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| U.S. Radiocommunications SectorFact Sheet |
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| **Purpose:** To initiate the studies called for under *resolves to invite the ITU Radiocommunication Sector* 1, 2, and 3 of Resolution 249 |
| **Abstract:** The contribution will include a description of the space-to-space operations to be studied, characteristics of incumbent and space-to-space systems, and a list of relevant existing material. |

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| **Radiocommunication Study Groups** | A blue logo with a black background  Description automatically generated |
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ITU-R Resolution 249 (WRC-23) calls for ITU-R to consider the technical and operational issues, and regulatory provisions, for space-to-space links among non-geostationary and geostationary satellites in the frequency bands 1 518-1 544 MHz, 1 545-1 559 MHz, 1 610‑1 645.5 MHz, 1 646.5-1 660 MHz, 1 670-1 675 MHz and 2 483.5-2 500 MHz allocated to the mobile-satellite service. Work on this issue has previously been conducted in Working Party 4C, most recently at the June 2019 meeting, with output in [Annex 6 to Document 4C/472 (2016-2019 cycle)](https://www.itu.int/dms_ties/itu-r/md/15/wp4c/c/R15-WP4C-C-0472%21N06%21MSW-E.docx). The United States herein submits as an attachment the content of this report as a starting point to the development of studies to be conducted under agenda item 1.11.

Further, the United States has identified characteristics and interference criteria for the mobile-satellite service between 1 and 3 GHz in ITU-R Recommendations M.1184-3 and M.1183-0, respectively. These recommendations are suggested for use in the required sharing and compatibility studies.

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| **ATTACHMENT****Non-geostationary satellites operating space-to-space links in mobile-satellite service (MSS) allocations in the 1-3 GHz range** |

**1 Introduction**

Recently, there has been increased activity involving non-geostationary (non-GSO) satellites with short duration missions. Much of the recent activity in this area has dealt with very small satellites referred to as “CubeSats” and other satellite missions using small LEO satellites. Continuous access anywhere on their orbits has been tested with CubeSats using a non-geostationary mobile-satellite service (MSS) system and GSO MSS operators are developing systems to provide communications access to LEO satellites.

One Administration has recently begun investigating regulations for these small satellite systems.[[1]](#footnote-2) Topics being considered in this inquiry include de-orbiting and orbital debris, orbital altitude, the mass of a single spacecraft, spacecraft lifetime, propulsion capability and compatible frequency usage without precluding future entrants in the band. GSO MSS operators are also developing systems to provide communications access to LEO satellites.

**2 Satellite systems potentially requiring space-to-space links**

**2.1 CubeSats – non-geostationary satellites with short duration missions**

The standard for CubeSats was created by California Polytechnic State University, San Luis Obispo and Stanford University's Space Systems Development Lab in 1999 to facilitate access to space for experimentation by university students. Since then the standard has been adopted by hundreds of organizations worldwide. CubeSat developers include not only universities and educational institutions, but also private firms and government organizations.

The relatively low cost and short development times of CubeSats and nanosatellites have provided researchers at universities and small companies unprecedented access to space. In contrast to typical large-satellite missions, CubeSat missions typically allow reduced cost and development time by using COTS (Commercial-off-the-Shelf) components and launching with other missions on the same launch vehicle. The result has been a significant number of satellite-based research and commercial space endeavours using CubeSats.

The standard 10×10×10 cm basic CubeSat is often called a “1U” CubeSat meaning one unit. CubeSats are scalable along only one axis, in 1U increments. CubeSats such as a “2U” CubeSat (20×10×10 cm), “3U” CubeSat (30×10×10 cm) and “6U” CubeSat (60×10×10 cm) have been both built and launched.

The CubeSat specification has been widely adopted even outside the academic community, largely due to low costs and access to launch services, and satellites based on the standard constitute a large percentage of small satellites deployed in recent years. While the advantages of small satellites have ensured their continuing use by universities and research institutions, it has also encouraged the growing number of CubeSat missions that are commercial.

**2.1.1 Examples of CubeSat missions with space-to-space links within in the frequency bands allocated to MSS at 1 610-1 626.5 MHz and 2 483.5‑2 500 MHz**

**TSAT** (**TestSat-Lite**) was a CubeSat designed and built by engineering students at a university in the USA. It was built on a 2U form factor.

TSAT was a dual mission using a communication modem working with a non-GSO MSS system to demonstrate a reliable and global CubeSat system and a satellite bus design for Space Weather research consisting of a Langmuir plasma probe, 3-axis magnetometer, and 3 ultraviolet photodiodes.

In February 2012, TSAT was selected for a launch opportunity through the USA National Aeronautics and Space Administration (NASA) Educational Launch of Nanosatellites (ELaNa) program. Final pre-launch tests were completed and it was delivered to NASA for successful launch in early 2014.

**GEARRS-1,** An Experiment And Risk Reduction Satellite, was launched in a project operated by a USA industrial firm. This CubeSat was used to determine whether it was possible to support CubeSat operations by using an existing mobile-satellite service (MSS) system. It was shown that the CubeSat was able to continuously maintain in contact with the existing MSS system over the entire CubeSat orbit for both CubeSat-to-MSS and CubeSat-to-CubeSat operation, through an associated feeder link earth station.

**GEARRS-2** was a second experimental satellite, launched to investigate the use of an existing MSS system for command and control of a small satellite system and a CubeSat flown in Low Earth Orbit (LEO). The project relied on the technology developed earlier at a USA University for the TSAT experiment flown in 2014. The first GEARRS satellite was deployed from the International Space Station (ISS) in March 2015 after being launched by the Cygnus Orb-2 mission in July 2014.

The use of an existing MSS system for telemetry and control of small satellites would enable continuous access to the spacecraft instead of the usual limited access provided by dispersed ground-stations. Using dispersed ground stations would only allow communication during the few passes that were in range of the ground-stations, lasting only minutes per day, depending on the number and locations of the ground-stations. The use of the non-GSO MSS system enables low‑latency, low-data rate communications such as voice and data connectivity between terminals including mobile users. The GEARRS-2, 3U CubeSat tested communication links through the non‑GSO MSS system to confirm the capability of operating “small” satellite systems, allowing low-cost access to space for scientific and commercial objectives.

**MakerSat-0** will be placed in a sun-synchronous, polar orbit through the NASA ELaNa program in preparation for the eventual construction on-board and launch of MakerSat-1 from the ISS. This project will **test communication links through a non-GSO MSS system to confirm the capability of operating “small” satellite systems in a Polar orbit.**

**MakerSat-1** is a technology proof-of-concept mission from another USA university that will demonstrate microgravity additive manufacturing, assembly, and deployment of a CubeSat from the ISS. MakerSat-1 is a 1U multi-project satellite, supporting up to four science payloads that can be developed by four independent experiment developers. In the upcoming MakerSat-1 mission, one university science team will measure the mass loss of several additively-manufactured polymers in orbit. The materials are expected to undergo mass loss due to monoatomic oxygen radicals, ultraviolet (UV) radiation, ionizing radiation, and outgassing. A secondary school science team payload will also be flown.

**2.2 Small LEO satellites**

In addition to CubeSats, other LEO satellites could make use of space-to-space links in the MSS to provide a communications link between spacecraft and ground.

As an example, this application could be of particular interest to operators of scientific, weather forecasting, earth observation and imaging missions which have a requirement to transmit the data collected by the payload sensors from space to ground. There is sometimes a requirement for the data to be transferred within minutes of acquisition which can be accomplished due to the near global coverage provided by some MSS systems. Space-to-space links could also be used to provide telemetry, tracking and command communications to and from the spacecraft.

**3 Examples of technical characteristics**

Two example system descriptions are provided, one for space-to-space links between CubeSats and non-GSO MSS system satellites and the other for space-to-space links between LEO satellites and GSO MSS satellites.

**3.1 Space-to-space links between CubeSats and non-GSO MSS system satellites**

The links between the CubeSat and the MSS spacecraft can be used to provide both payload and Tracking, Telemetry and Control (TT&C) communications. Further, the CubeSat radio operations may be transmit only or two-way. For transmit only links, the CubeSat is equipped with only a transmitter that can access the MSS system. Similar transmitters are routinely used terrestrially for asset tracking and personal location beacons. In the case of transmit only links, additional radio equipment for ceasing transmissions based on ground command must be included on the CubeSat. For two-way communications, the CubeSat has both transmit and receive capability similar to that in conventional mobile earth stations (MESs) used in terrestrial and aeronautical communications via a MSS system.

Representative communications characteristics of a typical CubeSat communicating with an MSS system are given in the Table below.

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| **CubeSat/MSS Communications Characteristics Transmit Only** |
| CubeSat Altitude | 400 km |
| Center Frequency | 1 616.25 MHz |
| Bandwidth | 2.5 MHz |
| Transmitter Power Output | –12.5 dBW |
| Line Loss | 0.6 dB |
| Antenna Gain (Front Lobe) | 4.5 dBi |
| Antenna Gain (Back Lobe) | < –4.5 dBi |
| **CubeSat/MSS Communications Characteristics Two-way Communication** |
| Transmit Band | 1 615-1 617.775 MHz |
| Receive Band | 2 483.5-2 495 MHz |
| Bandwidth | 1.23 MHz |
| Transmitter Power Output | –4.0 dBW |
| Line Loss | 0.6 dB |
| Transmit Antenna Gain (Front Lobe) | 4.5 dBi |
| Transmit Antenna Gain (Backlobe) | < –4,5 dBi |
| Receive Antenna Gain (Frontlobe) | 3 dBi |
| System Noise Temperature | 300 K |

In addition, CubeSats that have utilized these radios have included controls to ensure that the CubeSat transmitter radiates toward space rather than toward the earth. Attitude control has been accomplished either through magnetic or mechanical means and thermal sensors determine whether the spacecraft is oriented towards the Earth or, in the proper direction, towards space. Additionally, in some CubeSats, controls have been implemented to allow the transmitter to turn on only when data collected by the satellite is ready for transmission. In the event of a transmitter exceeding its pre-determined allowable transmission period, the transmitter can be commanded off in order to preserve battery life. If a transmitter were to fail in the permanently “on” state, the battery would become depleted after several hours and the spacecraft would shut down.

**3.2 Space-to-space links between LEO satellites and GSO MSS system satellites**

GSO MSS systems operate in the frequency bands 1 518-1 559 MHz (space-to-Earth) and 1 626.5‑1 660.5 MHz and 1 668-1 675 MHz (Earth-to-space). These bands are used for the service links to terminals on ships and aircraft and land portable terminals. The feeder links, connecting the GSO satellite with the ground network operate in other frequency bands, for example, C-band and Ku-band FSS bands. The service links at 1.5/1.6 GHz typically make use of multiple spot beams formed by the spacecraft antenna. An example of spot beam coverage from 3 GSO satellites is shown in Figure 1.

Figure 1

**Example of spot beam coverage from 3 GSO MSS satellites**



MSS operators have developed modified mobile earth stations that may be placed on a LEO spacecraft. As long as the LEO spacecraft is located within a GSO MSS satellite spot beam, it may communicate with the GSO spacecraft. Three GSO satellites equally spaced in geostationary orbit allow connectivity for almost 100% of the time, as shown in Figure 2.

Figure 2

**LEO satellite within coverage of GSO MSS satellites**



The data rates that can be provided are similar to those provided to terrestrial terminals. For this application, using a backgroundIP protocol, up to 200 kbit/s both to and from the spacecraft is provided.

Example characteristics are as follows:

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| **LEO/GEO MSS communications example characteristics** |
| Transmit Band | 1626.5-1660.5 MHz, 1668-1675 MHz |
| Receive Band | 1518-1559 MHz |
| Channel Bandwidth | 200 kHz |
| E.i.r.p. | 10 dBW |
| Antenna type | Switched, multi-element |
| Transmit Antenna Gain (Front Lobe) | 5 dBi |
| Receive Antenna Gain/Noise Temperature (G/T)  | -20 dB/K |

**4 Using space-to-space links in MSS allocations**

The current MSS allocations in 1 – 3 GHz do not include a space-to-space directional indicator. As a consequence, such operations may be conducted only on a non-interference basis, relying on No.**4.4** of the Radio Regulations. Given the interest in such space-to-space operations, reliance on No. **4.4** of the Radio Regulations provides an unsound basis for continued development of such systems seeking to use such equipment. Further actions may be needed to develop solutions, including consideration of amendments to the Radio Regulations, which would require the action of a competent World Radiocommunication Conference (WRC).

The total number of small satellites, including CubeSats, being deployed annually has increased significantly in recent years. In early 2017, for example, an Indian Space Research organization launch vehicle deployed over 100 small satellites into orbit in a single launch.[[2]](#footnote-3) One forecast estimates that between 2017 and 2023, nearly 2 400 satellites with masses between 1 and 50 kg will be launched.

**5 Compatibility with other services**

**5.1 Space-to-space links in the bands 1 610-1 626.5 MHz and 2 483.5-2 500 MHz**

The allocated services in the 1 610-1 626.5 MHz band include the MSS and the Radio Astronomy Service (RAS). The MSS system that operates with Cubesats within these bands has the technical characteristics specified for the HIBLEO-4 and HIBLEO-X systems.

According to Recommendation ITU-R RA.769-2, a power flux density of no more than –238 dB(W/(m2 · Hz)) is allowed at 1 612 MHz at a Radio Astronomy Observatory. The transmit only terminal has worse out-of-band emissions as compared to the duplex terminals. At the CubeSat, the emissions at 1 612 MHz, from a transmit-only terminal, are –119.3 dBW/Hz e.i.r.p. The nominal altitude of the CubeSat is 400 km implying a “spreading loss” of 123 dB/m2. Combining these numbers, the power flux density on the ground at 1 612 MHz is no more than
–242.3 dB(W/(m2 · Hz)). Operations at lower altitudes have occurred, and could exceed the recommended power flux density, if conducted within the RAS band at 1 610.6-1 613.8 MHz. Due consideration of the potential for interference to the Radio Astronomy Service needs to be an integral part of the regulation of these small satellite systems.

The use on board CubeSats of terminals developed for MSS may not be compatible with other MSS systems. Consequently, in bands where multiple MSS systems may operate, technical, operational, and coordination approaches are required to permit CubeSat use and ensure compatibility.

An example of why these approaches are necessary to ensure compatibility with other MSS systems is provided here. Another MSS system utilizing portions of the 1 610-1 626.5 MHz band is the HIBLEO-2 system. Its technical characteristics are used in the following example. Assuming a 6% *T/T* as the interference threshold as the criterion for acceptable interference at an MSS spacecraft receiver, this corresponds approximately to a level of –167.6 dBW at a HIBLEO-2 spacecraft. The nominal altitude of the HIBLEO-2 constellation is 780 km. The results in an altitude difference of 380 km between the CubeSat and a HIBLEO-2 spacecraft and corresponds to a path loss of 148.2 dB. The e.i.r.p. towards a HIBLEO-2 spacecraft from a CubeSat is –0.1 dBW, taken as 0 dBW. Taking into account a bandwidth differential between the 1.23 MHz CubeSat carrier and the 41.7 kHz HIBLEO-2 receive bandwidth, the resulting CubeSat power at the HIBLEO-2 spacecraft is ‑139.9 dBW, assuming a HIBLEO-2 typical receive antenna gain of 23.0 dBi. This interference results in an *I/N* = +15.5 dB, well above the interference threshold, indicating that the proposed co‑frequency use of this band by CubeSats will not be compatible with the HIBLEO-2 system.

Operations occurring to date have been limited to segments of the 1 610-1 626.5 MHz band that are not co-frequency with the RAS, and have followed existing band segmentation arrangements involving the HIBLEO-2 network, thereby avoiding co-frequency operations. The characteristics of such operations are listed above in the Table in Section 4.

With respect to the 2 483.5-2 500 MHz, the link from the MSS system to CubeSats is indistinguishable in its characteristic from the technical characteristics of the HIBLEO-4 and HIBLEO-X networks.

**5.2 Space-to-space links in the bands 1 518-1 559 MHz, 1 626.5-1 660.5 and 1 668‑1 675 MHz**

These frequency bands are shared among GSO MSS operators and generally inter-operator coordination issues are managed through regular multi-lateral coordination meetings, through a process agreed among the relevant Administrations. The frequencies available to any particular operator are defined for different geographic areas and hence the LEO spacecraft terminal may have to switch frequencies during the orbit or utilize a single frequency available globally.

Any potential changes to the RR in these bands should be based on operation of LEO spacecraft with GSO MSS networks and should ensure that harmful interference is not caused to those GSO networks.

Regarding the uplink bands, 1 626.5-1 660.5 MHz and 1 668-1 675 MHz, some parts of these bands are shared with the RAS, MetAids, the fixed service, the mobile service and the meteorological‑satellite service. In general, the operation of terminals on board a LEO spacecraft represents a more benign sharing situation with respect to these services compared with the operation of other MSS applications in these bands, including aircraft terminals. Therefore, no significant interference issues to other services are anticipated.

**6 Summary**

The missions described above involved the use of existing HIBLEO-4/X and GSO MSS satellite systems for communications links to and from CubeSats and other LEO spacecraft. The use of such systems holds the potential to provide an alternative to the use of other frequency bands that may be available for CubeSats operations, and may provide a higher level of throughput, availability and reliability to the missions.

The use on board LEO spacecraft of radio equipment developed for this purpose, needs to maintain compatibility with other MSS systems and other services. Consequently, technical, operational, and coordination approaches are required to permit the use of space-to-space links and ensure compatibility.

Operations occurring to date have been limited to segments of the MSS allocations in the 1-3 GHz range that are not co-frequency with other services and have followed existing band segmentation arrangements involving the MSS systems and networks, thereby avoiding co-frequency operations.

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EXCERPT OF RELEVANT CHARACTERISTICS FROM

RECOMMENDATION ITU-R M.1184

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|  | **C** | **Maritime**  |
| **High gain** | **Low gain** |
| Service | MMSS | MMSS | MMSS |
| Typical mobile station antenna gain (dBi) | 0 | 16 | 9 |
| Antenna type (example) | Quad helix | Phased array | Phased array |
| Typical antenna size | 5 cm diameter | 50 cm diameter | 30 cm diameter |
| Mobile earth station figure of merit (*G*/*T*) (dB(K–1)) | −23 | −7.5 | −15.5 |
| Mobile earth station e.i.r.p./channel (dBW) | 11 | 22 | 15.1 |
| User data rate | 600 bit/s | 500 kbit/s | 250 kbit/s |
| Modulation | BPSK | 16-QAM | 16-QAM |
| Typical *C*/*N*0 for communication channel (dB(Hz)) | 32 | 67 | 57 |
| Satellite e.i.r.p./channel (dBW) | 20 | 40.5 | 40.5 |
| Channel spacing(nominal) (kHz) | 5 | 200 | 200 |
| Satellite peak antenna gain (1) (dBi) | 18 | 41 | 41 |

Interference criteria for the mobile-satellite service is found in ITU-R Recommendation M.1183‑0, which provides:

*that the maximum level of interference power in any such digital channel caused by the transmitters of another mobile-satellite network or fixed-satellite network, should not exceed for more than (100 – X)% of any month, 6% of the total noise power at the input to the demodulator which would give rise to the desired performance objectives[.]*

The methodology for determining performance objectives for narrow-band channels in mobile satellite systems using geostationary satellites not forming part of the ISDN is contained in ITU‑R Recommendation M.1228, and other ITU-R M series recommendations may be relevant.

The United States proposes that these characteristics and criteria be taken into account in studies for agenda item 1.12 required by *resolves* 2 of ITU-R Resolution 252

1. “Streamlining Licensing Procedures for Small Satellites,” Notice of Proposed Rulemaking, FCC 18-44, International Bureau Docket No. 18-16, rel. April 17, 2018). [↑](#footnote-ref-2)
2. Jeff Foust, *India Sets Record with Launch of 104 Satellites on a Single Rocket*, SpaceNews (February 15, 2017), <http://spacenews.com/india-sates-record-with-launch-of-104-satellites-on-a-single-rocket>. [↑](#footnote-ref-3)