging

Attachment to Annex

TABLE 3

Frequency bands allocated to the SRS, corresponding pfd limits as specified in the Radio Regulations (Edition 2016) and the use of these frequency bands by SRS systems

Frequency bands		Use SRS = Non specific s-E = space-to-Earth E-s = Earth-to-space s-s = space-to-space	Power flux-density limit for angles of arrival (θ) Above the horizontal plane (dBW/m ²) ⁽¹⁾			Reference bandwidth
			$0^\circ \leq \theta \leq 5^\circ$	$5^\circ < \theta \leq 25^\circ$	$25^\circ < \theta \leq 90^\circ$	
2 501-2 502	kHz	SRS				
5 003-5 005	kHz	SRS				
10 003-10 005	kHz	SRS				
15 005-15 010	kHz	SRS				
18 052-18 068	kHz	SRS				
19 990-19 995	kHz	SRS				
25 005-25 010	kHz	SRS				
30.005-30.01	MHz	SRS				

TABLE 3 (end)

Frequency bands		Use SRS = Non specific s-E = space-to-Earth E-s = Earth-to-space s-s = space-to-space	Power flux-density limit for angles of arrival (θ) Above the horizontal plane (dBW/m ²) ⁽¹⁾			Reference bandwidth
			$0^\circ \leq \theta \leq 5^\circ$	$5^\circ < \theta \leq 25^\circ$	$25^\circ < \theta \leq 90^\circ$	
39.986-40.02	MHz	SRS				
40.98-41.015	MHz	SRS				
137-138	MHz	s-E				
138-143.6	MHz	s-E				
143.6-143.65	MHz	s-E				
143.65-144	MHz	s-E				
400.15-401	MHz	s-E				
410-420	MHz	s-s				
1 215-1 300	MHz	SRS active sensing				
2 025-2 110	MHz	E-s, s-s	-154	$-154 + 0.5 (\theta - 5)$	-144	4 kHz
2 200-2 290	MHz	s-E, s-s	-154	$-154 + 0.5 (\theta - 5)$	-144	4 kHz
3 100-3 300	MHz	SRS active sensing				
7 190-7 235	MHz	E-s				
8 450-8 500	MHz	s-E	-150	$-150 + 0.5 (\theta - 5)$	-140	4 kHz
8 550-8 650	MHz	SRS active sensing				
9 300-9 800	MHz	SRS active sensing				
9 800-9 900	MHz	SRS active sensing				
13.25-13.4	GHz	SRS active sensing				
13.4-14.3	GHz	SRS active sensing				
14.4-14.47	GHz	s-E				
14.5-15.35	GHz	SRS				
17.2-17.3	GHz	SRS active sensing				
22.55-23.55	GHz	s-s	-115	$-115 + 0.5 (\theta - 5)$	-105	1 MHz
22.55-23.15	GHz	E-s				
25.25-27.5	GHz	s-s	-115	$-115 + 0.5 (\theta - 5)$	-105	1 MHz
25.5-27	GHz	s-E	-115	$-115 + 0.5 (\theta - 5)$	-105	1 MHz
31-31.3	GHz	SRS	-115	$-115 + 0.5 (\theta - 5)$	-105	1 MHz
34.7-35.2	GHz	SRS	-115	$-115 + 0.5 (\theta - 5)$	-105	1 MHz
35.5- 36	GHz	SRS active sensing				
37-38	GHz	s-E, NGSO	-120	$-120 + 0.75 (\theta - 5)$	-105	1 MHz
37-38	GHz	s-E, GSO	-125	$-125 + (\theta - 5)$	-105	1 MHz
40-40.5	GHz	E-s				
65-66	GHz	SRS				
74-84	GHz	s-E				
94-94.1	GHz	SRS active sensing				

⁽¹⁾ Blank cell means the value is not available.