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Spectrum requirements for future EESS missions operating under a potential new EESS uplink allocation in the 7-8 GHz range

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Spectrum requirements for future EESS missions operating under a potential new EESS uplink allocation in the 7-8 GHz range

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1 Introduction

Agenda item 1.11 (WRC-15) aims at identifying a primary allocation for the Earth exploration-satellite service (EESS) (Earth-to-space) in the 7-8 GHz range. To prepare the technical basis of the work for WRC-15, Resolution **650 (WRC-12)** resolves that compatibility studies between EESS (Earth-to-space) systems and existing services need to be conducted, and that the spectrum needs of future Earth observation satellites need to be assessed.

EESS satellites and missions are used to gather characteristics of the Earth and its natural phenomena. These satellite missions contain a variety of sophisticated scientific instruments that are used to make measurements and observe the Earth, which provide invaluable societal benefits to all humans. Most data generated by EESS satellites are shared with all nations, and in most cases are available free of charge. Some examples of the diverse set of benefits provided by EESS missions include climate monitoring, the studying of natural systems, monitoring of potential hazards, disaster management, and to further human endeavours such as mapping and population monitoring.

EESS systems typically operate in non-geostationary orbits with high inclinations. Earth stations that support these systems are located worldwide and are usually positioned at high latitudes to take advantage of the orbits of many EESS missions. Only when a satellite is in line-of-sight of an Earth station, can a communication link be established. The planning of communication operations between an Earth station and the satellite is dependent on capabilities of the on-board data system, the satellite power system, the observation goals, mission parameters, and the available communications capacity.

The EESS missions currently perform the functions of Telemetry, Tracking & Command (TT&C) in the S-band. The 2 025-2 110 MHz band is used to uplink the command and ranging signals, and the 2 200-2 290 MHz band is used to downlink the spacecraft telemetry and ranging signals. Both up/downlink bands are shared with the space research service (SRS) and the space operations service (SOS). The EESS missions perform the payload data download in either the 2 200-2 290 MHz or 8 025-8 400 MHz bands, depending on the data rate requirements.

An EESS (Earth-to-space) allocation in the 7-8 GHz range would allow its use for TT&C in combination with the existing EESS (space-to-Earth) allocation in the band 8 025-8 400 MHz, thereby alleviating the congestion problem in the S-band, mitigating the frequency coordination problem, and eventually leading to a simplified on-board architecture and operational concept for future EESS missions.

2 Assessment of spectrum requirements

2.1 EESS telemetry, tracking and control operations

Unlike typical communication satellites, which are in constant contact with a commanding Earth station, EESS satellite missions are not in constant contact with commanding Earth stations. As a result, the highly sophisticated scientific instruments on board are controlled autonomously based on stored commands which are uploaded to the spacecraft on a regular basis. Telemetry, Tracking and Control (TT&C) operations are the primary satellite functions that provide the control necessary for the operation of the scientific instruments, as well as the power, attitude, and command and data handling systems of the spacecraft itself.

Tracking provides information necessary to determine the location and velocity of a satellite. This can be done by an on-board transponder in association with a command link. Telemetry is associated with the satellite reporting the condition of all its systems and also of the status and reception of commands. Commands are used to modify satellite operations, instruments, or to perform satellite manoeuvres.

As a satellite performs its observations or missions, new tasks may be required of the satellite instruments. These tasks need to be sent to an EESS mission by an uploaded command to be stored on-board for future operations. The commands can be simple operations or may be complex new mission parameters. Emergency commands may also need to be sent when there is a failure or malfunction in the satellite system.

The need for reliability in TT&C communication links is of high importance for the safety and success of an EESS mission. Without successful operations of the TT&C communications system, the operations of the satellite may fail, scientific experiments or instruments may fail to operate, observing goals may not be met, or the spacecraft may be lost entirely. Some reliability requirements set for EESS TT&C communication links are a bit error rate less than 1×10^{-5} and a bandwidth wide enough to provide all essential information.

The frequency and complexity of EESS missions is constantly expanding as new instruments to further our understanding of the Earth's atmosphere, environment, and ecosystem are developed by the scientific community. Further, there are a growing number of commercial remote sensing missions.

With the increasing complexity of these missions, there may be times when two or more satellites supporting the objectives of a single mission are flown in a formation for coordinated data gathering. Measurements from such formation flying missions can have a separation of 5 to 15 minutes, but can be as little as 15 seconds. When such a scenario occurs, a situation may occur where more than one satellite will be within the beamwidth of a common Earth station antenna and

require simultaneous communications. This operational scenario requires an Earth station bandwidth wide enough to accommodate several satellite signals for effective TT&C operations.

The data rates and bandwidth requirements for EESS missions depend on a multitude of variables including the type of EESS mission, the sophistication of the scientific instruments used by the mission, the satellite data storage capacity, and the amount of contact time available between the Earth station and satellite. The telecommand data rates typically vary from 4 to 64 kbit/s for current missions. Future EESS missions will involve higher complexity and will have increased TT&C requirements. It is expected that, in the near future, EESS missions may require higher data rates up to 2 048 Mbit/s, as considered in the CCSDS Recommendations for radio frequency and modulation systems (CCSDS 401.0-B-21S July 2011).

The telecommand uplink is typically established during all passes, while the ranging measurements can be initiated during some or all passes, depending on the mission phase and operational procedures. Some EESS missions rely partially or solely on global navigation satellite systems (GNSS) for orbit determination.

Most EESS missions require the capability to simultaneously support telecommand and ranging functions. Therefore, residual carrier modulation schemes need to be used in order to allow a distinct carrier component to be present for ranging in the up- and downlink. To ensure an optimum utilization of the spectrum, the CCSDS Standard 401.0B recommends:

– *for low rate telecommand systems* (transmission rates less than or equal to 4 kbit/s), CCSDS agencies should use a sine wave subcarrier for telecommand, with a frequency of either 8 kHz or 16 kHz, which has been PSK modulated. Modulation scheme: PCM(NRZ-L)/PSK/PM;
– *for medium rate telecommand systems* (transmission rates from 8 kbit/s to 256 kbit/s), CCSDS agencies should use PCM (bi-phase-L)/PM modulation direct on the carrier.

For high rate telecommand systems (up to 2 048 Mbit/s) that do not require simultaneously two-way ranging, the CCSDS recommends the use of BPSK modulation. More spectral efficient modulation schemes could be considered in future revisions of the CCSDS Standard 401.0B. EESS missions using suppressed carrier modulation schemes for the telecommand signal may use the doppler measurements on the carrier recovered from the RF signal for orbit prediction and determination.

Concerning the ranging function, the systems commonly used are the Tone Ranging System and the Pseudo-Noise Code Ranging System. The first system is typically used together with low rate telecommand signals and uses a 100 kHz major tone and several minor tones. The latter system utilizes PN sequences that modulate a tone frequency between 100 kHz and 1.5 MHz. The selection of the ranging tone frequencies will depend on the ranging accuracy necessary and the telecommand signal spectrum.

For most missions, the ranging signals occupy a larger bandwidth than the telecommand ones. Therefore, the total necessary bandwidth for the uplink is mainly determined by the ranging signal.

The technical characteristics of potential new EESS uplink systems operating in the 7-8 GHz frequency range would be similar to those of SRS near-Earth systems, but with lower transmit power requirements and smaller antenna size limited to a diameter between 11 and 15 m.

A summary of the characteristics and required bandwidth of the various types of EESS uplinks is presented in the Annex. The required bandwidth varies from few kHz to 4 MHz, depending on the mission requirements in terms of telecommand data rates and/or ranging tone frequencies.

2.2 Assessment of average bandwidth per uplink for future EESS missions

The assessment of the average bandwidth that would be required by future EESS uplink systems in the 7-8 GHz range is based on the calculation of the average bandwidth currently used by EESS uplink systems in the 2 025-2 110 MHz range for telecommand operations.

A query in the ITU SNS database was done in the range 2 025-2 110 MHz and the number of EESS missions identified was 112. The average bandwidth per mission was found to be 1.4 MHz.

2.3 Estimated number of future EESS missions using the proposed allocation

A query in the ITU Space Network Systems was made to estimate the number of missions that could use a new EESS uplink allocation in the 7-8 GHz band and 130 EESS missions were found to have a downlink in 8 025-8 400 MHz.

Making the assumption that within 10-15 years there will be an increase of approximately 25% in the number of EESS missions using 8 025-8 400 MHz for data downlink and that approximately 50% of these satellites could be using the new EESS (E-s) allocation, the estimated number of EESS missions with an uplink in 7-8 GHz in the next 10-15 years would be 81.

3 Total bandwidth requirements for EESS (E-s) in the 7-8 GHz range

Most Earth exploration-satellites use very similar (polar) orbits and the ground stations are co-located at high latitudes (e.g. Kiruna (Sweden), Poker Flat (Alaska), Prince Albert (Canada), Troll (Antarctica)). This situation imposes more restrictions to be taken into account for efficient frequency reuse and frequency coordination amongst different missions. A frequency reuse factor 1/3 has been considered for the case of EESS being the only space service allocated in the 7-8 GHz range. For the case when the EESS uplink band is being shared by the EESS and other space services, a lower frequency reuse factor (1/2) is considered more adequate. Therefore, based on the considerations explained above, it is estimated that the EESS uplink in the 7-8 GHz range would require an allocation between 38 and 56 MHz (see Table 1).

TABLE 1

Estimated bandwidth requirements for EESS uplinks in the 7-8 GHz range

Number of EESS satellites using 7-8 GHz uplink in the next 10-15 years (n)	81
Average bandwidth per uplink (BW)	1.4 MHz
Estimated total bandwidth ($n \times$ BW)	113.4 MHz
Considering EESS as the only space service using the allocated band: ** Estimated total bandwidth for 1/3 frequency reuse factor	38 MHz
Considering EESS sharing the allocated band with other space services: ** Estimated necessary bandwidth for 1/2 frequency reuse factor	56 MHz

4 Conclusion

Taking into account the assumptions described in § 3, the conclusion of this preliminary assessment is that the allocation to the EESS (E-s) in the 7-8 GHz band would need approximately 56 MHz, considering that most likely the EESS would be sharing the whole or part of the allocated band with other satellite services.

The necessary bandwidth would be 38 MHz in case the EESS would be the only service using the complete allocated band.

This estimation is based on a conservative projection of 25% growth of the number of EESS missions in the next 10-15 years.

Annex

Characteristics of the telecommand and ranging functions for EESS uplinks

Uplink function	**Modulation scheme**	**Symbol rate (R_s)**	**Maximum bandwidth requirements** (See Note 1)
Low rate telecommand	Residual carrier with subcarrier: PCM(NRZ)-PSK/PM	Up to 4 kbit/s	≈ 50 kHz (for f_{sc} = 8 kHz) ≈ 100 kHz (for f_{sc} = 16 kHz)
Medium rate telecommand	Residual carrier with direct phase modulation: PCM(SP-L)/PM	8 to 256 kbit/s	≈ 12 × R_s (See Note 2) i.e. from 100 kHz (for 8 kbit/s) to 3 MHz (for 256 kbit/s)
High rate telecommand	Suppressed carrier: BPSK	Up to 2 048 Mbit/s	≈ 2 × R_s (See Note 2) i.e. 2 MHz (for 1 Mbit/s), 4 MHz (for 2 Mbit/s)
Ranging	Tone ranging or PN code ranging systems	Ranging tone (f_t) from 100 kHz to 1.5 MHz	BW_{max} = 2.5 × f_t i.e. from 250 kHz to 3.75 MHz

NOTE 1 – Maximum bandwidth occupation permitted by the ECSS standard for space engineering-RF and Modulation (ECSS-E-ST-50-05C Rev.2, Oct. 2011) in the bands 2 025-2 120 MHz and 7 145-7 235 MHz. (ECSS standards are available at http://www.ecss.nl) where f_{sc} is the subcarrier frequency, R_s the symbol rate and f_t is the ranging tone frequency.

NOTE 2 – Filtering required to comply with bandwidth.