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| ***Space Frequency***  ***Coordination Group*** | SFCG_Logo_2006_Color_FINAL_PNG.png |

**Recommendation SFCG 32-2R3**

**Communication AND positioning, navigation, AND tIMING Frequency Allocations and Sharing in the Lunar Region**

THE SFCG

CONSIDERING

1. 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;
2. 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);
3. 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;
4. 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;
5. 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;

1. 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;
2. 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;
3. 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;
4. 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;
5. 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;
6. 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;
7. that techniques such as self-test on board are available to minimize the need for testing with Earth-based signals;
8. that Recommendation ITU-R RA.314-10 provides the preferred frequency bands for Radio Astronomical measurements,

NOTING

1. 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);
2. 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;
3. that lunar missions may need interoperable relay links to maintain communication with the Earth;
4. 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;
5. that passive observations in space need to be protected to the extent provided in the Radio Regulations;
6. 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]](#footnote-1);
7. 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

1. that lunar local links must not interfere with the direct communication links between space and the Earth using frequencies provided in the Radio Regulations;
2. that multiple frequency bands are needed for missions to meet various communications requirements and satisfy cost, mass and performance objectives.

RECOMMENDS

1. that for communications and PNT in the lunar region agencies select frequencies from Table 1 and Table 2, for which examples of service requirements are given in Table 3;
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 26-1R6.

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

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| **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  435-450 MHz (Note 4)  2.400-2.480 GHz  2.5035-2.620 GHz  5.15-5.835 GHz (Note 6)  25.25-25.5 GHz  27.225-27.5 GHz |
| Lunar Relay to Lunar Relay Cross Link | 13.75-14 GHz  14.5-15.35 GHz  23.15-23.55 GHz  27.0-27.5 GHz  37-38 GHz (Note 3)   * + 1. 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 used 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). | |

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

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| **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: Example of Lunar Communications and PNT Service Requirements**

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| **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 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 |

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| **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 |
| 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 |

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| **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 |
| 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 |  |

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| **Link Type** | **Frequency Band** | **Users** | **Service Type** | **Typical Data Rate per User** | **Limitations** |
| **4.0**  **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) | Sufficient OOB filtering to protect the 2483.5-2500 MHz LO-to-LS PNT band is necessary |
| Rover - LCT | Voice/data (comm & PNT)/video | 30 Mbps (max) |
| EVAs – Landers, Rover | Voice/data (comm & PNT)/video | 3 Mbps (max) |
| 2.5035-2.620 GHz | EVAs | Voice/data (comm & PNT)/video | 100 Mbps (max) | Sufficient OOB filtering to protect the 2483.5-2500 MHz LO-to-LS PNT band is necessary |
| Rover - LCT |
| EVAs – Landers, Rover |
| 5.15-5.835 GHz | EVAs | Voice/data (comm & PNT)/ video | 3 Mbps (max, rate will drop as distance increases) |  |
| Rover - LCT | Voice/data (comm & PNT)/video | 30 Mbps (max) |  |
| EVAs – Landers, Rover | Voice/data (comm & PNT)/video | 3 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 |

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| **Link Type** | **Frequency Band** | **Users** | **Service Type** | **Typical Data Rate per User** | **Limitations** |
| **5.0**  **Lunar Relay to Lunar Relay Cross Link** | 13.75-14 GHz | LRS | User data | Up to 300 Mbps |  |
| 14.5-15.35 GHz |  |
| 23.15-23.55 GHz |  |
| 27.0-27.5 GHz |  |
| 37-38 GHz |  |
| 40-40.5 GHz |  |

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| **Link Type** | **Frequency Band** | **Users** | **Service Type** | **Typical Data Rate per User** | **Limitations** |
| **6.0**  **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 |  |
| 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 |  |
| 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 |  |

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| **Link Type** | **Frequency Band** | **Users** | **Service Type** | **Typical Data Rate per User** | **Limitations** |
| **7.0**  **Earth based GNSS to Lunar Orbit and Lunar Surface** | 1164-1215 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 |
| 1215-1300 MHz |
| 1559-1610 MHz |

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| **Link Type** | **Frequency Band** | **Users** | **Service Type** | **Typical Data Rate per User** | **Limitations** |
| **8.0**  **In-situ Lunar based RNSS/RDSS to Lunar Orbit and Lunar Surface** | 2483.5-2500 MHz (LO-LS) | 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) |
| 2483.5-2500 MHz (LO-LO) |

**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 |
| RDSS | Radiodetermination-Satellite Service |
| RNSS | Radionavigation-Satellite Service |
| SRS | Space Research Service |
| SZM | Shielded Zone of the Moon |

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. [↑](#footnote-ref-1)