Recommendation SFCG 32-2R4

COMMUNICATION AND POSITIONING, NAVIGATION, AND TIMING FREQUENCY ALLOCATIONS AND SHARING IN THE LUNAR REGION

THE SFCG

CONSIDERING

a) that a regional communication network at the Moon, also including Positioning, Navigation, and Timing (PNT) services, can be expected in the foreseeable future as missions to the lunar region increase in number and variety;

b) that frequencies for direct communication between a spacecraft in the lunar region and an earth station are provided in the existing allocations to Space Research Service (SRS);

c) that separate frequencies are needed in the lunar region for compatible local communications between a surface vehicle and an orbiter, between surface vehicles, and between orbiters;

d) that major criteria for allocating frequencies in the lunar region include RF compatibility, technology availability and performance, mission scenarios, cost, and ability to conduct testing and emergency support from the Earth;

e) that the major benefit of an agreed frequency plan for the lunar region enables interoperability and sharing of communications and PNT infrastructure and service assets to support individual or joint exploration missions to accomplish complex objectives;

f) that envisioned lunar missions will involve complex communications architectures using earth stations that can communicate with near-Earth relay satellites, lunar orbiting satellites, and lunar surface elements in view of Earth;

g) that it is envisioned that missions in the lunar region will employ Lunar Relay Satellites (LRS) to allow relay communication coverage and to forward data gathered from lunar surface elements to earth stations;

h) that it is envisioned that missions in the lunar region by multiple administrations either independently or jointly can occur during the same time period and each mission may employ

many simultaneous communications links with another orbiter, the lunar surface elements, LRS, lunar communications terminals (LCT) and earth stations;

i) that sufficient frequency separation is required to enable compatible and simultaneous communications for a multiplicity of spacecraft in the lunar region with each other, earth stations, LRS, local lunar based vehicles, a lunar outpost and lunar vehicles transmitting to an earth station;

j) that lower frequency provides better SNR performance for a communication link between two vehicles using low gain broad beam antennas, such as between a vehicle in the lunar region and a LRS;

k) that higher frequency provides wider bandwidth and higher data throughput performance between two vehicles employing high gain antennas, such as between a large lander and an LRS with accurately pointed antennas;

l) that techniques such as self-test on board are available to minimize the need for testing with Earth-based signals;

m) that Recommendation ITU-R RA.314-10 provides the preferred frequency bands for Radio Astronomical measurements;

n) that Recommendation ITU-R RA.479-5 on the protection of frequencies for radio astronomical measurements in the SZM recommends the 0 MHz to 30 MHz and the 300 MHz to 2 GHz ranges should be reserved for radio astronomy observations in the SZM, notably for continuum observations.

NOTING

a) that the SFCG has resolved to provide assistance to member agencies in coordinating frequency assignment for lunar and Martian missions (see RES SFCG A26-1R6);

b) that, according to the provisions of the Radio Regulations, testing lunar local link radios with signals transmitted from an earth station is allowed only if it does not interfere with Earth-based radio systems operating in accordance with the Radio Regulations;

c) that lunar missions may need interoperable relay links to maintain communication with the Earth;

d) that missions may require Global Navigation Satellite Service (GNSS) signals for accurate Positioning, Navigation, and Timing (PNT) in the lunar region, and that these GNSS signals may originate from either Earth or Moon orbiting satellite constellations;

e) that passive observations in space need to be protected to the extent provided in the Radio Regulations;

f) that per Article 22, Section V, of the ITU Radio Regulations, emissions causing harmful interference to radio astronomy observations and to other users of passive services in the Shielded Zone of the Moon (SZM) are prohibited with some exceptions[1];

g) that Space Research Service and Space Operations Service frequency bands can contain radiocommunication signals with position and navigation information via an integrated ranging signal and should not be used for broadcast satellite PNT signals.

RECOGNISING

a) that lunar local links must not interfere with the direct communication links between space and the Earth using frequencies provided in the Radio Regulations;

b) that multiple frequency bands are needed for missions to meet various communications requirements and satisfy cost, mass and performance objectives;

c) that it is important to protect radio astronomy in the SZM;

d) that strict compliance of Radio Astronomy Service protection levels from adjacent band transmissions is expected through filtering and / or guard bands based on the design of the transmitting signal spectrum.

RECOMMENDS

1. that for communications PNT and SAR in the lunar region agencies select frequencies from Tables 1 2, and 3, for which examples of service requirements are given in Table 4;

2. that testing lunar local links in flight with signals transmitted from an earth station be minimized and non-interfering to the Earth-based radio systems operating under the provisions of the Radio Regulations;

3. that assignment of lunar local link frequencies be coordinated within the SFCG in accordance with RES A 26-1R7.

[1] 22.22 § 8 1) In the shielded zone of the Moon emissions causing harmful interference to radio astronomy observations and to other users of passive services shall be prohibited in the entire frequency spectrum except in the following bands:

22.23 a) the frequency bands allocated to the space research service using active sensors;

22.24 b) the frequency bands allocated to the space operation service, the Earth exploration-satellite service using active sensors, and the radiolocation service using stations on spaceborne platforms, which are required for the support of space research, as well as for radiocommunications and space research transmissions within the lunar shielded zone.

22.25 2) In frequency bands in which emissions are not prohibited by Nos. 22.22 to 22.24, radio astronomy observations and passive space research in the shielded zone of the Moon may be protected from harmful interference by agreement between administrations concerned.

Table 1: Recommended Frequency Bands for Communications in the Lunar Region

Link	Frequency
Earth to Lunar Orbit	2025-2110 MHz (Note 1), (Note 2) 7190-7235 MHz 22.55-23.15 GHz (Note 2) 40.0-40.5 GHz
Lunar Orbit to Earth	2200-2290 MHz (Note 2) 8450-8500 MHz 25.5-27.0 GHz 37-38 GHz (Note 3)
Earth to Lunar Surface	2025-2110 MHz (Note 1), (Note 2) 7190-7235 MHz 22.55-23.15 GHz
Lunar Surface to Earth	2200-2290 MHz (Note 2) 8450-8500 MHz 25.5-27.0 GHz
Lunar Orbit to Lunar Surface	390-405 MHz (Note 4) 2025-2110 MHz (Note 2) 23.15-23.55 GHz
Lunar Surface to Lunar Orbit	435-450 MHz (Note 4) 2200-2290 MHz (Note 2) 27.0-27.5 GHz
Lunar Orbit to Lunar Orbit	2025-2110 MHz (Note 2) 2200-2290 MHz (Note 2) 23.15-23.55 GHz 27.0-27.5 GHz
Lunar Surface Wireless Network	390-405 MHz (Note 4) 410-420 MHz (Note 8) 435-450 MHz (Note 4) 2.400-2.480 GHz (Note 7) 2.5035 – 2.655 GHz (Note 9) 3.5-3.8 GHz 5.15-5.835 GHz (Note 6) 5.855-5.925 GHz 25.25-25.5 GHz 27.225-27.5 GHz 27.5-28.35 GHz
Lunar Relay to Lunar Relay Cross Link	13.75-14 GHz 14.5-15.35 GHz (Note 9) 23.15-23.55 GHz 27.0-27.5 GHz 37-38 GHz (Note 3) 40-40.5 GHz
Amateur Radio Operation, Earth-to-Lunar Orbit	144-146 MHz 435-438 MHz (Note 5) 2.4-2.45 GHz (Note 5) 5.65-5.67 GHz (Note 5)
Amateur Radio Operations, Lunar Orbit-to-Earth	144-146 MHz (Note 4) 435-438 MHz (Note 4), (Note 5) 10.45-10.5 GHz (Note 5)
Notes to Table 1 (Note 1) In making frequency assignments for uplinks in the 2 025 – 2 110 MHz band to missions operating in the lunar vicinity, careful frequency coordination should be performed, and measures taken to minimize interference to spacecraft operating in low-Earth orbit and L1/L2.	

(Note 2) In these communication frequency bands, position and navigation information may be contained in integrated ranging signals. However broadcast signals intended for PNT in the lunar region should use the frequency bands specified in Table 2.
(Note 3) 37-38 GHz band subject to SFCG Rec.14-2R5.
(Note 4) Frequencies to only be transmitted or received outside the Shielded Zone of the Moon (SZM).
(Note 5) These frequencies are allocated on a secondary basis only, except 435-438 MHz is allocated primary in Region 1 and secondary in Regions 2 and 3.
(Note 6) 5.25-5.57 GHz is allocated to SRS (active) on a primary basis; use of these frequencies for communications in the lunar region is on a non-interference and unprotected basis to SRS (active).
(Note 7) Out-of-band filtering of the harmonic falling in the 4.8-4.99 GHz band (secondary RAS) is necessary in the SZM
(Note 8) 410-420 MHz is a space research service (space-to-space) allocation, and therefore, per ITU Radio Regulations Article 22 (specifically No. 22.24), is allowed for use in the SZM. The use of the 410-420 MHz frequency range shall take into account the protection of radio astronomy systems below 410 MHz through the use of measures to minimize out-of-band emissions.
(Note 9) The use of the 2.5035 – 2.655 GHz and 14.5-15.35 GHz frequencies shall take into account the protection of radio astronomy systems in 2.655 - 2.670 GHz (secondary allocation for RAS), 15.35-15.5 GHz (primary allocation for RAS, and 14.35-14.5 GHz (secondary allocation for RAS).

Table 2: Recommended Frequency Bands for RNSS or RDSS Applications in the Lunar Vicinity

Link	**Frequency**
Earth-based GNSS to Lunar Orbit and Lunar Surface	1164-1215 MHz 1215-1300 MHz 1559-1610 MHz
In-situ Lunar based RNSS/RDSS to Lunar Orbit and Lunar Surface	2483.5-2500 MHz

Table 3: Recommended Frequency Bands for Search & Rescue Beacon in the Lunar Vicinity

Link	**Frequency**
LunaSAR beacon	406 – 406.1 MHz[1]
Note 1 of Table 3: Additional SAR beacon transmission above 2 GHz including use in the SZM is under study to complement the 406 – 406.1 MHz capability, which is limited to outside of the SZM usage. It is intended to include these new lunar SAR bands above 2 GHz in SFCG 32-2R5.	

Table 4: Example of Lunar Communications and PNT Service Requirements

Link Type	Frequency Band	Users	Service Type	Typical Data Rate per User	Limitations
1.0 Earth to Lunar Orbit (E-LO) and Lunar Orbit to Earth (LO-E)	2025-2110 MHz (E-LO)	Lunar Orbiters	Voice/Commands/PNT	72 kbps	See Note 2 to Table 1
	2200-2290 MHz (LO-E)	Lunar Orbiters	Voice/Data/PNT	256 kbps	See Note 2 to Table 1
	7190-7235 MHz (E-LO)	Lunar Orbiters	Commands/ Ranging	Up to 1 Mbps	
	8450-8500 MHz (LO-E)	Lunar Orbiters	Telemetry/ Ranging	Up to 10 Mbps	Subject to SFCG Rec. 5-1 R5, up to a maximum bandwidth of 10 MHz
	22.55-23.15 GHz (E-LO)	Lunar Orbiters	Voice/data (comm & PNT)/ video	10 Mbps	RR No. 5.149 applies, taking into account 22.81-22.86 GHz and 23.07 - 23.12 GHz for RAS See Note 2 to Table 1
	25.5-27.0 GHz (LO-E)	Lunar Orbiters	Voice/data/video	25 Mbps	Crewed SRS missions should not claim interference protection in excess of the protection criteria of Recommendation ITU-R SA.609 applicable to unmanned missions
	37-38 GHz (LO-E)	Relay Satellites	Trunk line (downlink)	1200 Mbps	Subject to SFCG Rec. 14-2R5, up to a maximum of 500 MHz bandwidth
	40-40.5 GHz (E-LO)	Lunar Relay Satellites	Trunk line (uplink)	400 Mbps	Subject to SFCG Rec. 14-2R5

Link Type	Frequency Band	Users	Service Type	Typical Data Rate per User	Limitations
2.0 Earth to Lunar Surface (E-LS) and Lunar Surface to Earth (LS-E)	2025-2110 MHz (E-LS) /2200-2290 (LS-E) MHz	Surface Hubs (Hab, Landers, Rovers, etc), LCT	Voice/TT&C/ PNT	150 kbps/3Mbps	See Note 2 to Table 1
		End nodes (EVA, Science sites, robotic assistants)	Voice or health status/TT&C/ PNT	8 kbps	See Note 2 to Table 1
	7190-7235 MHz (E-LS)	Surface Landers (Landers, Rovers, etc)	Commands/ Ranging	Up to 1 Mbps	
	8450-8500 MHz (LS-E)	Surface (Landers, Rovers, etc)	Telemetry, Ranging	Up to 10 Mbps	Subject to SFCG Rec. 5-1 R5

Link Type	Frequency Band	Users	Service Type	Typical Data Rate per User	Limitations
	22.55-23.15 (E-LS)/25.5-27(LS-E) GHz	LCT	Voice/TT&C/ data/ video	25 Mbps/100 Mbps	
		Surface hubs (Hab, Landers, Rovers, etc)	Voice/TT&C/ data/ video	10 Mbps/ 25Mbps	Crewed SRS missions in the 25.5-27.0 GHz band should not claim interference protection in excess of the protection criteria of Recommendation ITU-R SA.609 applicable to unmanned missions

Link Type	Frequency Band	Users	Service Type	Typical Data Rate per User	Limitations
3.0 Lunar Orbit to Lunar Surface (LO-LS) and Lunar Surface to Lunar Orbit (LS-LO)	390-405 MHz (LO-LS)	Orbiter, Lunar Module, Rover, Lander	Command	1 kbps	See Note 4 to Table 1
	406-406.1 MHz (LS-LO)	EVAs	Emergency beacon; crew search and rescue	400 bps	For emergency use only; See Note 1 to Table 3 (outside of the SZM)
	435-450 MHz (LS-LO)	Orbiter, Lunar Module, Rover, Lander	Data/ Telemetry	8 kbps, 32 kbps, 1Mbps	See Note 4 to Table 1
	2025-2110 (LO-LS)/2200-2290 (LS-LO) MHz	Surface Hubs (Hab, Landers, etc), Lunar Module	Voice/ TT&C/PNT	150 kbps (bi-directional)	See Note 2 to Table 1
		LCT	Voice/TT&C/PNT	3 Mbps (bi-directional)	
		EVAs, Robotics Assistants	Voice/health & status/PNT	8 kbps (bi-directional)	
	23.15-23.55 (LO-LS) /27-27.5 (LS-LO) GHz	LCT	Voice/TT&C/ data/video	200 Mbps/400 Mbps	
		Surface hubs (Hab, Landers, etc)	Voice / TT&C	25/10 Mbps	

Link Type	Frequency Band	Users	Service Type	Typical Data Rate per User	Limitations
4.0 Lunar Orbit to Lunar Orbit (LO-LO)	2025-2110 /2200-2290 MHz (LO-LO)	Lunar orbiter [describe applications]	Voice/ TT&C/PNT	150 kbps (bi-directional)	See Note 2 to Table 1 A user channel bandwidth shall be below 6 MHz in S-band [make reference to new SFCG Recommendation containing bandwidth limits]
		Lunar orbiter	Voice/TT&C/PNT	3 Mbps (bi-directional)	
		Lunar orbiter	Voice/health & status/PNT	8 kbps (bi-directional)	
	23.15-23.55 /27-27.5 GHz (LO-LO)	Lunar orbiter	Voice/TT&C/ data/video	200 Mbps/400 Mbps	
		Lunar orbiter	Voice / TT&C	25/10 Mbps	

Link Type	Frequency Band	Users	Service Type	Typical Data Rate per User	Limitations
5.0 Lunar Surface Communications	390-405 MHz	Lunar Module Rover, Lander	Telemetry, Data	128 kbps,1 Mbps	See Note 4 to Table 1
	410-420 MHz	Lunar Module, Rover, Lander	Command/Telemetry/ Data	Up to 1 Mbps	
	435-450 MHz	Lunar Module, Rover, Lander	Command	1 kbps	See Note 4 to Table 1
	2.400 – 2.480 GHz	EVAs	Voice/data (comm & PNT)/ video	3 Mbps (max, rate will drop as distance increases)	2.480-2.4835 MHz is considered as the guard band. Sufficient OOB filtering to protect the 2483.5-2500 MHz LO-to-LS PNT band is necessary. OOB filtering of the harmonic falling in 4.8-4.99 GHz band (secondary RAS) is necessary in the SZM
		Rover - LCT	Voice/data (comm & PNT)/video	30 Mbps (max)	
		EVAs – Landers, Rover	Voice/data (comm & PNT)/video	3 Mbps (max)	
	2.5035 – 2.655 GHz	EVAs Rover - LCT EVAs – Landers, Rover	Voice/data (comm & PNT)/video	100 Mbps (max)	2.500-2.5035 MHz is considered as the guard band. Sufficient OOB filtering to protect the 2483.5-2500 MHz LO-to-LS PNT band is necessary. See Note 9 of Table 1
	3.50 – 3.8 GHz	EVAs	Voice/data (comm & PNT)/video	100 Mbps (max)	
	5.15-5.835 GHz	Rover - LCT	Voice/data (comm & PNT)/ video	3 Mbps (max, rate will drop as distance increases)	

Link Type	Frequency Band	Users	Service Type	Typical Data Rate per User	Limitations
		EVAs – Landers, Rover	Voice/data (comm & PNT)/video	30 Mbps (max)	
		EVAs – Landers, Rover	Voice/data (comm & PNT)/video	3 Mbps (max)	
	5.855-5.925 GHz	EVAs Rover - LCT EVAs – Landers, Rover	Voice/data (comm & PNT)/video	100 Mbps (max)	
	25.25-25.5 GHz	Base Station to LCT	Voice/data (comm & PNT)/video	20 Mbps	Subject to SFCG Rec. 15-2R4
	27.225-27.5 GHz	User Radio to LCT	Voice/data (comm & PNT)/video	9.5 Mbps	Subject to SFCG Rec. 15-2R4
	27.5-28.35 GHz	EVAs Rover - LCT EVAs – Landers, Rover	Voice/data (comm & PNT)/video	1 Gbps (max)	

Link Type	Frequency Band	Users	Service Type	Typical Data Rate per User	Limitations
6.0 Lunar Relay to Lunar Relay Cross Link	13.75-14 GHz	LRS	User data	Up to 300 Mbps	
	14.5-15.35 GHz				Note 9 in Table 1
	23.15-23.55 GHz				
	27.0-27.5 GHz				
	37-38 GHz				
	40-40.5 GHz				

Link Type	Frequency Band	Users	Service Type	Typical Data Rate per User	Limitations
7.0 Amateur Radio Operations: Earth to Lunar Orbit (E-LO) and Lunar Orbit to Earth (LO-E)	144-146 MHz (E-LO)	Amateur Radio Stations	Amateur Radio	10 kbps max	
	144-146 MHz (LO-E)	Lunar Orbiters/ Surface Systems	Amateur Radio	10 kbps max	See note 4 to Table 1
	435-438 MHz (E-LO)	Amateur Radio Stations	Amateur Radio	100 kbps max	
	435-438 MHz (LO-E)	Lunar Orbiters/ Surface Systems	Amateur Radio	100 kbps max	See note 4 to Table 1
	2.4-2.45 GHz (E-LO)	Amateur Radio Stations	Amateur Radio	10 Mbps max	
	5.65-5.67 GHz (E-LO)	Amateur Radio Stations	Amateur Radio	5 Mbps	
	10.45-10.50 GHz (LO-E)	Amateur Radio Stations	Amateur Radio	20 Mbps	See note 4 to Table 1

Link Type	Frequency Band	Users	Service Type	Typical Data Rate per User	Limitations
8.0 Earth based GNSS to Lunar Orbit and Lunar Surface	1164-1215 MHz 1215-1300 MHz 1559-1610 MHz	Lunar Orbiters, Surface hubs (Hab, Landers, Rovers, etc.), LCT	PNT	50 bps	Limited to transmission of signals from GNSS Constellations in the Earth region

Link Type	Frequency Band	Users	Service Type	Typical Data Rate per User	Limitations
9.0 In-situ Lunar based RNSS/RDSS to Lunar Orbit and Lunar Surface	2483.5-2500 MHz (LO-LS) 2483.5-2500 MHz (LO-LO)	Rover-Orbiter, EVAs- Orbiter, Surface hubs (Hab, Landers, etc) – Orbiter	PNT	10 kbps	Limited to one way PNT transmissions from LO to LS and LO to Low Lunar Orbit (LO to LLO)

Acronym List for typical lunar communication elements

E	Earth
EVA	Extra Vehicular Activity
GNSS	Global Navigation Satellite System
Hab	Habitat
LCT	Lunar Communications Terminal
LO	Lunar Orbit
LLO	Low Lunar Orbit
LRS	Lunar Relay Satellites
LS	Lunar Surface
OOB	Out-of-band
PNT	Positioning, Navigation, and Timing
RAS	Radio Astronomy Service
RDSS	Radiodetermination-Satellite Service
RNSS	Radionavigation-Satellite Service
SAR	Search and Rescue
SRS	Space Research Service
SZM	Shielded Zone of the Moon