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An Overview and Assessment of Today's U.S. Satellite Telemetry, Tracking and Telecommand (TT&C) Spectrum Allocation Needs

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Abstract

The Federal Communications Commission (FCC) and U.S. House Energy & Commerce Committee have recently focused attention on spectrum utilization and allocations for low earth orbit (LEO) broadband and direct-to-device satellites. In a recent Hearing, Congress additionally stressed the need for efficient authorization for our satellite and launch industry and spectrum allocations specifically for launch vehicles – noting that rockets are now launching at an impressive weekly cadence. On-board each of these vehicles is generally a satellite payload, which requires spectrum for telemetry, tracking and telecommand (TT&C) regardless of its application (broadband, direct-to-device, earth exploration, research, in-orbit servicing and manufacturing (ISAM)). Despite this need, it is becoming increasingly challenging to identify swaths of spectrum for TT&C in the United States. This predicament is forcing operators to consider filing and operating parts of their networks overseas, potentially posing economic and national security risks. As the space sector continues to grow at an unprecedented rate, it is imperative that the FCC consider national TT&C allocations that align with the ITU, as well as a method for sharing these bands. This paper provides an overview of FCC and International Telecommunications Union (ITU) frequency allocations in the UHF, S-, L-, C- and X-band for space operations, and identifies the regulatory advantages and hurdles for the potential use of each band for TT&C. Lastly, this paper provides policy recommendations for potential allocations, sharing frameworks and methods for maintaining leadership in U.S. spectrum regulations.

Introduction

The world has recently experienced an unprecedented growth in the funding and buildout of satellite networks offering services like imaging, broadband, direct-to-device communications

and in-space assembly and manufacturing. Aspects of national security and our daily lives have already started to depend on these systems, and as a result, governments have shifted their focus to address their underlying policies and satellite licensing frameworks. Rulemakings and working parties have covered topics ranging from the frequency allocations and the coexistence of these networks to space situational awareness and methods for orbital debris mitigation.

Today, regulatory bodies such as the International Telecommunications Union (ITU) and Federal Communications Commission (FCC) publish tables of frequency allocations that define bands for particular service use. These references are intended to offer network operators and component manufacturers with a guide for determining specific operational requirements associated with each band as well as other potential users with whom they must coexist.

In addition to the spectrum required to transmit payload and communications data, all satellite networks require spectrum for operational support generally via telemetry and command links. Commercial Fixed Satellite Service (FSS) systems like OneWeb and Starlink have the luxury of operating TT&C within their service allocations – generally using frequencies above Ku-band for combined service and TT&C use. For example, most FSS networks that deploy Ka-band file for TT&C between 19.3 - 19.7 GHz (space-to-Earth) and 29.1 - 29.5 GHz (Earth-to-space) where equivalent power flux density (EPFD) limits do not exist.

Unfortunately, for other commercial satellite systems, identifying swaths of spectrum for TT&C operations is not as simple, and often unclear. This has become particularly true for startups offering state of the art services like position navigation and tracking (PNT), in-orbit servicing, and weather radar in the United States. The lack of identifiable spectrum allocations poses major challenges for incumbents, who design their system for their planned mission, begin

pre-coordinating frequency use, but realize there are no obvious bands if they'd like to connect their TT&C channels to earth stations in the U.S.. It is imperative for networks supporting government customers to perform operations within the U.S., yet entities now have no choice but to route traffic overseas.

In early 2023, Representative Soto introduced The 'Launch Communications Act'' in the bipartisan Communication and Technology Subcommittee of the U.S. House Committee on Energy and Commerce[1]. This proposed legislation addressed the lack of efficient licensing and available spectrum for vehicle operations for our burgeoning launch sector. Establishing decided frequency bands for space operations would not only benefit commercial companies, and enable them to keep their operations in the United States, but would also alleviate the federal government from the overhead of needing to coordinate with each satellite system to avoid harmful interference.

In Q1 2023, the National Telecommunications and Information Administration (NTIA) released a request for comment[2] (RFC) with the goal of studying the potential repurposing of 1.5 GHz of spectrum as part of the United States's national spectrum strategy. The request focuses on the NTIA's three pillars of creating a spectrum pipeline to ensure U.S. leadership in spectrum-based technologies, long term spectrum planning and the unprecedented spectrum access and management through technology development.

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[1] U.S. Congress, House, *Launch Communications Act* , H.R.682, 118th Cong., 1st sess., introduced in the House January 31, 2023, https://www.congress.gov/bill/118th-congress/house-bill/682.
[2] U.S. Department of Commerce, National Telecommunications and Information Administration, *Development of a National Spectrum Strategy* (Washington DC, 2023), https://www.ntia.doc.gov/sites/default/files/publications/ntia_nss_frn_rfc_final.pdf

This paper addresses the urgent need for dedicated frequencies to support the operations of these systems – and aims to offer an accessible overview of current frequency allocations for potential TT&C use, including the advantages, challenges and risks of each band.

TT&C Frequency Allocation Overview

The two most common TT&C configurations for non-federal missions are currently: 1) *S-band telecommand (uplink) and X-band telemetry (downlink)* and 2) *S-band telecommand (uplink) and UHF telemetry (downlink).* Noting that the first option (8025-8400 MHz for downlink) is not allocated for Space Operations (TT&C). If the mission can justify using X-band downlink predominately for other services (EESS in particular) then it can be used for telecommand if the filer submits a significant spectrum sharing study. If X-band downlink can not be justified, then the entity must file under ITU No. 4.4 for utilization of the bands on a non-conforming basis, which in turn does not offer interference protection. A scenario that is clearly inappropriate for systems, like PNT, upon which our government and nation rely.

Table 1 summarizes the ITU and FCC allocations in the UHF, L-, S-, C-, and X-band for potential TT&C use[3]. The table also follows the FCC and ITU format designating frequency allocation on a primary basis with capital letters and secondary basis with lowercase letters. Services that are allocated on a secondary basis are required to protect the primary services from harmful interference. Table 1 does not include allocations for active earth exploration satellite service and active space research as those are for instruments like radards and can't be used for TT&C.

[3] U.S. Federal Communications Commision, *FCC Online Table of Frequency Allocations*, (Washington DC, 2022), https://transition.fcc.gov/oet/spectrum/table/fcctable.pdf.

Table 1. Summary of Spectrum Allocations for Potential TT&C Use

Frequency	**Uplink (MHz)**	**Downlink (MHz)**
UHF	399.9 - 400.05 MOBILE SATELLITE RADIONAVIGATION SATELLITE 401 - 403 Federal EARTH EXPLORATION SATELLITE SERVICE (EESS) Federal METEOROLOGICAL SATELLITE Meteorological Satellite Earth Exploration Satellite Service 449.75 - 450.25 Space Operations Space Research	400.15 - 401.00 Federal METEOROLOGICAL SATELLITE MOBILE SATELLITE SPACE RESEARCH space operations 401 - 402 SPACE OPERATIONS 460 - 470 Meteorological Satellite Earth Exploration Satellite Service
L-band	No Allocations for TT&C	1164 - 1215 RADIONAVIGATION SATELLITE 1215 - 1240 Federal RADIONAVIGATION SATELLITE
S-band	2025 - 2110 Federal SPACE OPERATIONS Federal EARTH EXPLORATION SATELLITE SERVICE (non-federal on a case-by-case basis) Federal SPACE RESEARCH (non-federal on a case-by-case basis) 2110 - 2120 Federal SPACE RESEARCH (NASA deep space network)	2180-2200 MOBILE-SATELLITE 2200 - 2290 Federal SPACE OPERATIONS Federal EARTH EXPLORATION SATELLITE SERVICE Federal SPACE RESEARCH 2290 - 2300 SPACE RESEARCH (deep space)
C-band	5000 - 5010 RADIONAVIGATION SATELLITE	5010 - 5030 RADIONAVIGATION SATELLITE
X-band	7145 - 7190 Federal SPACE RESEARCH (deep space) non-Federal space research (deep space)	8025 - 8400 Federal EARTH EXPLORATION SATELLITE SERVICE (non-federal on a case-by-case) (non-Federal authorizations are subject to a case-by-case

	7190 - 7235 Federal EARTH EXPLORATION SATELLITE SERVICE TT&C Federal SPACE RESEARCH 7235 - 7250 Federal EARTH EXPLORATION SATELLITE SERVICE TT&C	electromagnetic compatibility analysis) 8400 - 8450 Federal SPACE RESEARCH (deep space) Space research (deep space) 8450 - 8500 SPACE RESEARCH

Subsequent sections of this document expand upon the allocations and challenges of each band for TT&C use.

Potential use of UHF for TT&C

UHF frequency bands are often used for cubesats and applications that require low data rates. For uplink, there is 500 kHz of spectrum allocated in the 449.75 - 450.25 MHz band for space operations on a secondary basis that is subject to coordination. When a band is subject to coordination the operator is required to file a coordination request (CR) instead of an advance publication information (API) with the ITU complicating the licensing process. For downlink, there is 1 MHz of spectrum allocated in the 401 - 402 MHz band to space operations on a primary basis and 850 kHz in the 400.15 - 401 MHz band on a secondary basis.

<u>Uplink:</u>

There are three potential frequency allocations that can potentially be used by operators for command:

- **399.90 - 400.05 MHz:**

  The 399.90 - 400.05 MHz is primarily used for mobile satellite service (MSS) and radio navigation satellite service (RNSS), and can be used for command operations only from MSS and RNSS systems like GPS and Galileo.

- **401 - 403 MHz:**

  The 401 - 403 MHz band is allocated to Federal geostationary Earth-exploration satellite service (EESS) and meteorological satellites on a primary basis. Secondary allocations for non-federal Earth-exploration satellite service (EESS) and meteorological satellites also exist. As such, uplink UHF is difficult to coordinate for non-federal (commercial) operators, particularly given that NOAA is concerned with interference into their Radiosonde grounds stations, nineteen of which are in Alaska.

- **449.75 - 450.25 MHz:**

  The 449.75 - 450.25 MHz uplink band may be used for the space operation service (Earth- to-space) and the space research service (Earth -to-space) on a secondary basis. This would be suitable for satellite command, however, it is important to note that a separate antenna system is required to support a 401 - 402 downlink and 449.75 - 450.25 uplink. In Table 2, a set of companies are presented that have received authorization to use this band for TT&C operations. Some of which include: Loft Orbital and Spire.

<u>Downlink:</u>

There are three potential frequency bands that can be utilized for telemetry operations:

- **400.15 - 401.00 MHz:**

  The 400.15 - 401.00 MHz is used on a primary basis for federal meteorological satellite service, mobile satellite service (MSS) and space research and is also allocated on a secondary basis for space operations. This band is suitable for telemetry operations subject to protecting the primary services. As presented in Table 2, there are numerous

companies like Astro Digital and Loft Orbital that utilize this band for telemetry (downlink) operations. It is important to note that NOAA uses the 400.15-406.00 MHz band for communications with the Radiosondes and is therefore protective of this spectrum.

- **401 - 402 MHz:**

  The 401 - 402 MHz is primarily allocated to space operations and is one of the bands most widely used in satellite applications for telemetry (downlink). The disadvantage of this band is the lack of corresponding UHF uplink for full UHF TT&C coverage. Similarly, this band overlaps with the aforementioned 400.15 - 406.00 MHz band used for Radiosondes, which NOAA protects.

- **460 - 470 MHz:**

  The 460 - 470 MHz band does not appear in the FCC's Table of Allocations, yet it is allocated on a secondary basis for downlink operations in the meteorological satellite service and EESS in footnote US289. This allocation is subject to power flux density (PFD) limits. This frequency band can be utilized for telemetry (downlink) for systems operating in these services and could be suitable for systems that want to pair uplink at 450 MHz with dowlink at 460 - 470 MHz.

- **449.75 - 450.25 MHz:**

  The 449.75 - 450.25 MHz band has no allocation for downlink operations, however, as shown in Table 2 Spire has been authorized to use this band for TT&C operations on a non-conforming basis.

The lack of spectrum allocation for uplink space operations has made it challenging for non-federal networks like universities and companies to utilize this band for command. It is important to note that utilizing the 449.75 - 450.25 MHz band for uplink with the 400.15 - 402.00 MHz band for dowlink would require two separate antenna systems, increasing the cost of deploying a UHF system significantly. It is important to also note that UHF frequencies are more affordable from a hardware perspective than higher frequency bands, and are key for making low-cost cubesat missions possible.

Potential Use of L-band for TT&C

The use of L-band is not common for non-federal (commercial) TT&C uplink and downlink. Industry has raised questions as to whether portions of this band could serve as a viable option for TT&C, and if so what restrictions would exist. Diving into potential future use of L-band is outside the scope of this paper, but could be addressed in future work.

Uplink:

There are no uplink frequency allocations for TT&C operations in the U.S. At the international level, there is a primary allocation for Radionavigation Satellite Services (RNSS) in the Earth-to-space direction at 1300 - 1350 MHz. This band could be used for TT&C for RNSS systems. However, it is not viable for other service classes.

Downlink:

Companies that use L-band for satellite radio navigation (GNSS, Nac Star, Glonass, Galileo etc) could use the band to downlink telemetry.

Potential Use of S-band for TT&C

In S-band there is 85 MHz of spectrum that can be used for uplink command operations and 110 MHz that can be used for downlink telemetry. In addition, there is 10 MHz in both uplink and downlink allocated for deep space research that is primarily used by NASA's deep space communication network. It is important to note that most frequency allocations in S-band are allocated for federal use making it challenging for non-federal (commercial) companies to operate in this band. Many will advise that downlink in the 2200 - 2290 MHz band is "unusable" inside the United States unless it supports a Federal mission. The 2200 - 2290 MHz band is allocated to space operation services internationally, forcing companies to consider moving their fillings and operations abroad to meet their system's needs. Table 2 presents companies that operate in the S-band frequency range, but only outside the United States like R2 Space and Umbra Labs.

Uplink

There is one potential frequency range for command operations in the S-band with a second one being available for federal deep space research missions.

- **2025 - 2110 MHz:**

  The 2025 - 2110 MHz uplink frequency allocation is assigned on a primary basis for federal space operations, federal EESS and federal space research. US347 stipulates that non-Federal Earth-to-space transmissions may be authorized in the space research and EESS as long as they do not cause harmful interference to Federal and non-Federal stations operating in accordance with the Table of Frequency Allocations and are therefore authorized on a case-case basis. To date, NTIA has been willing to share parts of the S-band uplink spectrum, but applicants are at the whim of NTIA and they could

change their mind if they believe the band gets overcrowded. In addition, the increased use of S-band by federal and non-federal (commercial) users for TT&C operations is expected to increase the complexity of coordination among users.

- **2110 - 2120 MHz:**

  The 2110 - 2120 MHz uplink frequency allocation is assigned to deep space research on a primary basis for the NASA deep space network. This band is unlikely to be used by any non-federal (commercial) operator providing service in Earth's orbit.

Downlink

There are two potential frequency ranges that could be used for downlinking telemetry, 2180 - 2200 MHz and 2200 - 2290 MHz, while an additional allocation is available in 2290 - 2300 MHz for deep space research.

- **2180 - 2200 MHz:**

  The 2180 - 2200 MHz band is primarily used for mobile satellite service (MSS) and can be used for telemetry operations only from MSS systems.

- **2200 - 2290 MHz:**

  The 2200 - 2290 MHz frequency band is allocated on a primary basis to federal space operations, federal EESS and federal space research. Due to the federal nature of these allocations this is not an option for non-federal (commercial) use in this band. It is important to note that internationally this band is allocated for space operations forcing companies that wish to use this band to move their fillings and operations abroad. This is not only inconvenient for U.S. based companies, but also poses a national security threat to the United States. There are few examples of non-federal (commercial) companies that

have managed to secure frequency rights in this band, however, those came with strict requirements like Hawkeye 360's authorization that limits the use of this band to 10% duty cycle.

The ''Launch Communications Act'' introduced by Representative Soto in the Communications and Technology Subcommittee of the U.S. House Committee of Energy and Commerce was the first step in dedicating part of the 2200 - 2290 MHz for non-federal launch vehicle operations (telemetry and command). This legislation was in response to the increased number of launches and a time consuming coordination process with the NTIA before each launch.

- **2290 - 2300 MHz:**

  The 2290 - 2300 MHz frequency band is allocated on a primary basis to deep space exploration and is used for telemetry operations by NASA's deep space network. This band is unlikely to be used by any systems in Earth's orbit, and non-federal deep space missions would be required to protect NASA's operations.

Potential Use of C-band for TT&C

The use of C-band is not common for non-federal (commercial) TT&C uplink and downlink, although companies that operate their services in this band could utilize it for TT&C purposes.

<u>Uplink</u>

- **5000 - 5010 MHz:**

  The 5000 - 5010 MHz frequency allocation is assigned on a primary basis to radionavigation satellite service and could be utilized by systems in this service class (GNSS, Nac Star, Glonass, Galileo etc) to uplink commands.

Downlink

- **5010 - 5030 MHz:**

  The 5010 - 5030 MHz frequency band is allocated to radionavigation satellite service on a primary basis and could be used by operators in the class of service to downlink telemetry.

Potential Use of X-band for TT&C

The X-band frequency range is an alternative to the comparatively crowded S-band for operators aiming to achieve higher TT&C data rates. However, most of the X-band frequencies in the United States are allocated for federal use with few bands allocated for non-federal (commercial) use on a secondary basis. There is no allocation for space operations, yet systems in the EESS or space research can use X-band frequencies for TT&C operations. The lack of space operations allocations presents a challenge for the growing sector of in-space assembly and manufacturing (ISAM) as well as in-orbit servicing companies presented in Table 2 like Astroscale because these services may not naturally fall under EESS. When this is the case, the entity is required to submit extensive showings for X-band coordination, making the use of this band even more cumbersome.

Uplink

The uplink frequency allocations in X-band are restricted in the United States for federal use with the exception of 7145 - 7190 MHz that can be used by non-federal (commercial) systems for deep space research. There is no allocation that could be used for command operations of non-federal (commercial) earth orbiting systems.

- **7145 - 7190 MHz:**

  The 7145 - 7190 MHz frequency band is allocated for federal deep space research on a primary basis and non-federal (commercial) deep space research on a secondary basis. This band could be an option for deep research space missions, however, it would not be an option for commanding earth orbiting satellites.

- **7190 - 7235 MHz:**

  The 7190 - 7235 MHz frequency allocation is designated on a primary basis for EESS and federal space research. Footnotes 5.460A designates this band for TT&C operations of EESS satellites subject to additional earth station location restrictions. This band does not have provisions for non-federal (commercial) operators thus not making it a viable option.

- **7235 - 7250 MHz:**

  The 7235 - 7250 MHz frequency band is allocated to federal EESS systems with the same provisions as the 7190 - 7235 MHz bands, but does not have provisions for non-federal (commercial) operators.

- **7900 - 8400 MHz:**

  The 7900 - 8400 MHz frequency range consists of multiple federal allocations for fixed, mobile and meteorological satellite service. It is unlikely that non-federal (commercial) operators will be authorized to use this band even if they operate in those service classes.

Downlink

Similar to X-band uplink, frequencies designated for downlink use in X-band are primarily designated for federal use in the United States. There is 375 MHz of spectrum that can be used by non-federal (commercial) EESS systems for telemetry operations on a case by case basis and 100 MHz that can be used by non-federal (commercials) systems in the space research service area. The X-band downlink frequencies present similar NTIA coordination challenges as with the S-band frequencies.

- **7250 - 7900 MHz:**

  The 7250 - 7900 MHz frequency allocation hosts multiple federal services including fixed, mobile, maritime mobile and meteorological satellite service. These frequencies are unlikely to be an option for non-federal (commercial) satellites operating in those service areas.

- **8025 - 8400 MHz:**

  The 8025 - 8400 MHz frequency allocation is designated for federal EESS on a primary basis. Footnote US258 also designates this band for non-federal (commercial) EESS, with authorizations being subject to a case-by-case electromagnetic compatibility analysis. However, for non-EESS systems like ISAM it would be challenging to receive authorization for telemetry operations. Non-federal (commercial) use of this band is also subject to coordination with federal systems posing similar challenges with S-band allocations. This band also limits out of band emissions (OOBE) to protect deep space research in 8400 - 8450 MHz, making use of 8300 - 8400 MHz particularly challenging. Some operators like Loft Orbital, as presented in Table 2, choose to operate in this frequency outside the United States.

- **8400 - 8450 MHz:**

  The 8400 - 8450 MHz frequency band is allocated on a primary basis to federal deep space research and on a secondary basis to non-federal (commercial) deep space research. This band is not an option for a satellite system in earth's orbit.

- **8450 - 8500 MHz:**

  The 8450 - 8500 MHz frequency band is allocated to space research on a primary basis for both federal and non-federal (commercial) systems. This band would be suitable for telemetry downlink for operators in the space research service. It is important to note, that like 8025 - 8400 MHz, this band also limits out of band emissions to protect deep space research. As presented in Table 2, in-orbit service provider Astroscale was authorized for X-band downlink in this band, although it is important to note that their application was filed in Japan seeking approval from the FCC to also use the band in the U.S.. Any authorization in this band would also be subject to coordination with federal agencies.

Notable TT&C Authorizations

Table 2 provides a summary of FCC authorizations in the UHF, S-band and X-band for non-federal (commercial) satellites for TT&C purposes. The table includes key information for each system, including the authorized frequencies and any restrictions. Frequencies marked with "*" are granted for operation only outside the United States.

Table 2. Notable TT&C Grants

	UHF (MHz)	S-band (MHz)	X-band (MHz)	Additional Information
Astro Digital EESS Grant Notice	402.88-402.92 (Earth-to-space) ↑ 400.48-400.52	2045.1-2050.9 (Earth-to-space) ↑ 2051.1-2056.8		400.5 MHz downlink center frequency, 402.9 MHz uplink center frequency. For S-band max channel allowed is 300

	(space-to-Earth) ↓	(Earth-to-space) ↑		kHz
Astroscale No nature of service classification Grant Notice		2095 (Earth-to-space) ↑ 2275 (space-to-Earth) ↓	8470 (space-to-Earth) ↓	Application through Japan and request to operate in the bands in the US (Approved subject to coordination with federal)
AST&Science No nature of service classification Grant Notice		2026 (Earth-to-space) ↑		STA granted for uplink, FCC denied downlink at 2210 MHz due to NASA's objection. No US downlink.
Atlas EESS Grant Notice	450 (Earth-to-space) ↑ 401-402 (space-to-Earth) ↓	2072-2110 (Earth-to-space) ↑	8025 - 8375 (space-to-Earth) ↓	Earth station in 449.75-450.25 MHz may only operate in compliance with Table of Allocations Footnote US87
Capella Space EESS Grant		2036 (Earth-to-space) ↑	8027 (space-to-Earth) ↓	S-band subject to coordination with the Society of Broadcast Engineers(SBE), X-band subject to coordination with NASA, Air Force, NOAA, Navy
HawkEye 360 Pathfinder EESS Grant Notice	432-438 (Earth-to-Space) ↑	2025-2110 (Earth-to-space) ↑ 2200-2290 (space-to-Earth) ↓	8025 - 8400 (space-to-Earth) ↓	For S-band and X-band subject to coordination with the Society of Broadcast Engineers(SBE), X-band subject to coordination with NASA, Air Force, NOAA, Navy. S-band TT&C station max of 10% duty cycle.
Lynk Mobile Satellite Service Grant Notice		2025-2110 (Earth-to-space) ↑ 2200-2290 (space-to-Earth) ↓		TT&C operations using the 2200-2290 MHz and 2025-2110 MHz bands for emergency backup operations, contingent on completion of coordination with Federal systems. Primary TT&C at 20.1-20.2 GHz (space-to-Earth) and 29.9-30.0 GHz (Earth-to-space)
	450			UHF bands for backup only. Downlink in the 400.15-401

Loft Orbital EESS, Other Grant Notice	(Earth-to-space) ↑ 400.15-402 (space-to-Earth) ↓	2025-2110 (Earth-to-space) ↑	8025 - 8400 (space-to-Earth) ↓*	MHz and 401-402 MHz (space-to-Earth) bands, when in view of the satellite's earth station(s) must not exceed a 5% duty cycle.
Maxar EESS Grant Notice		2086 (Earth-to-space) ↑	8185 (space-to-Earth) ↓ 8380 (space-to-Earth) ↓	S-band uplink subject to not causing interference, X-band downlink for remote sensing TT&C subject to coordination with NASA, Air Force, NOAA, Navy
R2 Space EESS Grant Notice		2087 (Earth-to-space) ↑ 2264 (space-to-Earth) ↓*		S-band required coordination with NASA, Air Force, NOAA, Navy
Spire EESS Grant Notice	402-403 (Earth-to-space) ↑ 450 (Earth-to-space) ↑ 402-403 (space-to-Earth) ↓ 450 (space-to-Earth) ↓			Waiver granted for operations in the 402-403 MHz (E-to-s and s-to-E) (TT&C and data backup only). Earth stations in 402-403 must coordinate with DOC/NOAA. Must operate in 402.6-402.8 MHz with 15 kHz max bandwidth. 450 MHz (E-to-s) subject to coordination per US87.
Umbra Lab EESS Grant Notice		2080 (Earth-to-space) ↑ 2252 (space-to-Earth) ↓*		S-band required coordination with NASA, Air Force, NOAA, Navy

*Non-US Operations

Conclusion and Recommendations

To summarize, this paper provides an overview of the United States frequency allocations in the UHF, L-, S-, C- and X-band that could be used for TT&C operations of satellite systems. The growing number of satellites and emergence of new satellite services has made the sparse

allocations for TT&C challenging to navigate. UHF frequency allocations are important for cubesats and academic missions due to the lower hardware cost, compared to components that operate in higher bands. Internationally, S-band is the backbone of the TT&C operations across commercial systems, but the federal nature of these bands in the U.S. poses major challenges for non-federal (commercial) use. X-band TT&C frequencies have become popular as an alternative to S-band and can cater to higher data rate needs, but are often cost prohibitive to deploy.

The lack of streamlined licensing and dedicated frequencies for TT&C use, and the growing number of service classes that did not exist when the frequency allocations were first designated, are making it challenging for operators to efficiently identify spectrum for TT&C use. For UHF frequencies, the biggest challenge is the lack of allocated bandwidth for uplink operations and the need for separate antenna systems for the current uplink and downlink frequency configurations. In S-band, the biggest challenge is the federal nature of uplink and downlink frequencies, requiring long and complicated coordination for uplink and making downlink frequencies not an option inside the United States. The lack of S-band spectrum for TT&C also has the added consequence of companies choosing to file and operate outside the United States, leading to economic, regulatory and national security impacts. The X-band also lacks allocations for space operations, limiting its use to specific satellite services.

The identification and allocation of TT&C is critical for the United States to enable new technologies and to maintain its leadership in the space economy. To cater to all stakeholders, academia, industry and federal agencies, the FCC and NTIA must consider streamlining and designated frequency allocations for space operations in these bands. For the UHF band, there should be provisions for uplink and downlink operation in neighboring frequency bands to enable universities and research labs to launch cost effective technology demonstrations and

science missions. For S-band, the United States should align with international allocations and designate bands for uplink and downlink operations. For X-band, there should be provisions to allow higher data rate telemetry dowlinks regardless of satellite service under the space operations service class. These allocations will better streamline identification and authorization of TT&C frequencies, and would also encourage hardware manufacturers to lower cost by producing parts dedicated for those bands

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