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Spectrum 101

An Introduction to National Aeronautics and Space Administration Spectrum Management

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Table of Contents

Executive Summary

Electromagnetic spectrum is the valuable but limited resource that makes possible virtually every mission that the National Aeronautics and Space Administration (NASA) undertakes, including in the areas of earth science, space science, human space exploration and aeronautical research. Yet even as spectrum access is growing increasingly important for NASA missions, the migration of the Internet from wireline platforms to the world of mobile communications is creating unprecedented pressure for more spectrum capacity to be made available for commercial wireless broadband services.

What is Spectrum? The basic building block of radio communications are radio waves. The key characteristics of spectrum are the propagation features and the amount of information that signals can carry. A signal is broadly defined as a detectable quantity (e.g., current, voltage, electromagnetic field) that varies in time. An important signal for radio communications is one where the quantity varies as a periodic sine wave. Frequency is the number of cycles that occur in one second and is defined in units of Hertz (Hz), which is another name for cycle per second. The frequency of a signal is the reciprocal of its period. The amplitude of the signal is half the peak-to-peak separation of the quantity that is changing with time, e.g., voltage. In general, signals sent using the higher frequencies have lower propagation distances but a higher data-carrying capacity and the opposite for longer wavelengths with lower frequencies makes up for the Radiofrequency (RF) spectrum. The range from 3 kiloHertz (kHz) to 300 GigaHertz (GHz) that may be used for wireless communication. Shorter wavelengths with higher frequencies make up the optical spectrum, while the part of the spectrum that can be seen is the visible spectrum. NASA relies on a range of tools for communicating and creating images utilizing almost every single component of the electromagnetic spectrum in one way or another.

This report is designed to provide a better understanding of basic issues for NASA spectrum access and management by addressing: what spectrum is; how it is managed; key topics with respect to international and domestic policy decisions; how NASA organizes its spectrum management activities; opportunities and challenges; and future spectrum requirements for space missions. Individual sections are modular and designed to be read either in sequence or separately to address specific issues based on the following chapters: *(1) Introduction; (2) Spectrum Basics; (3) Domestic and International Spectrum Regulatory Environment; (4) NASA Spectrum Organization and Management; (5) NASA Spectrum Use; (6) National Spectrum Issues and NASA Equities; (7) International Spectrum Issues and NASA Equities; and (8) Conclusion.*

Introduction: Like all federal spectrum users, NASA requires assured access to spectrum to reflect the long-term nature of investments, in systems – including satellites – designed to remain in operation for decades, versus the 18-month lifecycle of new cellphones. Thus, new commercial technology trends present both opportunities and challenges. In addition, passive scientific use of spectrum – for example in the form of Earth remote sensing satellites that glean weather and climate information – must be protected from unwanted interference in the face of expanding activity from active services, such as wireless broadband.

Spectrum Basics: A transmitter generates a radio wave, which is then detected by a receiver. An antenna allows a transmitter to send energy into space and a receiver to pick up energy from space.

Transmitters and receivers are typically designed to operate over a limited range of frequencies. Use of the radio spectrum is regulated, access is controlled and rules for use are enforced because of the potential for interference between uncoordinated uses. Spectrum is scarce because at any time and place, one use of a frequency precludes its use for another purpose. This has given rise to technological innovation and regulatory flexibility to increase the extent to which spectrum is shared between different users, either on the basis of time or geography.

Regulatory Environment: In the US, two main policy bodies oversee spectrum use – the Department of Commerce's National Telecommunications and Information Administration (NTIA) and the Federal Communications Commission (FCC). For federal spectrum, NTIA is the lead authority and for non-federal spectrum, the FCC has regulatory purview. Both agencies work together to ensure that policy decisions promote spectrum use consistent with both US economic interests and government user requirements. The dual management framework used in the US is unique in the world; most other countries have a single government agency perform the spectrum management function over both public and private sector uses.

US activities regarding international frequency management are carried out under the leadership of the Department of State (DoS), whose role is to ensure the US speaks with one voice and that all applicable precedents and treaties are followed.

International regulation and coordination of spectrum use occurs through the International Telecommunication Union (ITU), in compliance with a set of international rules and regulations (also known as the Radio Regulations). The ITU is the UN agency for matters dealing with information and communications technology. The State Department, along with NTIA and the FCC, oversees US preparations for ITU meetings. The ITU publishes the Radio Regulations (RR) as agreed at World Radiocommunication Conferences (WRCs), which occur every three to four years and update the RR, including spectrum allocations to various services. ITU member nations generally develop national frequency management regulations consistent with the RR.

NASA Spectrum Management: Within this overarching national policy framework, NASA organizations manage the Agency's use of spectrum and ensure NASA access to spectrum for all missions using space-based and ground-based assets. The NASA Spectrum Management Program ensures that all NASA activities comply with national and international rules and regulations applicable to spectrum use and facilitates securing spectrum and orbital resources (both domestically and internationally) to enable aeronautical and space mission requirements.

Agency spectrum management responsibilities reside in the Space Communications and Navigation (SCaN) program office. *SCaN's Deputy Associate Administrator* oversees the overall planning, policy development, and administration of the NASA Spectrum Management Program. The *Director of Spectrum Policy and Planning* oversees: NASA activities to obtain adequate international and national allocations of frequency bands; to pursue coordination of proposed NASA frequency use with other domestic and foreign users of the frequencies; and to obtain approval of frequency assignments by NTIA. The *National and International Spectrum Program Managers* implement spectrum management initiatives and day-to-day spectrum management activities. They represent NASA in national and international fora, including committees and working groups responsible for developing frequency allocations and associated technical and procedural rules. *Center Spectrum Managers* provide the latest communications requirements regarding implementation of projects and missions at the Center to the National and International Spectrum Program Managers.

NASA has adopted procedures for requesting frequency assignments and obtaining new frequency allocations in order to effectively implement national and international spectrum management policy. In almost all cases, identification of spectrum support for NASA needs is focused on frequency bands allocated nationally and internationally for the particular radio service for which the Agency requires support. This includes both terrestrial use (e.g. fixed, mobile, radiolocation, radionavigation and other terrestrial radio service allocations) and space use (e.g., space radio service allocations that support the US space programs).

NASA Spectrum Use: NASA's investigations of the universe are accomplished mainly through the use of unmanned automated spacecraft. These missions employ both passive and active instruments operating at various frequencies to measure data from the Earth, planets, Sun, and other phenomena. They require highly reliable communications, often over long periods of time and at great distances, to guide and control the spacecraft and to bring back the images and new scientific data they collect. NASA's spacecraft must be: tracked and controlled; the health, condition, and safety of the spacecraft must be monitored; and the scientific data that is obtained must be transmitted to mission operators. Channels are needed for robust, low data rate communications designed for critical Tracking, Telemetry, and Commanding (TT&C), and in the case of crewed spacecraft, for voice services. Still other channels are needed for high data rate communications for transmission of mission data.

NASA operates a sophisticated global infrastructure, consisting of several component networks**,** including the *Deep Space Network (DSN)*, which is used to support scientific spacecraft; *Space Network (SN)*, which provides tracking and data relay for spacecraft, satellites, and expendable launch vehicles using space and ground segments. It includes the Tracking and Data Relay Satellite System (TDRSS); and *Near Earth Network (NEN)*, which consists of ground stations owned by NASA, commercial entities, and other partners that provide communications and tracking services to missions in the near earth region.

Earth science research at NASA has turned space-based observing technology and scientific expertise to use for the study of Earth and its integrated system of land, ocean, atmosphere, ice, and biological processes. Spaceborne sensors, which rely on spectrum, are the only tools that can provide environmental data repetitively on a global scale. To support the intermediate and long term goals of understanding the Earth, NASA has developed numerous radio sensors designed to fly onboard spacecraft.

NASA's space science missions are designed to study the mysteries of the universe from origins to destiny, to explore the solar system, to discover planets around other stars, to search for life beyond Earth and to chart the evolution of the universe and understand its galaxies, stars, planets, and life. NASA's scientific investigations are carried out via spectrum-dependent unmanned automated spacecraft.

NASA efforts to open the frontiers of space by human exploration could not be accomplished without spectrum. In exploring space, NASA has brought together a wide range of technologies, machines and people in the development of such programs as the Space Transportation System (STS) and the International Space Station (ISS). NASA is developing the capabilities needed to send humans to an asteroid by 2025 and Mars in the 2030s. Yet another spectrum-reliant focal point for NASA initiatives is Aeronautics and Space Technology Development. NASA is focused on developing technology solutions that will eliminate barriers to growth for the civil aviation system and provide a safe, efficient national aviation system.

National Spectrum Issues: Key drivers of the explosive growth in mobile broadband include the development of smartphones and other mobile computing devices, the emergence of broad new classes of connected devices (the Internet of things) and the rollout of Fourth-Generation (4G) wireless technologies such as Long Term Evolution (LTE). Several portions of the radio spectrum that are under consideration to keep up with wireless industry spectrum demand, including for unlicensed devices, carry potential implications for NASA equities.

To meet this burgeoning commercial demand, in 2010, the FCC released a National Broadband Plan that called for making additional spectrum available for wireless broadband use – 500 MegaHertz (MHz) by 2020, setting off a national spectrum "policy" race for even more spectrum bands to be considered to meet this goal. In a June 2010 Executive Memorandum, the President adopted this 500 MHz goal as US policy. A 2013 Executive Memo focused on increased sharing. Sharing efforts were further promoted when, in 2012, the President's Council of Advisors on Science and Technology (PCAST) concluded that the traditional method for accommodating new services by clearing and reallocating portions of federal spectrum is not a sustainable model for national spectrum policy because it is too costly and takes too much time. PCAST made a series of recommendations for federal spectrum focused on large-scale sharing opportunities.

NASA's spectrum use is also affected by the needs of the growing commercial space sector, which has grown beyond the provision of basic communications and broadcasting services through satellites, to the provision of Earth resources information and development of new markets such as space tourism. The private sector is developing launch vehicles and facilities, as well as payloads, which require access to spectrum resources. To support the increased spectrum requirements arising from the growth of this sector, NASA is working with federal regulators to assess ways that federal spectrum traditionally used by NASA for its own operations can be made available, when needed, by private sector stakeholders for commercial launches and operations in space.

International Issues: Because NASA missions require spectrum access on a global basis, NASA must influence developments in the international arena to ensure that its capabilities that are spectrum-dependent will have access to spectrum where and when needed. There are two paths within the US for the development of spectrum management rules and procedures contained in the international RR. One is a technical path where engineering studies concerning radio matters are conducted, which provide technical bases for international RR; the other is a more political path where preparations leading to a WRC involve discussions in domestic and international bodies. NASA participates in both domestic and international forums in making the technical studies necessary to promote and protect operations in the space science services. It also participates in bilateral and multilateral discussions, where negotiations occur that could affect these operations.

As with domestic spectrum policy trends, WRC issues in recent conference cycles have faced pressures relating to the dynamic tension between public sector users and commercial mobile wireless providers around the globe. Often, there is an interplay between domestic and international policy directions, including an interest on the part of US technology developers in the identification of certain bands for mobile broadband applications as part of the WRC process to help create further leverage for such bands being put into play for commercial reallocation at home (for example the 5 GHz bands.).

At WRC-12, NASA succeeded in getting several items of specific interest included for consideration on its agenda and subsequently approved at WRC-15,: (1) A possible Earth Exploration Satellite Service (EESS) uplink allocation in the 7-8 GHz range to help alleviate congestion in the 2 GHz bands; (2) A review of current limits on use of 410-420 MHz for Space Research Service (SRS) operations; (3) An expansion of 600 MHz around 9.5 GHz to support EESS (active) operations; and (4) Consideration of nanosat/picosat regulatory issues.

While NASA remains vigilant about a range of potential WRC issues that could affect its operations, there are several spectrum access issues that raise potentially higher concerns. These include: (1) spectrum allocations for mobile broadband/International Mobile Telecommunication (IMT); (2) increasing broadband spectrum for the fixed satellite service; and (3) various proposals for spectrum in or adjacent to passive sensing bands.

Conclusion: The spectrum management environment, which continues to be shaped by advanced technology capabilities, evolving policy frameworks and emerging operating requirements, poses both opportunities and challenges for NASA spectrum equities. NASA remains committed to proactively addressing both to meet its own mission requirements and help to contribute to balanced policy decisions regarding spectrum access. US policymakers are confronting what industry has described as a spectrum capacity crunch, with several bands that are under study for future wireless industry use carrying potential implications for NASA equities. At the ITU, the ITU-Radiocommunications Sector (ITU-R) is addressing future demand challenges, as well, as it works to finalize its vision of the connected future via planning efforts for Fifth-Generation (5G) Wireless. Simply put, challenges and opportunities in this complex electromagnetic spectrum environment are redefining how NASA carries out its roles as a proactive spectrum steward.

Chapter 1

1. Introduction

Chapter 1 Purpose: To provide an overview of why assured spectrum access is critical to all of NASA's missions, how the electromagnetic spectrum environment in which NASA operates is changing and how the Agency is responding.

Spectrum use is an essential element of NASA global missions and activities, ranging from satellite communications, earth remote sensing, and weather monitoring to disaster response, satellite-aided search and rescue and space weather forecast. Spectrum is the "lifeblood" that enables the execution of virtually every mission that NASA undertakes – whether in the areas of earth science, space science, human space exploration, or aeronautical research. These initiatives depend on electromagnetic spectrum to deliver important public benefits, including scientific advances, contributions to jobs in the aerospace industry and technology transfer to commercial markets.

1.1 Document Structure

This paper has been developed to provide background and perspective on basic issues and trends for NASA spectrum management. This includes explanations of what spectrum is; how it is managed from a regulatory, technology and engineering perspective; who the major players are with respect to international and domestic policymaking; how NASA organizes its own spectrum management activities; current spectrum management opportunities and challenges for the Agency; and future spectrum requirements for space missions. Respective sections in the document are modular and are designed to be read either in sequence or separately to address specific issue areas. Accordingly, the paper is divided into the following chapters:

Chapter 1: Introduction
Chapter 2: Spectrum Basics
Chapter 3: Domestic and International Spectrum Regulatory Environment
Chapter 4: NASA Spectrum Organization and Management
Chapter 5: NASA Spectrum Use
Chapter 6: National Spectrum Issues and NASA Equities
Chapter 7: International Spectrum Issues and NASA Equities
Chapter 8: Conclusion

1.2 What is Spectrum and Why Is It Important?

Frequency bands have relative advantages and disadvantages, and are chosen depending on the characteristics needed to carry out a mission or provide a service. NASA uses spectrum across a broad array of frequency ranges *(see Figure 1.1).*

In addition to the usable electromagnetic spectrum being a scarce resource, many prime pieces of spectrum "real estate" (bands that are appropriate for certain uses) are attractive to both government and private sector users. This is because the propagation characteristics that make certain bands useful for government purposes also make them similarly useful for commercial wireless services. These properties include the ability of radiowaves to penetrate terrain, travel long distances or pass through buildings or cloud cover. While signals at lower frequency bands (e.g., below 3 GHz) can propagate for miles and pass with relative ease through structures, millimeter wave signals (e.g., above 30 GHz) can travel only a few miles and do not penetrate buildings well for terrestrial applications.[i]

Across the US economy, mobile broadband is emerging as a disruptive technology *(see Figure 1.2)* because it represents the convergence onto new platforms of two major transformational communications trends – the Internet and wireless capabilities. Wireless broadband is an economic growth engine in the US and a cornerstone of technological competitiveness. At the same time, spectrum enables a broad range of federal government services and applications, including NASA operations.

All spectrum auctioned to commercial carriers so far by the FCC, which is the US regulator with purview over commercial spectrum, has been below 3 GHz. However, millimeter wave bands are also under study for potential broadband applications. Spectrum above 30 GHz can facilitate more densely packed communications links to provide efficient use and secure transmissions.

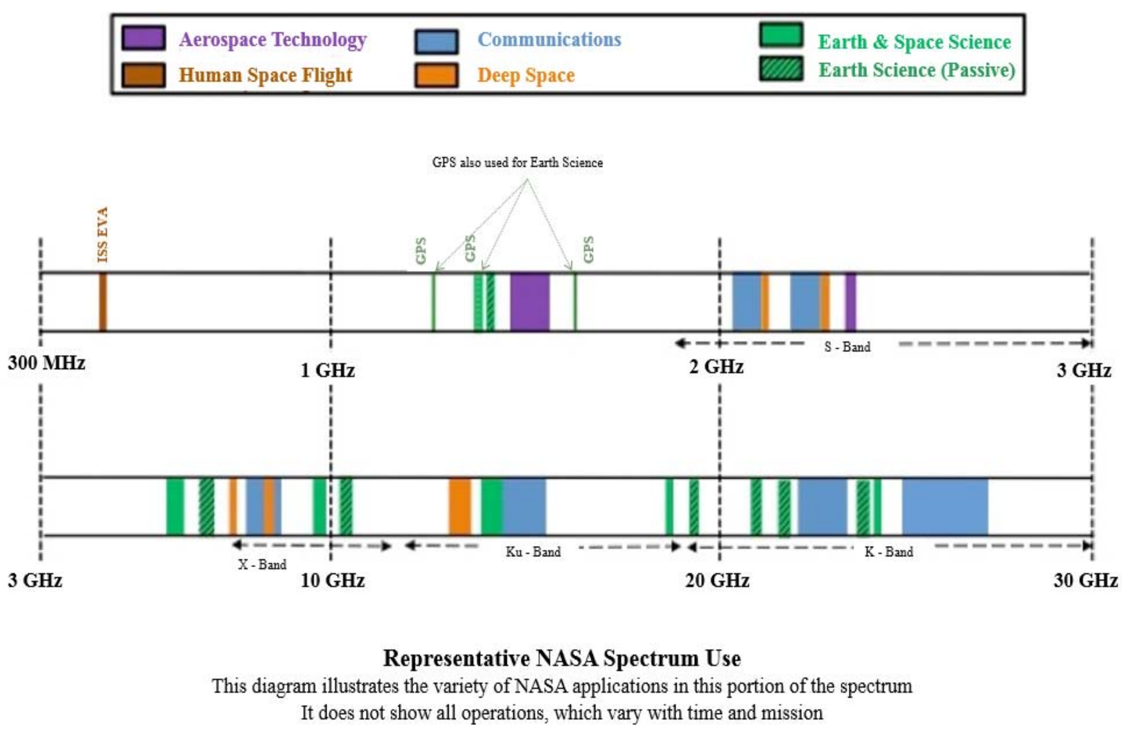

Figure 1.1: Representative NASA Spectrum Use

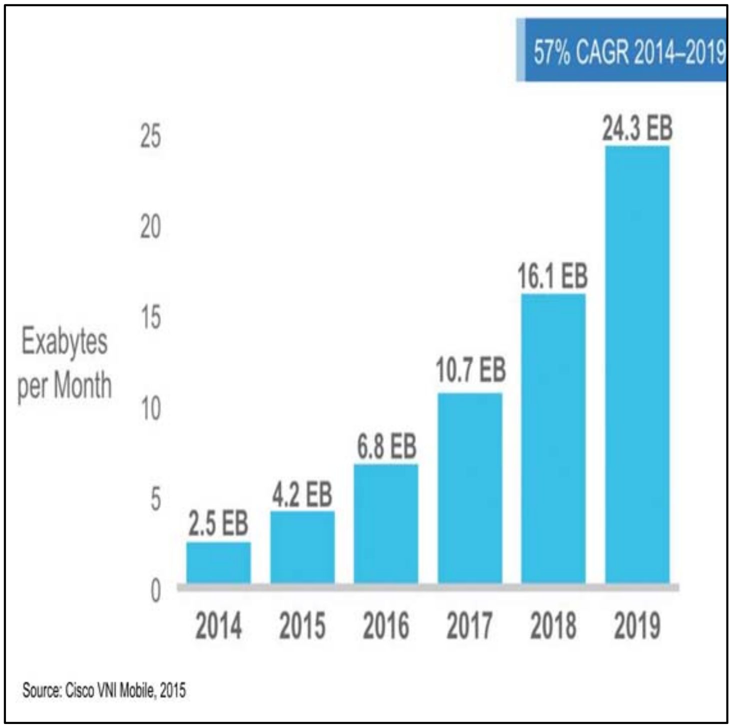

Figure 1.2: Cisco Forecasts Mobile Data Traffic (2014-2019)

Regulatory restrictions or requirements (the spectrum equivalent of "zoning") also affect how useful a piece of spectrum may be for certain kinds of services or users. One example are the limits of power levels in a particular RF band in order to avoid causing harmful interference to systems in adjacent or nearby bands.[ii]

1.3 Sources of Increased Congestion and Contention

All these factors make spectrum a valuable but limited resource. In the commercial world, contention for access to federal government bands is growing. Several federal bands are the focus of the National Broadband Initiative, for which the White House has set a goal of making an additional 500 megahertz (MHz) of federal and non-federal spectrum available for mobile broadband use by 2020.

Several bands that are under study for future wireless industry use carry potential implications for NASA equities. In other cases, new advanced wireless broadband uses that are entering spectrum bands adjacent to current NASA operations may impact Agency capabilities and require an adjacent band compatibility analysis to ensure that NASA missions do not encounter harmful interference and can continue without interruption. Global Positioning System (GPS) capabilities on which NASA relies face increased challenges with regard to the potential for harmful interference as new spectrum "neighbors" seek access to adjacent or nearby bands.

Policymakers have embraced an approach of increasingly making new capacity available through sharing, as well as the traditional methods of relocating and clearing incumbent users to repurpose bands to the private sector. These efforts are focused on bands above the traditional "beachfront" spectrum sought by wireless carriers at auction (i.e., below 3 GHz). Policymakers are assessing how some of these bands can be shared, including as part of a tiered system of access between government incumbents, private sector licensees and unlicensed applications. The PCAST issued a landmark report in 2012 that advanced this tiered concept of sharing. It made a series of recommendations for making additional federal spectrum available on a shared basis for commercial wireless broadband use.[iii]

1.4 Spectrum Opportunities and Risks for NASA

NASA spectrum requirements are complex, unique and evolving to support its critical missions.

NASA uses radio spectrum to track, command and control spacecraft from mission launch to completion, to collect scientific/environmental information using a variety of sensors, and to communicate collected information to Earth facilities, either directly or through relay satellites. Spectrum access for human exploration enables ISS operations, development of commercial spaceflight capabilities and human exploration beyond Low-Earth Orbit (LEO). To explore space, NASA has brought into play a wide breadth and depth of technologies, machines and people in the development of programs such as the STS and the ISS. All of these capabilities include spectrum access as a critical component, including as part of developing the capabilities needed to send humans to an asteroid by 2025 and Mars in the 2030s.

In comparison to commercial wireless applications, many aspects of spectrum-based NASA mission capabilities are designed for specific scientific purposes, for which no commercial substitute is available. Like all federal spectrum users, NASA requires assured access to spectrum to reflect the long-term nature of investments, in systems – including satellites – designed to remain in operation for decades, versus the 18-month lifecycle of new cellphones. Thus, new commercial technology trends regarding commercial applications and services present both opportunities and challenges.

In addition, passive scientific use of spectrum – for example, in the form of Earth remote sensing satellites used to glean weather and climate information – need to be protected from unwanted interference in the face of expanded activity from active services, such as wireless broadband.[iv] The challenge is that these important NASA systems and initiatives represent billions of dollars in investment and continue to provide vital services to the public, which are sometimes harder to quantify in economic terms than is the case for wireless broadband.

1.5 Way Forward

In a period of increased demand for spectrum, including NASA's, the development of spectrum policy that meets all users' needs has been challenged by economic, mission, and technology considerations. In general, policymakers have attempted to strike a balance between unlicensed wireless operations, which prefer cost-free methods of access to bands without guarantees of protection against harmful interference, and additional spectrum for licensed operators, which generate significant revenue through auction but require extensive clearing and sharing efforts to make spectrum usable.

Against this backdrop, NASA is an effective spectrum steward, harnessing technology to use limited spectrum resources more efficiently and effectively to address current requirements and to prepare for future needs for NASA's space communication and navigation services and global terrestrial communication services. NASA's approach to these spectrum roles and responsibilities is guided by a focus on safety, mission success, and risk management.

As part of this stewardship approach, the NASA Spectrum Management program provides the overall planning, policy, coordination and implementation necessary to ensure adequate access to and protection of electromagnetic spectrum in support of NASA's present and future programmatic goals. The Spectrum Management Division, located within the Human Exploration and Operations Mission Directorate (HEOMD) maintains NASA Policy Directives, NASA

Procedural Requirements, and other spectrum guidance documents, as needed. NASA missions requiring the use of the electromagnetic spectrum for communications or sensor operations follow the process outlined in Attachment A.

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[i] *See* FCC Office of Engineering and Technology Bulletin No. 70, July 1997, "Millimeter Wave Propagation: Spectrum Management Implications." It is important to note that for space-based operations, windows in the atmosphere exist that allow spaceborne instruments to see to the Earth's surface or to various layers in the atmosphere.

[ii] The amount of mobile data offloaded to WiFi networks rose by 875 percent in the US in 2013, as wireless carriers tried to address growing strain on their own networks. This represents remarkable growth given that WiFi offloading was such a nascent trend in 2010 that it was not accounted for in the FCC's National Broadband Plan.

[iii] *See* PCAST report *Realizing the Full Potential of Government-Held Spectrum to Spur Economic Growth,* 2012.

[iv] *See* National Academies Study, Spectrum Management for Science in the 21st Century, November 2010.

Chapter 2

2. Spectrum Basics

Chapter 2 Purpose: To describe the basic elements of what electromagnetic spectrum is, how it is managed and the implications for the electromagnetic environment in which NASA missions operate.

2.1 Overview

The electromagnetic spectrum refers to the phenomena of electromagnetic waves, which propagate through space at different radio frequencies. Longer wavelengths with lower frequencies make up the radio spectrum, which is typically the frequency range from 3 kHz to 300 GHz that may be used for wireless communication. Shorter wavelengths with higher frequencies make up the optical spectrum, while the part of the spectrum that can be seen is the visible spectrum. NASA relies on a range of tools for communicating and creating images utilizing almost every single component of the electromagnetic spectrum in one way or another.

2.1.1 Spectrum as "Fuel"

RF spectrum enables a broad range of wireless applications, including mobile broadband smartphones, radio and television broadcasting, GPS position locating, aeronautical and maritime radio navigation, satellite command and control, and remote sensing of the atmosphere and surface of the Earth and planets.

Radio waves constitute the basic building block of radio communications. Like waves in the ocean, they can be focused and bent and, like a wave traveling through water, have a wavelength (i.e., distance between wave crests) and a frequency (i.e., number of wave crests passing a point in a unit of time). Frequency is measured in the unit hertz (Hz), referring to a number of cycles per second.[i]

Bandwidth is the portion of spectrum that a given communications system can use (a system that operates on frequencies between 150 MHz and 200 MHz has a bandwidth of 50 MHz). A transmitter typically seeks to communicate with a particular receiver and the transmitting antenna directs the majority of the signal toward that receiver (the receiving antenna is most sensitive to signals coming from the direction of the transmitter). At the same time an antenna radiates signal at lower levels and can receive signals from all directions. An interfering signal will be amplified and detected like the desired signal once it enters the receiver.[ii]

To avoid interference, more than one person usually cannot transmit radio signals at the same frequencies, at the same time, in the same direction. As soon as one user stops transmitting signals over a portion of the spectrum, another can immediately re-use it. Spectrum is scarce because at any time and place, one use of a frequency precludes its use for another purpose. At the same time, this scarcity has given rise to technological innovation and regulatory flexibility to increase the extent to which spectrum is shared between different users, either on the basis of time or geography *(see Chapter 6)*.

2.2 Band Designators

Frequencies are often grouped in ranges called bands. There are numerous ways frequency bands have been designated. A common method is to use a letter designator to identify the various bands. The Institute of Electrical and Electronics Engineers (IEEE) has published a standard for the letter designation of RF bands *(see Figure 2.1)*. These codes are used by some engineers for radar, satellite, and terrestrial communications. The ITU designates bands *(see Figure 2.2)*.

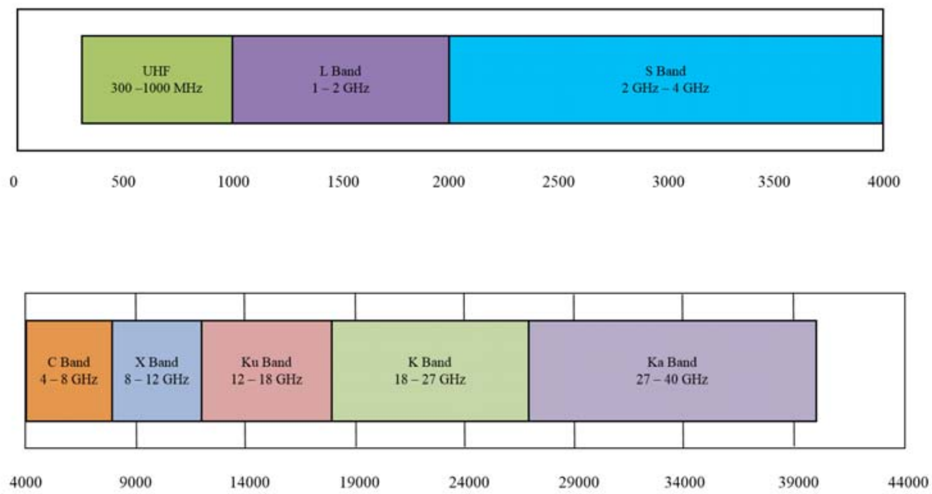


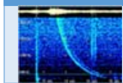
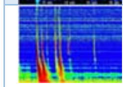
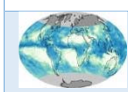
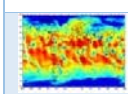
Figure 2.1: Letter Designation of RF Bands

In the US, the two main policymakers who oversee spectrum use – the NTIA and the FCC – have divided the usable radio spectrum (0-300 GHz) into about 800 frequency bands, which are allocated to 34 radio services (e.g., fixed, radionavigation, mobile, broadcasting, and various satellite services) *(see Chapter 3)*.

Frequency Range	Wavelength	Band
3-30 MHz	100-10 m	High Frequency (HF)
30-300 MHz	10-1 m	Very High Frequency (VHF)
300-1000 MHz	100-30 cm	Ultra High Frequency (UHF)
1-2 GHz	30-15 cm	L
2-4 GHz	30-15 cm	S
4-8 GHz	15-7.5 cm	C
8-12 GHz	7.5-3.75 cm	X
12-18 GHz	3.75-2.5 cm	Ku
18-27 GHz	1.67-1.11 cm	K
27-40 GHz	11.1-7.5 mm	Ka
40-75 GHz	7.5 mm-4 mm	V
75-110 GHz	4 mm-2.73 mm	W

Figure 2.2: ITU Band Designation

Table 2.1: Spectrum Bands Used by NASA

	Band	Frequency Range
	**Very Low Frequency (VLF)** Dynamic Spectrograph of a VLF "Whistler".	(3 kHz-30 kHz)
	**Low Frequency (LF)** STEREO/WAVES (SWAVES) uses LF radio imaging to study coronal mass ejections.	(30 kHz-300 kHz)
	**Medium Frequency (MF)** Non-Directional Beacons use MF radio frequencies to deliver directional information to aircraft. NASA and the Federal Aviation Administration (FAA) are working to improve non-directional beacon technology.	(300 kHz-3000 kHz)
	**HF** Also called "short wave" and used for long distance communications; NASA uses HF at test ranges.	(3 MHz-30 MHz)
	**VHF** NASA utilizes the VHF band by airborne sensors to study the thickness of sea ice.	(30 MHz-300 MHz)
	**UHF** NASA astronauts use UHF systems as backups for their voice communication systems. NASA also uses these frequencies to remotely sense the Earth's surface (e.g. soil moisture with the Soil Moisture Active Passive (SMAP) mission) and atmosphere.	(300 MHz-3000 MHz)
	**Super High Frequency (SHF)** Numerous NASA and National Oceanic and Atmospheric Administration (NOAA) missions use SHF frequencies to probe the Earth's atmosphere and surface. The Tropical Rainfall Measuring Mission and Global Precipitation Measurement missions observe the structure of rain in 3 dimensions.	(3 GHz-30 GHz)
	**Tracking and Data Relay Satellite (TDRS)** The current configuration consists of nine in-orbit satellites (four first generation, three second generation and two third generation satellites) distributed to provide near continuous information relay service to missions like the ISS.	S band (2-4 GHz) Ku-Band (12-18 GHz) Ka-band (27-40 GHz)
	**Extremely High Frequency (EHF)** Numerous NASA and NOAA missions can use EHF frequencies to probe the Earth's surface, although they primarily are used to probe the atmosphere.	(30GHz-300GHz)
	**Infrared (IR)** The Geostationary Operational Environmental Satellite (GOES) satellites use IR technology to view and track hurricane paths.	(.003 x 10^{14} Hz-4 x 10^{14} Hz)
	**Visible** Terra uses the visible light spectrum to take true color images of the Earth and its features.	(4 x 10^{14} Hz-7.5 x 10^{14} Hz)
	**Ultraviolet (UV)** The Solar and Heliospheric Observatory is studying the sun- from its core to its outer corona to its outer wind.	(7.5 x 10^{14} Hz-3 x 10^{16} Hz)
	**X-Ray** The GOES satellites use an X-ray imager to photograph and study the sun.	(3 x 10^{16} Hz-Upward)
	**Gamma Ray/Cosmic Ray** Gamma Rays or Cosmic Rays are used to further study the universe.	

2.3 What is Spectrum Management?

Spectrum management is the oversight of RF spectrum use. Use of the radio spectrum is regulated, access is controlled and rules for use are enforced because of the potential for interference between uncoordinated uses. In the spectrum management process, frequency bands are allocated for particular uses, and specific technical and operating rules, developed by spectrum managers, govern the use of spectrum within those allocations. As the complexity and sheer number of radiocommunication systems has grown, the responsibilities for coordinating spectrum use also have become more complicated.

2.3.1 Spectrum Allocation

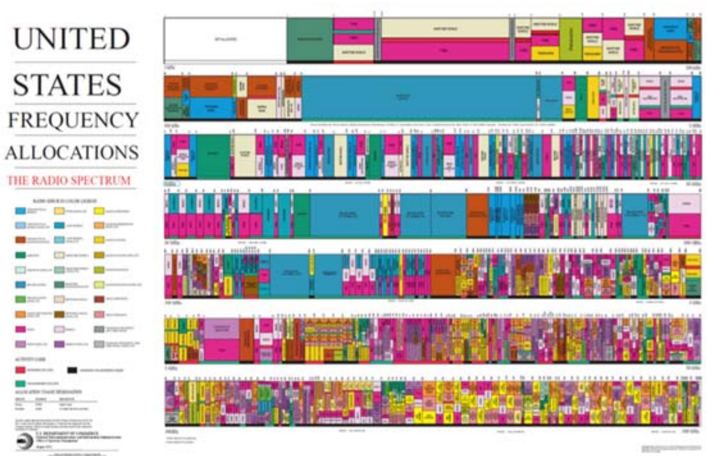


Figure 2.4: Table of Frequency Allocations

Spectrum allocation is a distribution of frequencies to *radio services*. An allocation designates the use of a given band by one or more radiocommunication services. National and international tables of frequency allocations contain lists of these band designations. The US Table of Frequency Allocations[i] covers the radio spectrum between 9 kHz and 300 GHz *(see Figure 2.4).*

The key characteristics of spectrum are the propagation features and the amount of information that signals can carry. In general, signals sent using the higher frequencies have lower propagation distances but afford more bandwidth and thus a higher data-carrying capacity. NASA's Earth Science Division sensors operate at specific frequencies depending on the physics of substances to be studied. Required sensor frequencies occur throughout the radio spectrum, from 1.4 GHz to beyond 300 GHz.

There are a number of considerations taken into account when spectrum allocations are made. These might include: the public need for and benefits of a proposed service; amount of spectrum required; potential for interference to/from other services; technical considerations, such as propagation conditions and apparatus limitations; and international considerations.

2.3.1.1 Primary vs. Secondary Allocation

The ITU and, in turn, individual national regulators designate spectrum allocations as primary or secondary.

- **Primary allocations** grant specific services priority in using a particular swathe of allocated

[i] U.S. Frequency Allocation Chart as of October 2011. (2011, August 1). Retrieved October 16, 2015, from http://www.ntia.doc.gov/

spectrum. In cases where there are multiple primary services within a band, they have equal rights. A station has the right to be protected from any others that start operation at a later date.
- **Secondary allocations** involve services that must protect all primary allocations in a particular band. Services operating in secondary allocations must not cause harmful interference to, and must accept interference from, primary users. All secondary service stations have equal rights among themselves in the same band.

2.3.2 Spectrum Authorization

Authorization – via frequency assignments – is the process by which users are licensed to access the spectrum resource. An assignment is a frequency or set of frequencies allotted to a given *radio station* for use under specified conditions. This may involve assigning specific frequencies to users, assigning certain frequency bands or sub-bands to users who may be able to transfer such spectrum rights to others, or it may mean authorizing the use of specific categories of equipment (unlicensed devices).

Spectrum authorization activities include analyzing requirements for proposed frequencies in accordance with national frequency allocations and any applicable technical standards in order to select the most appropriate frequencies for radiocommunication systems. These activities also include actions to coordinate proposed assignments with existing assignments and to protect radiocommunication systems from harmful interference. An operator is assigned a frequency or set of frequencies in order to provide communications services, and this assignment of frequencies is done in a way to avoid harmful interference with other users of the spectrum. Spectrum authorization strategies ensure proper radio spectrum use, facilitate reuse, and achieve spectrum efficiency.

2.3.3 Spectrum Engineering (Technical Standards)

There are technical standards that describe procedures for how spectrum is used (spectrum operating standards) and standards that state conditions of apparatus compliance (radio equipment standards).

- Spectrum operating standards state the minimal technical requirements for the efficient use of a specified frequency band or bands.
- Equipment standards involve certification of radio equipment such as transmitters, receivers and antennas in order to determine compliance with radio operating standards.

In general, technical standards are important to users of radio services and radio equipment since operators rely on them as a basis for preventing interference and for ensuring that radio systems perform as designed. Standards documentation might include: general information describing the equipment and the application; an indication of licensing and certification requirements; spectrum channel plan arrangements; modulation techniques used by the equipment; transmitter power; and transmission limits for unwanted emissions. Radio equipment standards basically define the limits on how certain radio equipment can interfere with other equipment in either shared or nearby frequency assignments. Regulators typically use technical standards to determine how certain radio equipment will interact with other equipment in either shared or adjacent frequency assignments. The mutual interaction of electronic equipment is known as “Electromagnetic Compatibility” (EMC).

2.3.4 Spectrum Compliance

Spectrum monitoring and compliance activities are needed to ensure user compliance with frequency allocations, terms of assignments and technical standards. These activities help users to avoid incompatible frequency usage through the identification of sources of harmful interference, and to resolve interference problems for existing and potential users. Ensuring compliance with national spectrum management regulations maximizes the benefit of the spectrum resource to society.

2.4 How It Works

These spectrum management aspects all come into play as part of how the FCC and NTIA carry out their respective roles and responsibilities *(see Chapter 3).*

Over the years, the FCC has used a variety of methods to assign spectrum for commercial users, including assigning mobile licenses as part of comparative hearings. In 1993, Congress authorized the FCC to use auctions to award spectrum licenses for certain wireless communications services. Besides auctions, there are other mechanisms that the FCC uses to make spectrum available for wireless services, including licensed and unlicensed spectrum. Some licensed frequencies are allocated for public safety. In spectrum designated as "unlicensed," users can operate without a license but must use certified radio equipment and comply with technical requirements (i.e., power limits). Under the Commission's rules, users of license-exempt bands do not have exclusive use of the spectrum and are subject to interference. Should harmful interference occur, the operator is required to immediately correct the interference problem or cease operations. Typically, unlicensed devices operate at very low power over relatively short distances, and often employ various techniques, such as dynamic spectrum access or listen-before-talk protocols, to reduce the interference risk to others as well as themselves. NTIA, on the other hand, assigns frequencies to, and amends, modifies, and revokes assignments for radio stations operated by federal users. NTIA also makes frequency allocations and establishes policies concerning spectrum assignment allocation and use.

In some cases, different federal agencies also have various direct responsibilities for certain activities that have spectrum management implications, depending on the services and operations at issue. For example, an NTIA frequency assignment covers authorization for federal (civil, military) agencies to transmit from terrestrial or space radio stations. An FCC license, on the other hand, is required for permission to non-federal (i.e., commercial) entities to transmit from terrestrial or space radio stations. Other non-spectrum regulatory activities may influence spectrum authorizations and licensing. For example, the FAA issues licenses for commercial space launch and reentry activities to protect public health and safety, safety of property, and national security and foreign policy interests of the US consistent with its statutory authorities.

2.4.1 Active vs. Passive Services

Spectrum is also used by both active (transmitting and receiving) and passive (receive-only) services, both of which are utilized by NASA for its missions *(see Chapter 5)*. Examples of active or radiating services include radar and advanced wireless broadband applications. Receive-only or passive services do not radiate and examples include the EESS and Radio Astronomy Service (RAS).

At the World Radio Administrative Conference (WARC) in 1959 (a predecessor to the current WRC)[iii], the ITU accepted the idea of a "passive service." The WARC agreed the needs of radio astronomy and space science would be included in the international RR, including the Table of Frequency Allocations. The RAS was established.

- An Extraordinary Administrative Conference for space communications in 1963 revised the frequency allocation table laid down by the 1959 WARC, to provide frequency allocations for radionavigation-, meteorological- and communication-satellite services and for space research and radio astronomy.
- At the ITU's WARC for Space Telecommunications in 1971 (WARC-71), the EESS was established. Frequencies were allocated for the transmission of data from space to Earth in order to accommodate the needs of satellite programs that use sensors to obtain data about the Earth's environment.

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[i] One thousand hertz is referred to as a kilohertz (kHz), 1 million hertz as a megahertz (MHz), and 1 billion hertz as a gigahertz (GHz).

[ii] *See* NTIA Web site. http://www.ntia.doc.gov/book-page/regulating-use-spectrum.

[iii] For further explanation of WRC, see section 3.2.

Chapter 3

3. Domestic and International Spectrum Regulatory Environment

Chapter 3 Purpose: To provide an overview of the various domestic and international regulatory agencies involved in the management of RF spectrum.

Given the critical importance of radio frequency spectrum, governments participate in both international and national spectrum management policymaking bodies. NASA plays an active role in all these organizations.

3.1 National Spectrum Management – Dual Agency Management

In the US, two federal agencies have responsibilities for management of spectrum. For federal spectrum, NTIA is the lead authority. For non-federal spectrum, the FCC has regulatory purview. The Communications Act of 1934 divided authority over spectrum between the executive branch (federal uses) and the FCC (non-federal uses). Historically, the White House Office of Telecommunications Policy administered frequency assignments for federal uses. In 1977, this White House authority was delegated to the Commerce Department, through the Assistant Secretary who administers the NTIA.[i] As an independent agency, the FCC is under direct Congressional oversight.

The NTIA Organization Act stipulates that the Assistant Secretary's responsibilities include assigning frequencies to federal government users, establishing policies for spectrum assignment allocation and use, and providing departments and agencies with guidance "to assure that their conduct of telecommunications activities is consistent with these policies."

The NTIA and FCC are required to work together to ensure that spectrum policy decisions promote efficient use of the spectrum consistent with both US economic interests and national security requirements. NTIA can file comments on behalf of the Administration and as part of its role in managing use of federal spectrum in FCC proceedings. In such cases, it cites its role as the President's principal adviser on telecommunications policies. To accomplish these goals of economic benefits balanced with national security needs, the Chairperson of the FCC and the Assistant Secretary for Communications and Information, NTIA signed a Memorandum of Understanding (MOU) in January 2003 that formalized their long-standing cooperative relationship.

Under the MOU, the Chairperson of the FCC and the Assistant Secretary for Communications and Information agree to meet at least twice each calendar year to conduct joint spectrum planning. Further, they agree that their staffs will meet regularly to exchange information of mutual interest concerning spectrum management. Both agencies give notice to each other of all proposed actions that could potentially cause interference to operations authorized by the other. Final action by the either agency, however, does not require approval of the other.

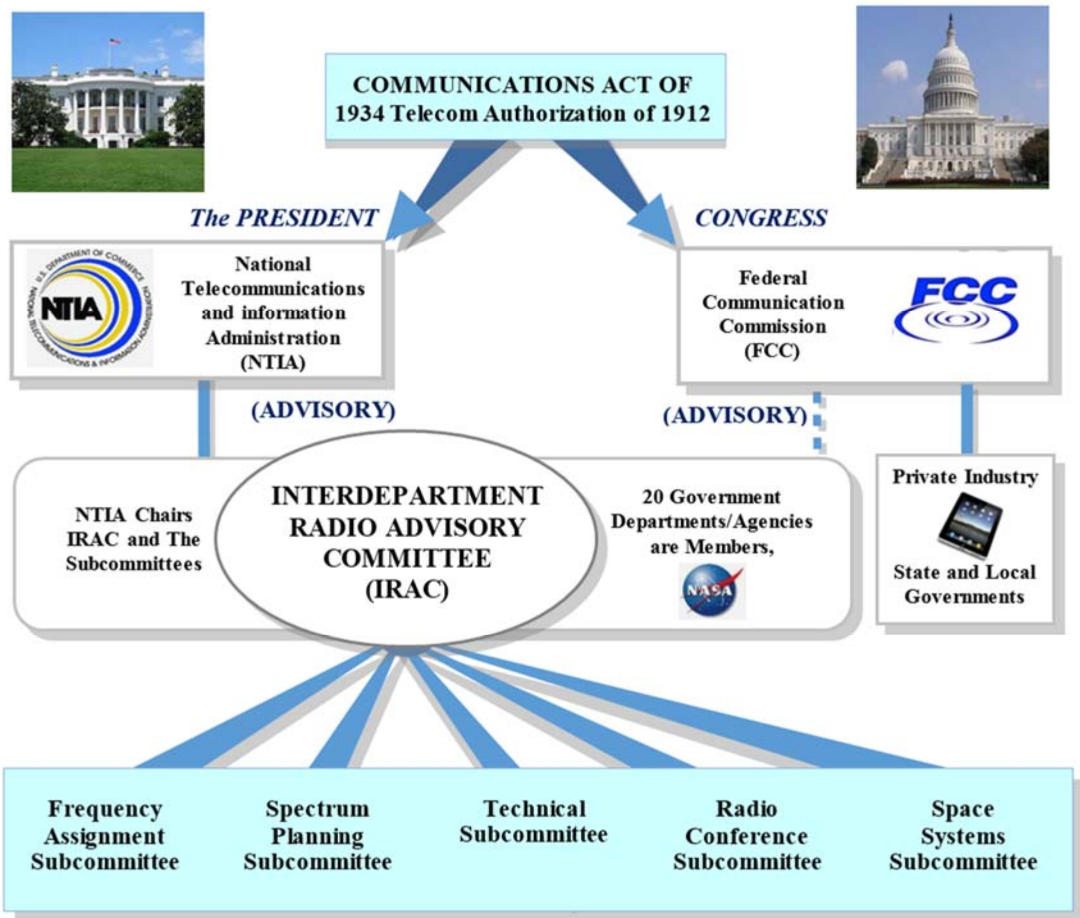

Figure 3.1: US Spectrum Management Process

The majority of all spectrum has been allocated for shared use between both federal government and non-federal government users, but both groups have exclusive access to some bands and federal spectrum is typically extensively shared among different government services and applications. Some shared bands allow significant interaction between government and non-government uses. For example, federal radio facilities allow private sector ships and aircraft to communicate and navigate. Federal law enforcement agencies communicate with their state and local government counterparts, and federal electrical power systems interconnect with non-federal power systems. The allocation plan changes to meet evolving domestic and international spectrum needs.

The dual management scheme used by the US to manage spectrum is different than most other countries, which typically have a single government agency perform the spectrum management function over both public and private sector uses. Both approaches have advantages and disadvantages. When a single agency manages spectrum, it is much easier for those countries to arrive at a unified national position. The dual management scheme makes arriving at a single position more challenging, but it ensures that private and government concerns are both considered. As the commercial potential of spectrum use is ever increasing, the kind of bifurcated system used in the US helps to ensure that decisions concerning commercial interests are balanced with their impact on government uses of spectrum. Similarly, decisions concerning government interests are made while taking into account commercial interests.

Further details on the various federal spectrum agencies and advisory groups are discussed below:

3.1.1 National Telecommunications and Information Administration (NTIA)

As the executive branch agency principally responsible for advising the President on telecommunications and information policies, NTIA also manages the day-to day federal use of spectrum in planning for spectrum uses and granting specific frequency assignments to agencies. It performs its spectrum management function through the Office of Spectrum Management (OSM). OSM establishes plans and policies that are intended to ensure the effective, efficient, and equitable use of spectrum. This includes public safety operations and the coordination and registration of federal government satellite networks. It also satisfies the specific frequency assignment needs of federal agencies and provides spectrum certification for new federal agency radio communication systems. The NTIA Manual of Regulations and Procedures for Federal Radio Frequency Management is the guidebook for frequency authorization to federal agencies in the US. The manual defines the information required for obtaining frequency authorization and provides the standards and guidelines for frequency use. NTIA seeks collaboration through several groups, discussed below.

Interdepartment Radio Advisory Committee (IRAC)**:** IRAC assists NTIA in assigning frequencies to US government radio stations and in developing policies, programs, procedures and technical criteria for allocation management and use of spectrum. This includes coordinating federal spectrum use and resolving interference conflicts among federal agencies. In addition to NASA, the following agencies are members of the IRAC: the Departments of Agriculture; Army; Air Force; Commerce; Energy; Health and Human Services; Homeland Security; Interior; Justice; Navy; State; Treasury and Veterans Affairs; the US Coast Guard; the FAA; the General Services Administration; the National Science Foundation; the Broadcasting Board of Governors; and the US Postal Service. The FCC is not a formal member but has a designated liaison representative. The NASA IRAC representative is the Deputy Director of Spectrum Policy.

NTIA reaches its decisions by using the consensus advice from the IRAC, NTIA staff technical and policy analyses, and, when appropriate, public input. This allows each agency to review proposals for new radio services and stations from other federal users (and non-federal users in bands where regulatory jurisdiction is shared by NTIA and the FCC) to determine if the new proposals will have an adverse impact on existing and planned operating systems. Affected users can then negotiate directly and develop a timely technical resolution to the potential problem.

Each government agency decides – on the basis of factors such as policies, rules, regulations, frequency allocations, and the availability of frequencies – whether, what, and how many mission requirements can be fulfilled by using telecommunications systems. Each agency makes the

necessary technical studies, selects potential frequencies, coordinates with other agencies involved, and prepares and files an application with NTIA's OSM's Spectrum Services Division (SSD), for consideration by the Frequency Assignment Subcommittee (FAS) of the IRAC.[ii]
Other key policy advisory groups include:

Policy and Plans Steering Group (PPSG): The NTIA's Assistant Secretary has a coordination process - in the form of the PPSG - to ensure that Federal matters are considered as part of policy decisions and to resolve policy disputes. The PPSG consists of the Assistant Secretaries, or equivalent, with spectrum management oversight in agencies that have major spectrum issues. The PPSG provides advice to NTIA's Assistant Secretary and helps resolve major contentious spectrum policy issues that affect the use of spectrum by federal and non-federal users. NASA's Director, Spectrum Policy and Planning Division serves as part of this group, which was created as part of a series of recommendations that arose from an Executive Memorandum signed in June 2003.

Commerce Spectrum Management Advisory Committee (CSMAC): The CSMAC consists of private sector spectrum experts who advise the Assistant Secretary, NTIA on a broad range of issues regarding spectrum policy, including many issues specific to federal government users, although agencies do not have representation on CSMAC outside of NTIA's own participation. The CSMAC is a federal advisory committee that has been in operation since 2006. In recent years, CSMAC has addressed issues ranging from potential user fees to sharing scenarios between federal and non-federal users as part of specific preparatory activities leading to the 2014 FCC Advanced Wireless Service (AWS)-3 auction.

3.1.2 Federal Communications Commission (FCC)

The FCC is directed by five commissioners, who are appointed by the President and are confirmed by the Senate for five-year terms. The President designates one of the Commissioners as Chairman (only three commissioners can belong to the same political party, so the party affiliation of the Chairman is always determined by which party is in control of the White House). FCC Commissioners make all regulatory decisions, except for those made on delegated authority at the agency's bureau-level. FCC rules and regulations (allocations/standards) governing non-federal spectrum are maintained in the Code of Federal Regulations.

NTIA works closely with the spectrum management components of the FCC, discussed below.

Office of Engineering and Technology (OET): The OET advises the FCC on technical and policy issues pertaining to both wireless and wireline proceedings. In cooperation with other organizations in the FCC, OET directs staff work with respect to general frequency allocation proceedings and other proceedings involving technical issues. In addition, OET prepares recommendations for legislation concerning technical issues, and reviews recommendations for rulemaking involving technical proposals that are initiated by other offices. OET serves as the primary contact point between the spectrum management activity of NTIA and the FCC by providing liaison with the IRAC for the Commission.

Wireless Telecommunications Bureau (WTB): The WTB handles the FCC's domestic wireless telecommunications programs and policies – except those involving satellite communications or broadcasting – including licensing and regulatory functions. The WTB is also responsible for implementing the FCC's statutory authority to assign spectrum licenses by competitive bidding.

International Bureau (IB): The IB serves as the focal point within the FCC for cooperation and consultation on international telecommunications matters with other federal agencies, international or foreign organizations, and appropriate regulatory bodies and officials of foreign governments. The IB develops, recommends, and administers policies, rules, and procedures for the authorization and regulation of international telecommunications facilities and services, including domestic and international satellite systems. The IB represents the FCC on international telecommunications matters at conferences and meetings, and directs and coordinates the FCC's preparation for such conferences and meetings. The IB also oversees the international coordination of spectrum allocations and specific frequency and orbital assignments.

Enforcement Bureau (EB): The EB is the primary unit within the FCC responsible for enforcement of provisions of the Communications Act, the FCC rules, FCC orders, and the terms and conditions of station licenses. The EB investigates alleged violations of the FCC's technical, operational, and competitive rules, and recommends or issues appropriate enforcement actions.

3.1.3 NASA Engagement with other Domestic Entities Concerned with Space Sciences Spectrum

SPACE-BASED POSITIONING NAVIGATION & TIMING NATIONAL EXECUTIVE COMMITTEE

NASA participates in the Space-based Positioning, Navigation and Timing Executive Committee (PNT EXCOM). Space based PNT EXCOM covers GPS, GPS augmentation and other global navigation satellite systems. The National Committee is chaired by the Deputy Secretaries of Defense and Transportation. The membership includes top leaders for the Departments of State; Interior; Agriculture; Commerce; Homeland Security; the Joint Chiefs of Staff; and NASA. The PNT EXCOM has addressed timely policy issues as national regulatory decisions increasingly have created new challenges for GPS operations. Recent regulatory issues addressed by the PNT EXCOM that have had high visibility have included inputs to the FCC's LightSquared regulatory proceeding.

3.2 International Spectrum Management

US activities regarding international spectrum management are carried out under the leadership of the DoS. The DoS is involved in all international aspects of spectrum management including bilateral discussions with neighboring countries about operations of radio systems near the borders. Its role is to ensure that the US speaks with one voice and that all applicable precedents and treaties are followed

International regulation and coordination of spectrum use occurs through the ITU, in compliance with a set of international rules and regulations. The DoS, along with NTIA and the FCC, oversees US preparations for meetings of the ITU.

3.2.1 International Telecommunication Union (ITU)

The ITU was founded in 1865, and since 1947, it has been the UN's agency for matters dealing with information and communications technology (*see Figure 3.2*). Within the ITU, the ITU-R carries out activities concerning radio communications and spectrum management. The ITU publishes the international RR, which are the recognized framework for the use of the spectrum and have treaty status. ITU member nations generally develop national spectrum management regulations consistent with the RR. The ITU publishes the RR as agreed at WRCs (states remain sovereign and may operate systems in derogation of the RR, provided they do not cause and are willing to accept interference. Such national exceptions are usually listed in footnotes to the RR).

Four of the ITU-R organizations affect spectrum and spectrum management:

WRC*:* The WRC meetings occur periodically, about every four years. Each WRC has a specific agenda associated with specific radiocommunication services and updates the international RR, which include the allocations of spectrum to the various radio services. These allocations have worldwide effect except where regional or national requirements differ and regional members agree to these differences.

Radio Regulations Board (RRB): The RRB approves the Rules of Procedure used by the Radiocommunication Bureau (BR) to register frequency assignments. It addresses matters referred by the BR that cannot be resolved by reference to the Radio Regulations or to the Rules of Procedure. It adjudicates interference conflicts among member nations.

BR*:* The BR operates under the Rules of Procedure established by the RRB to achieve an orderly recording and registration of frequency assignments, and, when necessary, the associated orbital characteristics of satellites. It maintains the Master International Frequency Register. It also advises member nations and the RRB on technical matters of interference and spectrum use.

Radiocommunication Study Group (SGs)*:* The SGs evaluate a variety of questions relating to radiocommunication issues. The focus of their work is on the use of spectrum in terrestrial and space communications, the characteristics and performance of radio systems, the operation of radio stations, and the radiocommunication aspects of distress and safety matters. Currently there are six study groups, each of which is divided into permanent working parties.

3.2.2 US Engagement in the ITU Process

While the DoS has responsibility for all international negotiations concerning international spectrum usage, both NTIA and the FCC advise the DoS in this role. Each agency has responsibility to seek assurance that the multi-year preparatory effort for the WRC meets US needs and is supported by the best technical information available.

The international negotiation process occurs in cycles that match the occurrence of each WRC. Each WRC proposes Agenda Items (AIs) for the next WRC. These lead to a list of issues that must be resolved and proposals that must be generated. The US begins the WRC cycle by operating within a well-defined advisory committee process that precedes establishment of the US delegation and appointment of a head of delegation. Meetings are conducted throughout the cycle to prepare US positions and strategy. Negotiations are held in bilateral, multilateral, and regional conferences to garner support for US positions. US delegations to these conferences are comprised, for the most part, of those who have participated in the multi-year process that prepared the US proposals and supporting material. These individuals include career government professionals who are experienced in this type of negotiation and private sector individuals with extensive technical expertise who have participated in the preparatory process and past conferences.

- NASA, as well as other federal agencies, submits proposals to the IRAC Radio Conference Subcommittee (RCS). Upon approval within the RCS, proposals are then coordinated with an FCC WRC Advisory Committee for acceptance by the private sector. In a similar fashion, private sector proposals are coordinated through the RCS for approval by the federal sector. Proposals are ultimately reconciled between the FCC and NTIA before going to the US DoS for submission to the conferences.
- In general, technical studies of current interest are supplied to the US Study Group or appropriate Working Party by member agencies.
- When approved by the Study Group or Working Party, they are forwarded to the National Committee of the US DoS's International Telecommunications Advisory Committee for the Radiocommunication Sector for national policy review prior to being submitted to the ITU-R Radiocommunication Assemblies, Study Groups, Working Parties, or item specific Task Groups.
- The results of these studies provide the technical bases for Radiocommunication Conferences.

Significant technical interests for NASA are in the ITU-R Study Group concerned with the space science services, Study Group 7 and its Working Parties 7A, 7B, 7C, and 7D, which support federal and commercial space programs. In addition to the space sciences services, NASA also contributes to the work of Study Group 1 (Spectrum Management), Study Group 3 (Radiowave Propagation), Study Group 4 (Satellite Service), Study Group 5 (Terrestrial Services), and Study Group 6 (Broadcasting Services). These efforts occur to assist the commercial industry in better meeting the long-term communications requirements of NASA, as well as to protect and promote NASA use of the spectrum.

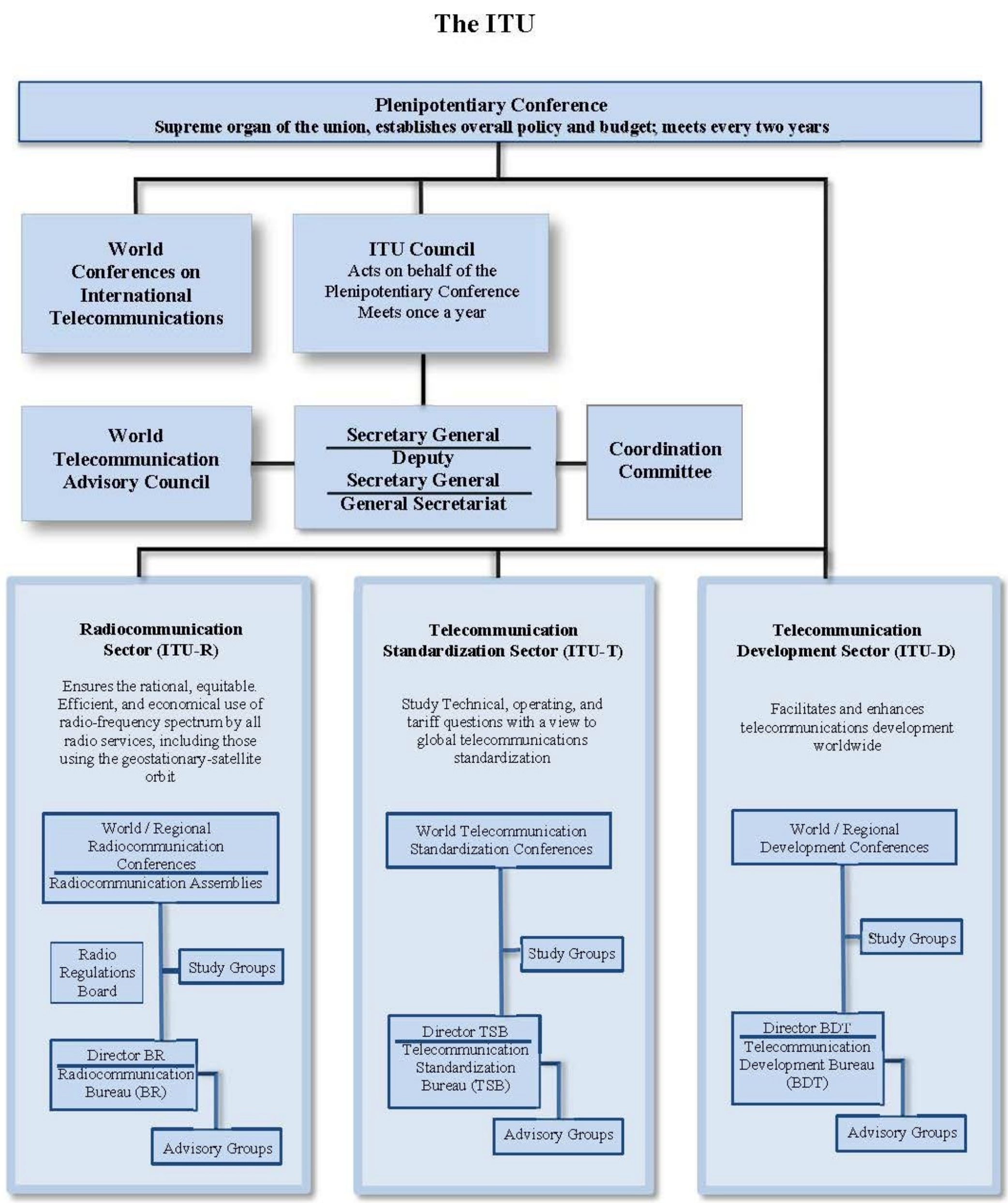

Figure 3.2: ITU Structure

3.2.3 International Spectrum Issues and NASA Equities

NASA must maintain a steady awareness of developments in the international arena. The primary venue of concern is the ITU where the international rules and regulations for use of the radio spectrum are developed.

In preparation for WRCs, NASA participates in both domestic and international forums, providing technical studies necessary to promote and protect operations in the space science services. It also participates in bilateral and multilateral discussions, such as in meetings convened by the CITEL.

As with domestic spectrum policy trends, WRC issues in recent conference cycles have faced pressures relating to the dynamic tension between public sector users and commercial mobile wireless providers around the globe. In early 2012, the ITU-R embarked on a program to develop "IMT for 2020 and beyond". In 2015, the ITU-R finalized its vision of the "5G" mobile broadband connected society. This view of the horizon for the future of mobile technology was considered at WRC-15. At WRC-19, further deliberations on additional spectrum to support the future growth of IMT will take place. The entire process is planned to be completed by 2020 when draft new ITU-R Recommendations detailing specifications for the new radio interfaces are expected to be submitted for approval within ITU-R. Attachments B and C provide some details regarding WRC-15 and WRC-19, respectively.

NASA has been historically successful in obtaining AIs for consideration at WRCs in support of NASA's changing mission requirements and in reflection of NASA spectrum policy directions. NASA continues to be vigilant in protecting existing spectrum provisions from proposals that could affect its existing and planned operations.

3.2.4 NASA Engagement with Other International Entities Concerned with Space Sciences Spectrum

NASA's responsibilities include informally regulating and overseeing (together with its partner space agencies) the spectrum allocations that have been made to the space science services by the ITU. In addition to meeting regularly with international counterparts such as the European Space Agency (ESA) and the Space Agency of Japan (JAXA), NASA leads the Space Frequency Coordination Group (SFCG) and the Interagency Operations Advisory Group (IOAG). These are organizations of space agencies that make agreements and provide recommendations about how best to use allocated frequency bands, and how to provide cross-support for each other's missions. NASA also participates in activities of Inter-American Telecommunicaiton Commission (CITEL), an entity within the Organization of American States (OAS), which coordinate telecommunications matters in the hemisphere. Participation by NASA in the SFCG and CITEL is especially important because at ITU conferences, the SFCG provides a unified position from space sciences interests and CITEL provides a unified position from countries of the hemisphere.

NASA is also the leader of the Consultative Committee for Space Data Systems (CCSDS); another world-wide group of space agencies that develop and promulgate standards for space hardware and software, for example, for spectrum efficient modulation techniques, that improve spectrum efficiency.

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[i] The NTIA Organization Act directs the Commerce Secretary to assign to the Assistant Secretary and the NTIA the responsibility for the performance of the Secretary's communications and information functions. These functions were transferred to the Assistant Secretary of Commerce for Communications and Information (Administrator,

NTIA) by Department of Commerce Organization Order 10-10 of Oct. 5, 1992. This authority and delegation has been codified in the NTIA Organization Act, Pub. L. No. 102-538, 106 Stat. 3533 (1992) (codified at 47 U.S.C. 901 et seq.)

[ii] The OSM/SSD, using a combination of computer and manual procedures, reviews the applications for accuracy, completeness, and compliance with regulations and procedures. FAS agendas are distributed to each FAS member agency for study regarding the protection of their existing assignments. OSM/SSD reviews the agendas to ensure adequate justification, compliance with policy and regulations, technical appropriateness, potential for major problems, whether or not spectrum support for the system, if applicable, has been certified by the Spectrum Planning Subcommittee, and whether there is a conflict with the assignments of the FAS non-member agencies. Each month the FAS considers pending items and takes action within established policy guidelines.

Chapter 4

4. NASA Spectrum Organization and Management

Chapter 4 Purpose: To provide an overview of the NASA spectrum organization and its process for securing spectrum for mission requirements.

This chapter describes the NASA organizations that manage the Agency's use of the electromagnetic spectrum and the general processes that are involved in securing NASA's access to spectrum for all missions using space-based and ground-based assets. The NASA Spectrum Management Program ensures that all NASA activities comply with national and international rules and regulations applicable to use of the electromagnetic spectrum and facilitates securing spectrum and orbital resources (both domestically and internationally) needed to enable aeronautical and space mission requirements.

Per NASA Policy Directive (NPD) 2570.5 and NASA Process Requirements (NPR) 2570.1, it is NASA policy that any NASA system that requires use of the electromagnetic spectrum for transmission, reception or both shall follow the spectrum regulatory rules and processes. NASA has a comprehensive procedural requirements document, NPR 2570.1 that provides step-by-step guidance to all programs, projects and activities on the process of obtaining spectrum access.
In addition, the requirement for NASA's spectrum management activities is codified in federal law, including the Communications Act of 1934, as amended, the Communications Satellite Act of 1952, the Commercialization of Space Act of 1983 and National Space Policy.

4.1 NASA Spectrum Organization

Agency spectrum management responsibilities reside in the SCaN program office, as delegated from the Associate Administrator, HEOMD, the NASA Spectrum Manager.

SCaN's Deputy Associate Administrator oversees the overall planning, policy development, and administration of the NASA Spectrum Management Program *(see Figure 4.1)*.

The Director of Spectrum Policy and Planning oversees NASA's activities to obtain adequate international and national allocations of frequency bands, to pursue coordination of proposed NASA frequency use with other domestic and foreign users of the frequencies, and to obtain approval of frequency assignments to NASA by NTIA. The Director is also responsible for the planning of long-term national and international spectrum management initiatives aimed at improving the spectrum environment for NASA, including maintaining long-range spectrum forecasts to identify needed spectrum management initiatives. These forecast demands are, in turn, driven by the projected launch dates of planned missions and other spectrum needs.

The National and International Spectrum Program Managers are responsible for the implementation of spectrum management initiatives and for day-to-day spectrum management activities. They represent NASA in national and international fora, including committees and working groups responsible for developing frequency allocations and associated technical and procedural rules. They maintain records of NASA frequency usage and track NASA's efforts toward coordination and approval of proposed frequency usage. They also draft policy proposals and recommendations for consideration by national and international regulatory bodies, such as for the IRAC and ITU.

Center Spectrum Managers have the responsibility to provide the latest communications requirements regarding implementation of projects and missions at the Center to the National and International Spectrum Program Managers. The National Spectrum Program Manager, in consultation with each Center Spectrum Manager and the International Spectrum Program Manager, provides an assessment of these spectrum requirements and the actions needed to fulfill them. The Center Spectrum Manager of the originating project is responsible for obtaining an approved frequency assignment(s) and has the overall responsibility for spectrum at the execution site. Each spectrum user within NASA is responsible for contacting his or her Center's Spectrum Manager during the earliest phase of a planned project to convey its spectrum requirements.

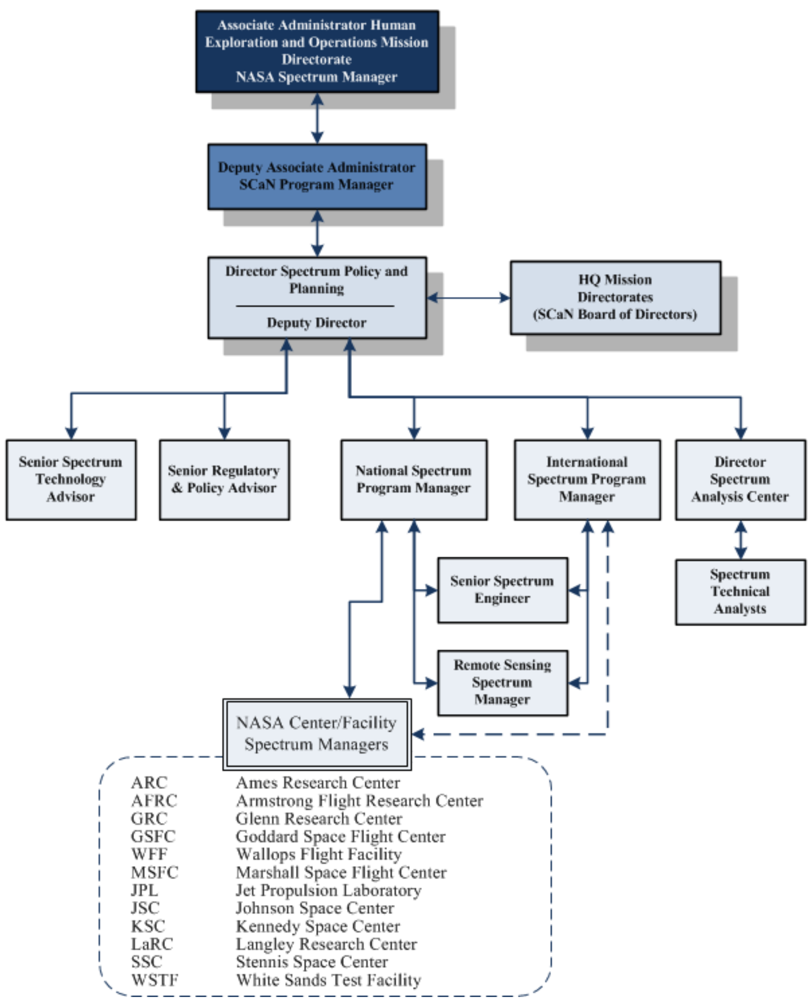

Figure 4.1: NASA Spectrum Management Organization

4.2 NASA Frequency Allocation and Assignment Process and Procedures

NASA has adopted procedures for requesting frequency assignments and obtaining new frequency allocations in order to effectively implement national and international spectrum management policy. These procedures allow for a thorough, coordinated process from identification of Agency program/project needs to national and international recognition of actual frequency band usage and are outlined in the NPR 2570.1.

4.2.1 Frequency Allocations

In almost all cases, identification of spectrum support for NASA needs is focused on frequency bands currently allocated nationally and internationally for the particular radio service for which the Agency requires support. This includes both terrestrial use (e.g. fixed, mobile, radiolocation, radionavigation and other terrestrial radio service allocations) and space use (e.g., space radio service allocations that support the US space programs).

When selecting operating frequencies, NASA must adhere to the National Table of Frequency Allocations published in the NTIA Manual and adhere to the standards and recommendations for spectrum use established by ITU and SFCG.

Some terrestrial systems operated by NASA may be classified as major telecommunications systems. These are systems which, even though spectrum allocations currently exist, are required to be submitted to NTIA for certification of spectrum support, because they have large bandwidth requirements, new modulation techniques, novel applications, or are considered to have a significant impact on the existing electromagnetic environment. For these, NTIA has established a systems review process, for the purpose of certification of spectrum support, by which that use is coordinated within the US and internationally.

Further, the use of a frequency that has been allocated to two or more services or is used by multiple federal government agencies often requires coordination with the other affected agencies. This coordination is handled *unofficially* prior to a formal frequency authorization request in order to address any interference concerns and to avoid any resulting delays in spectrum certification.

However, when policymakers make decisions to reallocate certain bands of spectrum to different uses, or from federal to non-federal allocations, it may be necessary to relocate Agency operations elsewhere in the spectrum where appropriate allocations do not currently exist. Requirements to seek access to different spectrum also may arise when current bands used by NASA become congested as new scientific, technological, and commercial requirements emerge and take up additional capacity. As part of long-range planning for new systems, NASA also may seek access to bands that require allocation changes, as current bands used by federal space operations on a primary or a secondary basis become increasingly congested from other services and applications whose spectrum requirements are also growing. In such cases, the identification of the need for a new allocation may be made by reference to the Table of Frequency Allocations or as a result of the systems review process, which includes a study of current frequency band occupancy.

An example of this need for a new allocation occurred in recent years regarding Ka-band spectrum. As the spectrum used for communications links between ground stations and spacecraft in S-band and X-band became more heavily used and congested, NASA realized that spectrum at Ka-band might be required to accommodate communications for future missions. Spectrum for an uplink was needed to complement spectrum already allocated for space-to-Earth transmissions. NASA was successful at WRC-12 in achieving a new allocation at 22.55-23.15 GHz to complement spectrum at 25.5-27.0 GHz.

In cases where new frequency allocations are deemed necessary, it is imperative that very long-lead-times (i.e., ten years or longer) be allowed for the national and international processes which are required for new allocations. WRCs review, and if necessary, revise the RR. Since WRCs are conducted on a periodic basis (i.e., normally every three-four years), it is essential that NASA is prepared to identify new requirements well in advance of these conferences, so that supporting technical and regulatory information can be prepared and presented. NASA can seek to influence WRC outcomes, but only as part of the US governmental preparatory process. NASA promotes its position within the US delegation, which is comprised of other US federal agencies, non-governmental entities and commercial/private companies. The delegation meets regularly and refines its position. Key members of the US delegation also attend preparatory meetings with other countries and other regional bodies to share their preliminary thoughts on AIs before the WRC. As mentioned earlier, each nation is sovereign, and the US seeks to incorporate WRC decisions into its National Table of Frequency Allocations.

4.2.2 Frequency Assignments

All Center activities are assigned frequencies by NTIA through the NASA IRAC FAS representative. The NASA FAS representative forwards these assignments to the appropriate Center Spectrum Manager upon completion of the frequency coordination process. The NASA FAS representative also informs the National Spectrum Program Manager when the assignment has been approved by NTIA. Based on this authorization, Center Spectrum Managers may issue Center RF Authorizations (RFA).

The frequency assignment process *(see Figure 4.2)* is initiated at the user NASA center/facility and results in the issuance by NTIA of an RFA or Special Temporary Authorization (STA). If the use is not for a major terrestrial program or not for frequencies to be used for transmissions to and from space, the frequency assignment process is fairly simple.

NASA has a specified step-by-step process to guide the process for both terrestrial and space assignments, which is outlined in the NPR 2570.1 *(see Attachment A)*. For a *federal system*, the frequency authorization process is well defined by NASA procedures. For *non-federal designated systems* affiliated with or supported by NASA, the non-NASA owner and/or operator of the satellite and electromagnetic spectrum systems must obtain spectrum licensing through the appropriate FCC process.

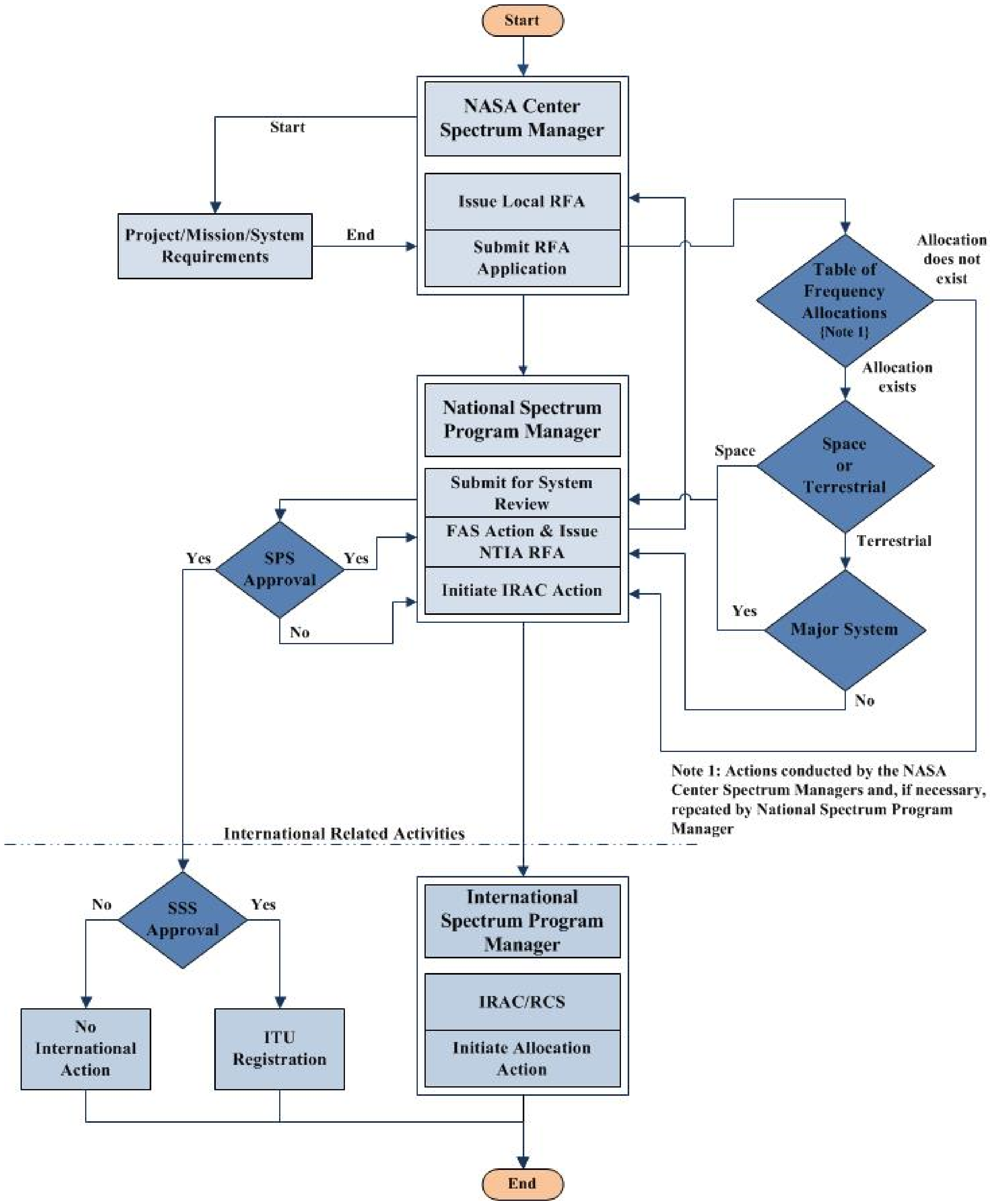

Figure 4.2: Frequency Authorization Process

Chapter 5

5. NASA Spectrum Use

Chapter 5 Purpose: To provide an overview of NASA spectrum utilization that conveys the diversity of its operations and associated spectrum requirements.

NASA's needs for radio frequency spectrum have evolved and grown over the decades and include a wide array of programs and applications. NASA conducts missions encompassing space exploration, Earth science, basic scientific research, and technology development. Virtually every one of these endeavors requires use of the radio spectrum.

NASA's requirements for access to the radio spectrum are unique. There are no alternatives available to the Agency to command its complex spacecraft, since any use of landlines is impossible. NASA missions may operate at great distances from the earth, resulting in the need to receive and process very weak signals from spacecraft and to transmit commands with very high power to reach spacecraft. These missions employ both passive and active instruments operating at various frequencies to measure data from the Earth, planets, Sun and other phenomena.

5.1 Overview

NASA's investigations of the universe are accomplished mainly through the use of unmanned automated spacecraft. Missions require highly reliable communications, often over long periods of time and at great distances, to guide and control the spacecraft and to bring back the images and new scientific data they collect. Because many deep-space missions continue for periods of several years, and because there are usually several missions in progress at the same time, there is a corresponding need to provide for communication with several spacecraft at any given time.
NASA's spacecraft must be tracked and controlled; the health, condition and safety of the spacecraft must be monitored; and the scientific data that is obtained must be transmitted to mission operators. Channels are needed for robust, low data rate communications designed for critical TT&C and, in the case of crewed spacecraft, for voice services. Still other channels are needed for high data rate communications for transmission of scientific or payload data.
To satisfy its communications needs, NASA operates a sophisticated global infrastructure, consisting of several component networks:

- The DSN is used to support scientific spacecraft; it provides coverage from LEO to the edge of the solar system.
- The SN provides tracking and data relay for spacecraft, satellites, and expendable launch vehicles using space and ground segments. It includes the TDRS, which are communications satellites in geostationary orbit used to relay data from spacecraft to fixed ground locations. The satellite relays provide continuous global coverage of Earth orbits from equatorial to highly inclined orbits.

- The NEN consists of ground stations owned by NASA, commercial entities, and other partners that providing communications and tracking services to missions operating in the near earth region. Most of the EESS-related missions use this network.

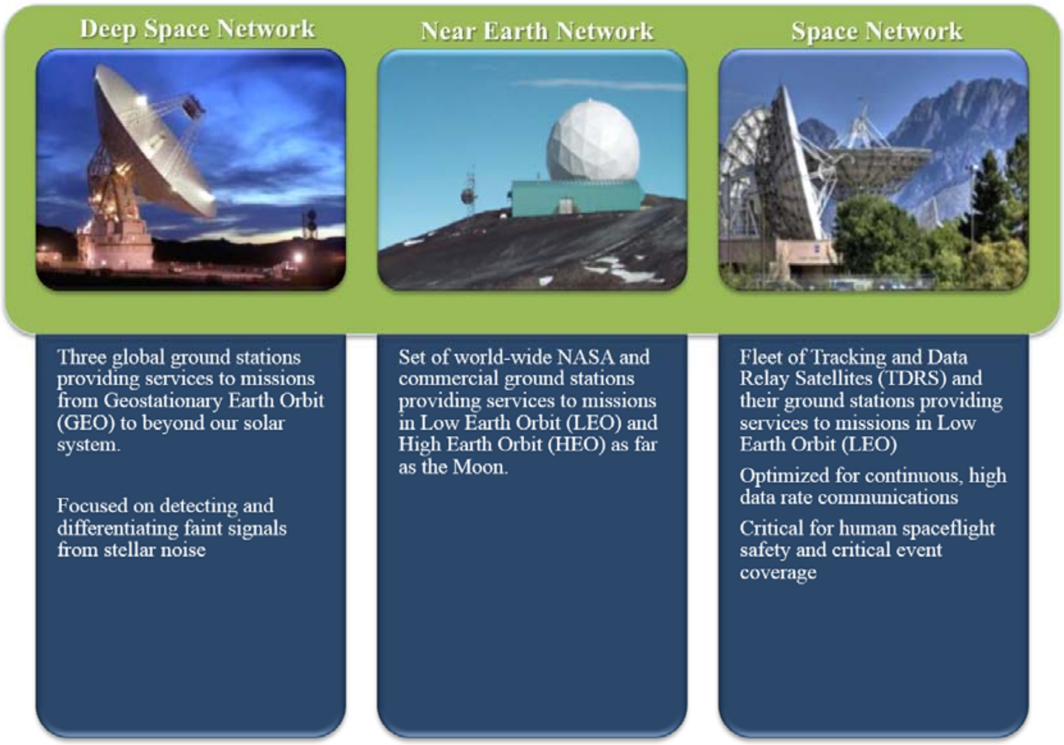

Figure 5.1: NASA Communications Networks

In order to support the intermediate and long term goals of understanding the Earth, NASA has developed numerous radio sensors designed to fly onboard spacecraft. These sensors may be passive or active in operation. Passive sensors measure the natural emissions of the Earth's and atmospheric constituents at particular frequencies or frequency ranges in order to provide a description of the Earth's environment. These sensors are particularly prone to RF interference from other emitters and, if possible, need exclusive allocations in bands of critical importance. Active sensors are spaceborne radars that can provide information on the geological structure of the Earth and the state of and movement of Earth's oceans. These sensors use spectrum allocated to the EESS.

In most cases, identification of RF spectrum support for Agency needs is focused on frequency bands currently allocated nationally and internationally for the particular radio service for which NASA requires support. This includes both space use (in spectrum allocated to space science services) and terrestrial use (in fixed and mobile service allocations). However, in some cases, particularly as new scientific, technological or commercial requirements emerge or as bands become congested, it may be necessary to consider implementing Agency operations elsewhere in the RF spectrum where appropriate service allocations do not currently exist.

5.2 Earth Science

Earth Science research at NASA has turned space-based observing technology and scientific expertise to use for the study of our home planet. Planet Earth is an integrated system of land, ocean, atmosphere, ice, and biological processes. The lives of people everywhere on Earth are affected by environmental conditions of the land, the oceans, and the atmosphere. Spaceborne sensors are the only tools that can provide environmental data repetitively on a global scale. From the vantage point of space, we are beginning to understand how environmental processes work and how they interact.

EESS sensors utilize several frequencies driven by the physics involved but observed everywhere on the Earth's surface or in its atmosphere (this is unlike the RAS, which, in the extreme, would like to observe the spectrum from direct current to gamma rays but only from a few geographical locations, e.g. an observatory on a mountain top). These EESS sensors allow global "pictures" to be taken of the Earth on a daily basis in a wide range of frequencies. Use of the passive and active microwave sensors removes the need for sunlight and permits penetration of clouds, thus providing nighttime as well as all-weather coverage. These sensors can measure: temperature, humidity, cloud, and trace gas profiles; surface soil moisture; ocean and estuarian salinity; sea-surface temperature; land-surface roughness and biomass; ocean surface wave height and sea state; and the moisture content and melt character of ice and snow. Snow and ice-covered areas and bodies of water can be mapped under all weather conditions and at various penetration depths.

The passive observations of the EESS require significant bandwidth to achieve measurable signal levels. EESS passive observations can be divided into two categories, observations around specific absorption bands (at lower frequencies, primarily atmospheric water lines and oxygen lines) and measurements of geophysical parameters requiring simultaneous observations from many bands.

Passive observations around the water lines yield the profile of water in the atmosphere as a function of altitude, while observations around the oxygen lines yield the temperature profile of the atmosphere. Although a single observation may not be critical in itself, when combined with other such observations they are used to produce modern weather forecasts. The forecasting programs constantly update and fine-tune the resulting forecasts by assimilating real-time, or near real-time data. Substantial improvements have been made in such forecasts by the addition of satellite microwave observations of the atmosphere, particularly in the southern hemisphere where other observations had been fewer and farther between.

Other passive observations yield geophysical parameters such as vegetation biomass, soil moisture, surface roughness, cloud liquid water, and integrated water content over the land and salinity, wind speed, sea surface temperature, water vapor, and liquid clouds over the oceans. However, these parameters frequently appear in combination with most, if not all, of the others. This situation requires multiple observations at different frequencies to resolve the individual components. Rarely is one parameter predominant and able to be measured with adequate accuracy using only one or two bands.

Regulatory agencies have recognized the need for protecting passive bands. The ITU frequency allocation table states that no station shall be authorized to transmit in the following bands: 1400-1427 MHz, 2690-2700 MHz, 10.68-10.7 GHz, 15.35-15.4 GHz, 23.6-24 GHz, 31.3-31.5 GHz, 31.5-31.8 GHz (in Region 2), 50.2-50.4 GHz, 52.6-54.25 GHz, 86-92 GHz, 100-102 GHz, 109.5-111.8 GHz, 114.25-116 GHz, 148.5-151.5 GHz, 164-167 GHz, 182-185 GHz, 190-191.8 GHz, 200-209 GHz, 226-231.5 GHz, and 250-252 GHz.

RFs are formally allocated up to 275 GHz. However, the ITU recognizes that some higher frequencies are of interest to the EESS, RAS, and SRS. Passive bands between 275 GHz and 1000 GHz have been identified and are listed in the RR. The use by passive services in these bands does not preclude the use of active services, and all frequencies in the range 1000-3000 GHz may be used by both active and passive services.

Active measurements take many forms. A Synthetic Aperture Radar (SAR) uses the Doppler shift in the return signal to substitute for one dimension of the antenna, and the full two-dimensional aperture is synthesized computationally. An SAR produces images of the rain and terrain below and to the side of the spacecraft, depending upon the frequency used. Lower frequencies (typically below 10 GHz) penetrate rain and vegetation, while higher frequencies are used to measure rain and cloud parameters. SAR images of the same terrain taken from two locations can be used to produce topographic maps. SAR images taken from the same location but at different times can be combined (as both the amplitude and phase of the return signal are recorded) to produce interferograms, which map the surface movement associated with earthquakes, landslides, and volcanoes. This technique, called interferometric SAR, can measure sub-centimeter ground movement at distances of over 700 kilometers. Another technique, called scatterometry, uses variations in the return signal as a function of azimuth to resolve the speed and direction of sea surface winds. Satellite-borne altimeters are used to monitor sea surface heights, which can be used to forecast upcoming El Niño/La Niña conditions. Precipitation radars (typically around 13 GHz) determine the rainfall rate over the Earth's surface and the three-dimensional structure of the rainfall. Cloud profile radars (~94 GHz) measure the cloud reflectivity profile.

In addition to their use of spectrum for sensors, the Earth science missions also use spectrum for tracking, guidance of spacecraft, monitoring of spacecraft "health", and control of instrumentation. The data collected by sensors is transmitted by radio links to facilities on Earth, either directly or through relay satellites. The radio spectrum utilized for this purpose is primarily in the vicinity of 2 GHz (S-band) for low-rate data and 7/8 GHz (X-band) for high-rate data.

Recent missions contributing to Earth Science are the Orbiting Carbon Observatory-2 (OCO-2) and SMAP. OCO-2 is NASA's first Earth remote sensing satellite dedicated to study atmospheric carbon dioxide from Space. OCO-2 collects global measurements of atmospheric CO_2 with the precision, resolution, and coverage needed to characterize its sources and will also be able to quantify CO_2 variability over the seasonal cycles year after year. SMAP data have both high science value and high applications value. The accuracy, resolution, and global coverage of SMAP soil moisture and freeze/thaw measurements will be invaluable across many science and applications disciplines including hydrology, climate, carbon cycle, and the meteorological, environmental and ecology applications communities. Current climate models' uncertainties result in disagreement on whether there will be more or less water regionally compared to today; however, SMAP data will enable climate models to be brought into agreement on future trends in water resource availability. SMAP contains both an active sensor SAR operating at 1.26 GHz and a passive sensor radiometer operating at 1.41 GHz.

In addition, NASA provides complete satellites and their instruments to the US Geological Survey to monitor the Earth's surface with their Land Remote Sensing Satellite series and to the NOAA to monitor weather with their geosynchronous satellites (GOES series) and low Earth orbiting series. These missions monitor the Earth's environment for operational purposes, rather than the research orientation of NASA.

5.3 Space Science

NASA's space science missions are intended to examine the mysteries of the universe from origins to destiny, to explore the solar system, to discover planets around other stars, to search for life beyond Earth and to chart the evolution of the universe and understand its galaxies, stars, planets, and life. Active and passive remote sensing of the Moon and other planetary bodies is performed in the SRS. NASA's scientific investigation of the solar system is being accomplished mainly through the use of unmanned automated spacecraft. These spacecraft have created a virtual human presence in the solar system, exploring new territories and investigating the solar system in all its complexity. NASA has also sent probes into interstellar space, beginning a human presence even beyond the solar system. NASA is probing the universe to the beginning of time, looking ever deeper with increasingly capable telescopes.

Space science missions require highly reliable communications, and in turn spectrum access, often over long periods of time and great distances. The large distances involved in deep-space research result in a need for high power transmitters and very sensitive receivers at Earth stations that communicate with the spacecraft. Spectrum to support deep space research specifically has been allocated in S-band at 2110-2120 MHz (Earth-to-space) and 2290-2300 MHz (space-to-Earth). Because many deep-space missions continue for periods of several years, and because there are usually several missions in progress at the same time, there is a corresponding need for communication with several spacecraft at any given time. Coverage of simultaneous missions requires nearly continuous usage of RF bands allocated for space research communication.

Many are familiar with NASA's space science efforts through images received from the Hubble Space Telescope. Hubble is the largest optical telescope to be placed in space to date, and is the first science mission designed to be repaired and upgraded while in orbit. Above the distortion of the atmosphere, far above rain clouds and light pollution, it has an unobstructed view of the universe. Scientists have used Hubble to observe the most distant stars and galaxies as well as the planets in our solar system. It has made more than one million observations since its mission began in 1990; and as of Hubble's 24th anniversary in April 2014, Hubble observations have produced more than 100 terabytes of data. Since January 2013, the Hubble has generated 844 gigabytes of data per month.

The James Webb Space Telescope, planned for later in the decade, will be the premier observatory of the next decade, serving thousands of astronomers worldwide. Webb will be located at the second Lagrange point, about a million miles from the Earth. It will study every phase in the history of our Universe, ranging from the first luminous glows after the Big Bang, to the formation of solar systems capable of supporting life on planets like Earth, to the evolution of our own Solar System.

The Solar Dynamics Observatory (SDO) is taking a close look at the Sun, the source of all space weather. Space weather affects not only our lives here on Earth, but the Earth itself, and everything outside its atmosphere (astronauts and satellites out in space and even the other planets). SDO will help us understand where the Sun's energy comes from, how the inside of the Sun works, and how energy is stored and released in the Sun's atmosphere. SDO produces enough data to fill a single compact disc every 36 seconds. SDO has no recording system but sends all of its date, in real time, directly to its own ground station in New Mexico.

5.4 Human Space Exploration

NASA seeks to open the frontiers of space by human exploration, enabling the development of operations in space and expanding the human experience into the far reaches of the solar system. In exploring space, NASA has brought together a wide range of technologies, machines and people in the development of such programs as the STS and the ISS. NASA now has even more ambitious goals in sight. NASA is developing the capabilities needed to send humans to an asteroid by 2025 and Mars in the 2030s – goals outlined in the NASA Authorization Act of 2010 and in the US National Space Policy, also issued in 2010. A fleet of robotic spacecraft and rovers already are on and around Mars, paving the way for future human explorers. While robotic explorers have studied Mars for more than 40 years, NASA's path for the human exploration of Mars begins in LEO aboard the ISS. Astronauts on the orbiting laboratory are helping to prove many of the technologies and communications systems needed for human missions to deep space, including Mars.

NASA is building a new spacecraft that will usher in the new era of space exploration. The Orion spacecraft is designed to meet the evolving needs of our nation's deep space exploration program for decades to come. It will be the safest, most advanced spacecraft ever built, and it will be flexible and capable enough to take astronauts to a variety of destinations. Orion will utilize advances in propulsion, communications, life support, structural design, navigation and power. Its unique life support, propulsion, thermal protection and avionics systems will enable extended duration deep space missions. With destinations including near-Earth asteroids, our own Moon, the moons of Mars and eventually Mars itself, Orion will carry astronauts into a new era of exploration.

The next step will be to deep space, where NASA will send a robotic mission to capture and redirect an asteroid to orbit the moon. Astronauts aboard the Orion spacecraft will explore the asteroid in the 2020s, returning to Earth with samples. This experience in human spaceflight beyond LEO will help NASA test new systems and capabilities, such as Solar Electric Propulsion, which will be needed to send cargo as part of human missions to Mars.

Beginning in 2017, NASA's Space Launch System (SLS) rocket will enable "proving ground" missions to test new capabilities. Human missions to Mars will rely on Orion and an evolved version of SLS that will be the most powerful launch vehicle ever flown. SLS will be the most powerful rocket in history and is designed to be flexible and evolvable, to meet a variety of crew and cargo mission needs. SLS will launch astronauts in the Agency's Orion spacecraft on missions to an asteroid and eventually to Mars, while opening new possibilities for other payloads including robotic scientific missions to places like Mars, Saturn and Jupiter.

As NASA sets its sights on exploring beyond LEO, the ability of the private sector to provide routine access to space and the ISS is of vital importance. NASA's Commercial Orbital Transportation Services (COTS) program was the catalyst for this expanding new industry. Under COTS, NASA helped commercial partners develop and demonstrate their own cargo space transportation capabilities to serve the US government and other potential customers. Two companies, Space Exploration Technologies (SpaceX) and Orbital Alliant Techsystems (ATK) developed technologies and capabilities to complete orbital space flight demonstrations. The ISS Program has purchased cargo delivery services from both companies to resupply the space station through 2015.

NASA's Commercial Crew Program (CCP) was formed to facilitate the development of a US commercial crew space transportation capability with the goal of achieving safe, reliable and cost-effective access to and from the International Space Station and LEO. CCP has invested in multiple American companies that are designing and developing transportation capabilities to and from LEO and the ISS. By supporting the development of human spaceflight capabilities, NASA is laying the foundation for future commercial transportation capabilities. After several rounds of development and certification, two contracts have been awarded, to Boeing and SpaceX, for commercially built and operated transportation systems, which will transport NASA crew to the ISS.

All of these programs have required, and will continue to require, extremely complex and critical radio systems. These radio systems will require bands of frequencies spanning the spectrum from about 100 MHz up to more than 30 GHz.

5.5 Aeronautics and Space Technology Development

Another of NASA's endeavors is to pioneer the identification, development, and verification of high-payoff aeronautics technologies. NASA is focused on developing technology solutions that will eliminate barriers to growth for the civil aviation system and provide a safe, efficient national aviation system. To these ends, it conducts testing in the areas of aviation, flight research, airframes, and aeropropulsion. NASA operates one-of-a-kind aircraft to support a wide variety of research missions. These "testbeds" provide platforms for aerodynamic system and propulsion research and testing, and for validation of sensors intended for use in space. NASA uses RF spectrum for the reception of data, including video, from airborne vehicles and for telecommand of those vehicles. Vehicles include experimental aircraft, remotely piloted aircraft, and high altitude balloons.

NASA requires access to the radio spectrum in order to conduct these tests of new technologies in aeronautics and space transportation. NASA flight test and research operations vary in both scope and time. Aircraft, which include models, may fly at altitudes from a few feet up to altitudes on the order of 5000 feet and ranges may extend from an immediate locale out to a range of several hundred miles. Missions might last from minutes, to hours or days, and their scheduling may be dependent upon competing missions at the test centers.

In many cases, prototypes undergo various test and validation phases using conventional terrestrial spectrum allocations for mobile or point-to-point operations. For links between in-flight aircraft and ground systems, NASA requires access to spectrum allocations for aeronautical telemetry. The RF spectrum is used to provide real-time flight data information from test vehicles to the ground, real time video of cockpit or project information, and real time command and control of the vehicle, including flight termination.

In addition to flight test and research operations for experimental aircraft, NASA also operates Unmanned Aeronautical Vehicles (UAVs) and scientific balloons. UAVs are used for the purpose of conducting airborne remote sensing and science observations. These operations might involve development and calibration of sensors, or collection of data to support NASA Earth science programs concerned with the measurement of environmental parameters. The primary objective of the NASA balloon programs is to provide high altitude platforms for scientific and technological investigations; they also provide a platform for the demonstration of promising new instrument and spacecraft technologies. NASA balloons will routinely fly above 100,000 feet. Balloon operations vary in their time and frequency of use. Shorter missions may last between two hours to three days and may occur 15 to 20 times per year; longer missions, lasting up to several weeks, may occur several times per year, while extended duration missions, up to 100 days, may also occur once or twice per year.

NASA requires spectrum for links between aircraft and ground systems. This spectrum is used to provide real-time flight data information from test vehicles to the ground, real time video of cockpit or project information, and real time command and control of the vehicle, including flight termination. For its testing, NASA uses spectrum allocated for Aeronautical Telemetry Service in the L-Band at 1435-1525 MHz; S-Band at 2200-2300 MHz; Upper S-Band at 2310-2390 MHz; and C-Band at 4400-4940 MHz and 5925-6700 MHz.

Chapter 6

6. National Spectrum Issues and NASA Equities

> **Chapter 6 Purpose**: To provide an overview of current domestic spectrum issues and their relationship to NASA spectrum utilization.

Contention for spectrum is coming from both unlicensed and licensed wireless operations, which seek access to additional federal government bands to meet burgeoning consumer demand for broadband, including in federal bands used by NASA.

Looking toward the future, the development and distribution of new wireless broadband products and services will accelerate, driven by consumer demand for ubiquitous access to communications and information.

To address growing demands for spectrum, several domestic policy trends are coming together right now, including expanded use of sharing between different types of users (such as federal government and commercial). Policymakers and technology developers are also looking to both leverage the potential use of higher frequencies and to increase the efficiency of utilization in the most desirable spectrum below 3 GHz. Another issue is an increase in demand from the commercial sector for the use of the same frequencies and in the same geographies that are critical for NASA applications. Against this backdrop, policymakers are also increasingly interested in finding new ways to create incentives for more efficient federal Agency spectrum use, including potential use of new economic tools such as market-based spectrum user fees or incentive auctions of Federal spectrum bands. Collectively, such issues are affecting NASA's existing and planned operations throughout the radio spectrum.

6.1 Mobile Broadband

Key drivers of mobile broadband growth include the development of smartphones and other mobile computing devices, the emergence of broad new classes of connected devices (the Internet of things) and the rollout of 4G wireless technologies such as LTE. According to the Cisco Visual Networking Index, worldwide mobile data traffic is expected to reach 15.9 exabytes[i] per month by 2018.[ii] An increase in mobile broadband use raises demand for other wireless services, such as point-to-point wireless services for backhaul and unlicensed Wi-Fi networks, to enhance the overall delivery of broadband to consumers.

Unlicensed services such as Wi-Fi are important complements to licensed mobile networks and to wireline networks. Wi-Fi provides wireless Internet access for personal computers and handheld devices and is also used by businesses to link computer-based communications within a local area. Many wireless devices that operate on licensed frequencies can also use the unlicensed frequencies set aside for Wi-Fi. Most smartphones and tablets available today feature Wi-Fi, and users take advantage of this capability inside homes or businesses where high-speed broadband connectivity is available.

Several portions of the radio spectrum that are under consideration for future wireless industry use for mobile broadband – as a result of the above-mentioned drivers – carry potential implications for NASA equities. One example is the so-called S-band (2025-2110 MHz and 2200-2290 MHz), in which the Agency has vital command and control uplinks and important data return downlinks as well as links to its TDRSS relay satellite system. Another is the 5 GHz band (5150-5925 MHz), in which the Agency operates sensors that collect important data on the Earth's environment.

6.2 National Broadband Plan

In 2010, the FCC released a National Broadband Plan that called for making additional spectrum available for wireless broadband use – 500 MHz – by 2020. The National Broadband Plan made several recommendations for obtaining the additional spectrum for wireless broadband use.
For example, the plan recommended that the FCC create a new way of auctioning certain commercial spectrum bands, based on providing a portion of auction revenues to incumbents as an incentive for giving up spectrum entirely or giving up a portion of licensed channels and sharing remaining capacity.

The plan provided details for how the FCC would carry out these voluntary incentive auctions, which will be the first of their kind in the world, starting with broadcast television bands in the highly valued 600 MHz range (there has also been interest, including in Congress, for applying this nascent auction model to federal bands). The plan recommended that the FCC should accelerate terrestrial deployment in 90 MHz of MSS spectrum by building on past efforts to enable terrestrial deployment in MSS bands, which originally had been restricted for satellite-based uses.

A June 2010 Executive Memorandum adopted the same 500 MHz goal by 2020 as the Broadband Plan. The President directed the Secretary of Commerce, through NTIA, to collaborate with the FCC to produce a ten-year plan and timetable for making available 500 MHz of federal and non-federal spectrum suitable for wireless broadband use on a shared or exclusive basis. A follow-up memorandum in 2013 focused on expediting progress toward making more spectrum available for broadband, including as part of new sharing efforts.

6.2.1 Evolving Auction Policy

Most importantly for federal agencies, the plan said that the FCC should make up to 60 megahertz available by auctioning AWS bands, including, if possible, 20 MHz from federal allocations. This recommendation expedited momentum toward repurposing the federal spectrum band of 1755-1780 MHz, in which NASA has some user equities paired with the commercial band of 2155-2175 MHz. Potential synergies existed between this AWS-3 band and spectrum allocated to federal use at 1755-1780 MHz.

Subsequent to the release of the FCC's plan, Congressional action was taken in the form of the spectrum provisions in the Middle Class Tax Relief and Job Creation Act of 2012. The spectrum provisions of this legislation, known as the Spectrum Act, gave the FCC incentive auction authority and set a series of auction deadlines in order to meet deficit reduction goals and to provide funding for a planned national first responder network, FirstNet. The 1755-1780 MHz band was not among those included in the 65 megahertz required to be auctioned, but the paired commercial band, 2155-2180 MHz was, providing momentum for an auction of both bands.

In April of 2014, the FCC adopted rules governing use of AWS-3 spectrum in the 1695-1710 MHz, 1755-1780 MHz, and 2155-2180 MHz bands. The 1755-1780 MHz band was made available on a shared basis with a limited number of federal incumbents indefinitely, while most of the federal systems will over time relocate out of the band. As part of new requirements under the Spectrum Act, NASA successfully submitted a transition plan to a new Technical Review Panel for its operations that will relocate from this spectrum on a reimbursed basis as a portion of auction revenue. The Commission also adopted rules to allocate and license the 1695-1710 MHz band for uplink/mobile operations on an unpaired shared basis with incumbent federal meteorological-satellite data users. Upon its conclusion in January 2015, the AWS-3 auction had generated the highest auction revenue in FCC history, about $45 billion. This result is leading policy makers to consider its implications for future spectrum allocations.

Potential Reallocation – Case in Point

Since 2010, the NTIA, in collaboration with the FCC and other federal agencies, has prepared a plan and timetable that identified over 2,200 MHz of federal and non-federal spectrum that could be evaluated for potential opportunities for wireless broadband use. Among the bands identified were those containing NASA equities, including 2200-2290 MHz. As of the start of 2015, NTIA has identified more than 405 MHz of federal spectrum as available or potentially available for broadband use.

NTIA has described a methodology for reviewing additional federal spectrum bands to reach the 500 MHz goal. As part of these deliberations, one band mentioned for reallocation was 2200-2290 MHz, which is the “backbone spectrum band” for NASA and is critical to the agency. This spectrum provides ideal propagation characteristics for reliable communications with spacecraft; it permits use of omni-directional spacecraft antennae for emergency/all-weather situations. Many of the world’s space agencies also operate or plan communications networks in 2 GHz; and efforts are underway toward interoperability, that would permit resource sharing and cross-support. NTIA and the ITU-R have documented the results of studies that show that it is not feasible to share between the space science services and high density mobile systems.

If this spectrum were to be re-allocated in the US, existing and planned spacecraft would lose the ability to communicate data or would face costly redesign. Existing communications networks would face re-fitting into other bands, if spectrum were even available. NASA would become isolated from other space agencies, and the US would lose benefits of international harmonization, including potential interoperability.

6.3 Spectrum Sharing

Spectrum sharing among federal agencies, including NASA, is already widely practiced to gain efficiencies from crowded federal bands. New sharing considerations between federal *and* non-federal bands marks a point of departure and large-scale sharing between government incumbents and new commercial entrants is largely untested in many bands. Policymakers are assessing how bands such as 3.55-3.65 GHz and frequencies in the 5 GHz range can be shared between federal users and new commercial wireless applications. Although the spectrum used by NASA has not been affected thus far, the methodologies being developed could be considered by policymakers in the future for imposition in frequencies of interest to NASA.

In July 2012, PCAST (*see Chapter 1*) concluded that the traditional method for accommodating new services by clearing and reallocating portions of federal spectrum is not a sustainable model for national spectrum policy because it is too costly and takes too much time.

In part, PCAST recommended that the federal government should share underutilized federal spectrum to the maximum extent possible and identify 1,000 MHz of federal spectrum for shared use. It also recommended that policymakers authorize and implement, in collaboration with industry partners, a federal Spectrum Access System (SAS), which would serve as an information and control clearinghouse for the band-by-band registrations and conditions of use that would apply to all users with access to each shared federal band under its jurisdiction.

Under PCAST's vision, the federal SAS would be designed to address the availability of both geolocation databases operating almost in real time along with cognitive radio capabilities (i.e., sensing, dynamic spectrum access), working separately or in combination, make opportunistic access feasible on a band-by-band basis, subject to conditions that would be tailored to avoid harmful interference to licensed operations. While tech players such as Google have been advocates for this solution, it has not yet been deployed and it is not yet clear how a database would address federal government incumbent system (i.e., SAS) security concerns.

PCAST recommended that the shared spectrum be organized into three tiers:

- The first tier would consist of incumbent federal users, who would be entitled to full protection for their operations within their deployed areas.
- The second tier would consist of users that would receive short-term priority authorizations to operate within designated geographic areas. Secondary users would receive protection from interference from third tier users but would be required to avoid interference with and accept interference from the federal primary users.
- Third tier users (General Authorized Access [GAA]) would be entitled to use the spectrum on an opportunistic basis and would not be entitled to interference protection.

6.3.1 Sharing in 3.5 GHz

Prior to new sharing rules adopted for 3.5 GHz by the FCC in April 2015, NTIA had identified this spectrum for potential shared federal and non-federal broadband use (NASA does not have operations in this band but has a potential interest in how such a framework may be applied to other swathes of Federal spectrum in the future).

Incumbent uses in the band include high powered Department of Defense (DoD) radars as well as non-federal Fixed Satellite Service (FSS) earth stations used for receive-only, space-to-earth operations and feeder links. In the adjacent band below 3550 MHz there are high-powered ground and airborne military radars. NTIA initially recommended, based on the commercial wireless broadband technology that it assessed, that new commercial uses of the band should occur outside of large “exclusion zones,” which would be designed to protect government operations. Tech companies had a particular interest in finding more flexible sharing solutions for commercial access to this spectrum because they perceived the exclusion zones as being too large – and covering too many critical markets – to facilitate broadband operations.

The final rules for the band, for a so-called Citizens Broadband Radio Service, include a three-tiered spectrum authorization framework for Incumbent, Priority, and GAA users. The FCC’s order creates a roadmap to allow commercial operations in the band on a shared basis by leveraging spectrum sensing technologies. In an initial phase, coastal protections will be 77 percent smaller than previously anticipated to protect military users. The FCC said this reduction reflects extensive cooperative work between the FCC, NTIA and DoD. For the incumbent tier, a two-phase approach will reduce the exclusion zones. The first phase will feature the exclusion zones, which are smaller than initially proposed. The second will feature an environmental sensor network to enable devices to operate in the exclusion zones when incumbents are not operating.

Besides the incumbent tier, rules for the GAA will let any user with a certified device to operate without seeking further FCC approval, similar to how unlicensed uses can function, except that they will need to register. Under the Priority Access tier, short-term priority rights to a portion of the band will be available through future spectrum auctions. One or more SASs, operated by commercial entities, will allow coexistence among the different user tiers, similar to what PCAST envisioned.

6.3.2 Sharing in the 5 GHz Band

Many of the spectrum issues facing NASA are embodied in current deliberations regarding future use of spectrum in the 5.150-5.975 GHz portion of the radio spectrum. Broadband proponents seek increased access to the 5 GHz bands for unlicensed use. Policymakers have endorsed sharing concepts and may consider applying methods being developed at 3.5 GHz. In the meantime, NASA and other agencies use the spectrum for important services, which could be affected by the new entrants.

The Commission first made available 300 megahertz of spectrum in the frequency bands 5.15-5.35 GHz and 5.725-5.825 GHz bands for unlicensed intentional radiators, known as Unlicensed National Information Infrastructure (U-NII) devices in 1997. In 2003, the Commission made an additional 255 megahertz of spectrum available in the 5.47-5.725 GHz band for U-NII devices.

The 5.35- 5.47 GHz band is allocated on a primary basis to the EESS Research, and Radiolocation Services for federal operations and on a secondary basis for non-federal operations. NASA uses this band for test and launch range instrumentation radars to track rockets, missiles, satellites, launch vehicles, and other targets. NASA operates a limited number of Unmanned Aircraft systems in the band that are used for downlink transmissions of data to ground control receivers. SAR systems in the 5.35-5.47 GHz band perform space-based observations and measurements of surface topography, soil moisture, and sea surface height. These wideband SARs provide the resolution necessary for applications such as high-resolution surface mapping.[iii] NASA, in joint ventures with the French agency, Centre National d'Etudes Spatiales, also operates a space-based altimeter system in the 5.14-5.46 GHz band to obtain measurements of the Earth's ocean surface height.

As required by the Spectrum Act, NTIA has published a report, prepared in consultation with DoD and other affected federal agencies, evaluating spectrum sharing technologies and the risk to federal users of unlicensed operations in the band. In 2013, the FCC issued a Notice of Proposed Rulemaking (NPRM) seeking comment on making available an additional 195 megahertz of spectrum in the 5.35-5.47 GHz and 5.85-5.925 GHz bands for unlicensed broadband use. The FCC has not yet adopted final rules.

6.4 "New Space" Issues

Beyond the mobile broadband policy debate, NASA's spectrum use is affected by the needs of the growing commercial space sector. This sector has grown beyond the provision of basic communications and broadcasting services through satellites, to the provision of Earth resources information and the development of envisioned markets such as space tourism. The private sector is developing launch vehicles and facilities, as well as payloads, which require access to spectrum resources. NASA is working with federal regulators to assess ways that federal spectrum traditionally used by NASA for its own operations can be made available, when needed, by private sector stakeholders for commercial launches and operations in space.

Under the National Aeronautics and Space Act of 1958, NASA has the responsibility to encourage, to the maximum extent possible, the commercial use of space. In June 2010, the President announced a National Space Policy, which expresses the President's direction for the Nation's space activities.[iv] Most, but not all, of the spectrum allocated to the Space Research and Space Operations services in the US has been designated for federal-only use. Since federal agencies have been the primary users of this spectrum, historically there has been no incentive to establish the allocations on a shared basis in the US frequency allocation tables. However concern is now being raised by commercial providers over their lack of access to currently allocated space services spectrum.

The end of NASA's space shuttle program has led to the development of a new era of cargo delivery and manned space travel initiatives that promise to continue the US legacy of exploration, education and discovery. Several private companies have been selected to take cargo and, in the future, people into space to support the ISS and other NASA initiatives. SpaceX and Orbital ATK have recently accomplished successful missions to the space station. Other companies are developing the capability to take tourists on suborbital forays into space. To support the nascent private launch industry, a number of non-federal government owned space ports have been established.

Commercial users currently utilize two avenues to secure FCC authorization of their proposed use of space services spectrum:

- They may pursue a license, including a STA, under the Commission's rules and regulations covering the commercial Satellite Communications Services. This is a less certain form of spectrum access for commercial providers, since STAs are granted with a fixed expiration date, usually six months. [v]
- Commercial users may also pursue an Experimental Radio Service license (or an STA) under the rules governing the Experimental Radio Service. This service is intended to provide for experimental uses of radio frequencies and development of techniques and systems that are not otherwise permitted under existing service rules.

In May 2013, the FCC released an NPRM/Notice of Inquiry (NOI), which addresses the spectrum needs of the commercial space launch industry. The FCC proposed several alternatives for providing spectrum for use during commercial space launches, thereby providing launch vehicles with interference protection. During launches by federal agencies, spectrum in the 420-430 MHz, 2200-2290 MHz, and 5650-5925 MHz bands has been typically used to send a self-destruct signal to the launch vehicle (if needed) and information from the launch vehicle to controllers on ground, as well as to track the launch vehicle by radar. The Commission is considering how to modify the allocations to allow non-federal use of these bands in order to provide commercial entities access to spectrum. In the NOI, the FCC sought comment broadly on the future spectrum needs of the commercial space sector. It asked about the communication needs of suborbital space flights and commercial space stations, whether access to other frequency bands will be required, and whether amendments to the Commission's rules will be needed.

The federal bands under consideration for more predictable commercial space industry access for launches are already used by government agencies, including the key NASA band of 2200-2290 MHz. Among issues of interest to NASA are whether there is sufficient spectrum available in this band for use during commercial launches and whether use of this band could sustain the anticipated growth of the commercial launch sector and if additional federal bands will be studied for other aspects of commercial space services, including re-entry or the "on orbit" phase of a mission that would require changes in allocations to Federal spectrum.

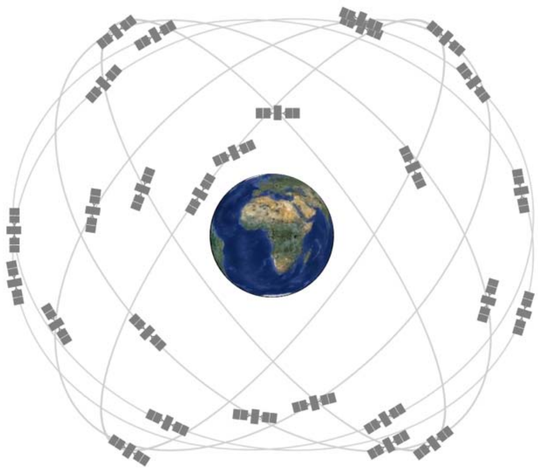

Figure 6.1: The GPS Constellation flies in medium Earth orbit at an altitude of 20,200 km (12,550 miles)

6.5 GPS Issues

New wireless broadband uses that are entering spectrum bands adjacent to current NASA operations may impact Agency capabilities and require an adjacent band compatibility analysis to ensure that NASA missions do not encounter harmful interference and can continue without interruption. One example of this involves GPS capabilities on which NASA relies and which faces greater challenges with regard to the increased potential for harmful interference as new spectrum "neighbors" seek access to adjacent or nearby bands. GPS service is provided in the frequency band, 1559-1610 MHz.

In the era of advanced wireless communications, new technology capabilities have created challenges for the continued operation of GPS without harmful interference. In 2002, for example, after a protracted regulatory proceeding, the FCC approved new rules for ultra-wideband, which is a technology that spreads a low-level signal across a very wide swath of spectrum. The final rules included provisions to protect GPS systems, however, during the development of the rules, the potential threat to GPS was a critical part of the policy debate.

More recently, concerns over how to protect GPS have been sparked by flexibility for terrestrial operations sought by MSS licensee, LightSquared, using the bands allocated for this service at 1525-1544 MHz and 1545-1559 MHz downlink and 1626.5-1645.5 MHz and 1646.5-1660.5 MHz uplink. LightSquared also has an authorization to use Ancillary Terrestrial Component (ATC) in the same frequency bands. ATC facilities are intended to provide voice and data communication for users equipped with dual-mode MSS/ATC devices; when MSS/ATC operation was first considered by the FCC, it was expected the number of ATC devices would be small.

- LightSquared's business plan called for utilizing this ATC authority to develop a nationwide terrestrial network, and to sell wholesale access to its network's infrastructure. In January 2011, the FCC granted LightSquared a waiver of the Commission's rules, which allowed LightSquared and its wholesale customers to offer terrestrial-only devices rather than having to incorporate both the satellite and terrestrial services.
- Companies that provide global positioning systems and the United States Air Force, which maintains and operates the space and control segments of the GPS system, opposed the FCC waiver, because of concerns that LightSquared's service might interfere with GPS service. Tens of thousands of base stations transmitting in the satellite-to-earth part of the MSS spectrum closest to the GPS spectrum raised the possibility that the high power terrestrial signals would interfere with far weaker GPS signals coming from space.

In April 2011, responding to concerns raised by the US GPS Industry Council and NTIA about LightSquared's planned operations, the FCC stated that LightSquared could not commence offering a commercial terrestrial service until the FCC had concluded that the concerns about harmful interference were resolved. The FCC stated that responsibility lies also with incumbent users, who should use receivers that reasonably discriminate against reception of signals outside their allocated spectrum.

NASA has a number of GPS-dependent applications, which could be vulnerable to interference from the network as originally proposed by LightSquared. Affected systems could include ground-based, airborne, and space-based receivers used to support activities such as: Earth science research; weather forecasting; disaster monitoring; ground-truth calibration of instruments on orbit; precision navigation for aircraft and spacecraft; and search and rescue efforts. Research into development of future aeronautical applications might be affected, as well.

In September 2012, LightSquared submitted applications to modify its licenses as part of an alternative proposal, which it said would provide a comprehensive solution to the issues that had precluded the deployment of its terrestrial wireless network. Lightsquared's proposal include a spectrum swap to replace its terrestrial downlinks in 1545-1555 MHz and, instead, conduct them at 1670-1680 MHz.

The FCC has not yet made final decisions on LightSquared requests for regulatory relief. To date, the LightSquared proceedings underscore the new challenges that policymakers and incumbent government operations face in balancing concerns about protecting mission critical Federal operations from interference and providing capacity for new broadband services.

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[i] One exabyte is one quintillion bytes, a billion gigabytes, or 10^{18} bytes.

[ii] See Cisco Visual Networking Index, available at http://www.cisco.com/c/en/us/solutions/service-provider/visual-networking-index-vni/index.html.

[iii] Canada operates an Earth exploration-satellite, known as RADARSAT, in the 5.35-5.47 GHz band to provide mission critical data in support of national security, public safety, law enforcement, and civilian applications in Canada and the United States. For example, the United States Coast Guard International Ice Patrol uses RADARSAT data to detect and track icebergs.

[iv] One of the principles in this Policy is that a robust and competitive commercial space sector is vital to continued progress in space. It states that the US is committed to encouraging and facilitating the growth of a US commercial space sector that supports US needs, is globally competitive, and advances US leadership in the generation of new markets and innovation-driven entrepreneurship.

[v] In the case of contemplated new space services, for which there are no current applicable rules, the Commission has traditionally granted operating authority on an ad-hoc, case-by-case, basis until it has obtained sufficient experience and information to proceed to a formal rulemaking process.

Chapter 7

7. Conclusion

Because nearly every endeavor that NASA undertakes requires communications or data transfer via the electromagnetic spectrum, the Agency remains committed to meeting the spectrum access needs of its global missions and activities. The electromagnetic spectrum environment in which NASA operates is constantly evolving, driven by both its own operating requirements and the rapidly escalating demands of the commercial wireless broadband sector for access to this limited resource.

The spectrum management environment – driven by advanced technology capabilities, evolving policy frameworks and emerging operating requirements – poses both opportunities and challenges for NASA spectrum equities. With regard to challenges, national policymakers in the US have referred to the spectrum capacity crunch, with several bands that are under study for future wireless industry use carrying potential implications for NASA equities. These dynamic tensions between public sector and private sector spectrum access for existing and planned operations are playing out internationally, as well. At the ITU, this is occurring most visibly in the WRC arena and beyond, as the ITU-R works to finalize its vision of the connected future via planning efforts for 5G.

New sources of congestion and contention in spectrum bands used by NASA to carry out vital space missions are coming not just from the consumer wireless broadband sector but also from the commercial space sector, which is developing launch vehicles and facilities, as well as payloads, which require access to spectrum resources.

Simply put, challenges and opportunities in this complex electromagnetic spectrum environment are redefining how NASA carries out its roles as a proactive spectrum steward. As part of critical international deliberations, including most notably those that unfold at WRCs, NASA remains ever vigilant to protect existing spectrum provisions from proposals that could affect its existing and planned operations.

Increasingly, challenges and opportunities are intertwined. For example, NASA is working with federal regulators to assess ways that federal spectrum traditionally used by NASA for its own operations can be made available, when necessary, by private sector stakeholders for commercial launches and operations in space. On the one hand, NASA has statutorily mandated roles and responsibilities to encourage, to the maximum extent possible, the commercial use of space. At the same time, NASA is actively engaged in ensuring that spectrum access will be available when and where needed to support communications services essential to the operations of all NASA space flight missions.

An increased focus by policymakers on spectrum sharing also presents both a challenge and an opportunity for NASA. The challenge is that a new range of bands that are critical to NASA mission requirements remain under scrutiny for potential mobile broadband access, including on a shared basis. The opportunity is that shared access, if the rules of the road are balanced to protect

NASA's current and future user requirements, can provide new opportunities for meeting the needs of both private sector and public sector users.

Attachment A - Process for Spectrum Authorization

All NASA missions requiring the use of the electromagnetic spectrum for communications transmission or reception (or both) or for sensor operations should follow the basic process outlined below.

Per NPD 2570.5 and NPR 2570.1, it is NASA policy that any NASA system that requires the use of the electromagnetic spectrum for transmission, reception, or both shall follow the US spectrum regulatory rules and processes. The Spectrum Policy and Planning Division recently updated NPR 2570.1, and all NASA programs and projects should obtain and review the latest version (NPR 2570.1C, 22 Sep 2014). NPD 2570.5 and NPR 2570.1 provide detailed information that applies to all NASA science, technology, and exploration spaceflight programs/projects, both human-crewed and robotic.

For guidance, NASA spaceflight projects that require the use of the electromagnetic spectrum for transmission, reception, or both should consider the following:

- Frequency bands allocated to the science services[i] are appropriate, from a regulatory perspective, for spaceflight nominal operations, critical events, contingency operations, and emergency applications. For all spaceflight trajectories and distances from Earth (e.g. low-Earth, Lunar, or Mars missions), the frequency selection should be based on program requirements and considerations, as well as spectrum regulations.
- From the NASA's Spectrum Policy and Planning Division's perspective, there is no preference to any of the science service allocated bands for routine and emergency applications of human-crewed or robotic missions.
- All NASA spaceflight missions, regardless of size, to include small satellite systems, shall comply with United States spectrum regulatory rules and processes. All missions, including those sponsored by NASA via contract or grant to non-NASA entities, shall be coordinated with the relevant Center Spectrum Manager.
- Center Spectrum Managers shall ensure that all missions comply with US spectrum regulatory rules and processes, to include hosted payload services.

As noted in NPD 2570.5 and NPR 2570.1, all NASA program spectrum-related decisions and processes shall be coordinated with the Center Spectrum Managers and the NASA Spectrum Plans and Policy Division.

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[i] For example, one such science service, the Space Research Service (SRS), includes a number of bands useful for space communications including, but not limited to: 2025-2120 MHz, 2200-2300 MHz, 7145-7235 MHz, 8400-8500 MHz, 25.5-27.0 GHz, 31.8-32.3 GHz, 34.2-34.7 GHz, etc. Specific constraints (e.g., Earth-to-space, space-to-Earth, use beyond 2M km (deep space), power flux density limits, etc.) may apply depending on the frequency band. NASA Center Spectrum Managers, as per NPD 2570.5 and NPR 2570.1, can assist in identifying these constraints.

Attachment B - NASA WRC-15 Objectives and Results

NASA was successful at WRC-12 in getting several items added to the WRC-15 agenda: (1) An EESS uplink allocation in the 7-8 GHz range; (2) Review of current limits on the use of the 410-420 MHz band for SRS operations; (3) An expansion of 600 megahertz around 9.5 GHz to support EESS (active) operations; and (4) Consideration of nanosat/picosat regulatory issues.

Band	Type	Use	NASA Recommendations
7-8 GHz	EESS uplink	-EESS (space-to-Earth) allocation in the frequency band 8025-8400 MHz; terrestrial allocations to FS and MS in this range -2025-2110 MHz uplink band is crowded and many new satellite networks are anticipated	Sharing with other services shown to be possible; provide primary allocation in the 7190-7250 MHz to alleviate growing congestion at 2025-2110 MHz
410-420 MHz	SRS	Astronaut EVA in the immediate vicinity of the ISS	Remove five km distance limitation to permit proximity operations by visiting vehicles
9.5 GHz	EESS	Active sensors (SARs) in 9300-9900 MHz	Expand by 600 MHz at 9900-10500 MHz with appropriate provisions to protect incumbent services in order to enable higher resolution by next generation SAR sensors

Table B1: NASA WRC-15 Spectrum Objectives

B1 EESS Uplink at 7-8 GHz

A sizable number of future EESS missions will require large data transmissions to spacecraft for operations plans and dynamic spacecraft software modifications. These requirements cannot be accommodated in the existing EESS uplink; 1,000 satellite networks have been filed with the ITU and many new are expected, including many microsatellites, nanosatellites and picosatellites. It will become extremely difficult, if not impossible, to coordinate the satellite networks' spectrum requirements within the 2025-2110 MHz band.

The EESS (Earth-to-space) allocation in the 7-8 GHz frequency range would help alleviate constraints in the 2025-2110 MHz band, sharing studies between EESS and other services in the 7-8 GHz frequency range showed that sharing would be feasible in the 7190-7250 MHz band. As a result, WRC-15 established a new primary allocation to the EESS (Earth-to-space) in the 7190-7250 MHz band, with conditions that ensure the protection of currently allocated services.

B2 SRS at 410-420 MHz

The 410-420 MHz band is used today for astronaut Extra Vehicular Activities communications in the immediate vicinity of the ISS. This band would be advantageous for proximity operations of ISS visiting vehicles. The band currently has power (Power Flux Density [PFD]) and distance limitations (5 km), agreed at WRC 1992. NASA proposed to modify the regulations to remove the five km limit, while the PFD limits are sufficient to protect the terrestrial and mobile services in the band. WRC-15 agreed to the removal of the distance limitation.

B3 EESS Expansion at 9.5 GHz

WRC-15 considered an expansion to the EESS (active), by 600 MHz, to the 9300-9900 MHz band within the 8700-9300 MHz and 9900-10500 MHz frequency ranges. The expansion would enable higher image resolutions of less than 30 cm for next generation SAR sensors.

NASA supported an extension of the current allocation to include the 9300-9900 MHz band. Currently, the US supports a primary allocation to EESS in the 9900-10500 MHz band, with appropriate provisions to ensure the protection of the incumbent services. Agreement was reached at WRC-15 on an EESS (active) extension in the bands 9200-9300 MHz and 9900-10400 MHz on a primary basis with provisions protecting incumbent services. However agreement under RR 9.21 is required for operation in Algeria, Saudi Arabia, Bahrain, Egypt, Indonesia, Iran, Lebanon and Tunisia.

B4 Regulations for Nanosatellites and Picosatellites

WRC-15 considered regulatory aspects for nanosatellites and picosatellites. WRC-12 invited the ITU-R to examine the procedures for notifying space networks and to consider possible modifications to enable the deployment and operation of nanosatellites and picosatellites, while taking into account the short development time, short mission time and unique orbital characteristics of these types of satellites.

Many of these satellites are launched for scientific, experimental or educational purposes, sometimes in the form of constellations, but there is a growing interest for commercial non-scientific applications.

Consideration of this AI took into account the comparatively short development time and the potential lack of advance knowledge of certain operational parameters. It was also recognized that there is a need to educate the operators of these satellites regarding their regulatory obligations for filing with the ITU and, in some cases, coordinating operations internationally.

WRC-15 concluded that frequency bands should align with their associated applications. The unique physical characteristics of these satellites are largely irrelevant to spectrum management and these satellites should be treated in the same manner as any other satellite technology. However, WRC-15 recognized that the time frames associated with the development and operations of these satellites, as well as the lack of advance knowledge of certain orbital parameters, can make the existing satellite filing procedures difficult. Any changes to the filing procedures in the RR will be considered under a standing WRC AI, which considers satellite coordination and registering procedures.

B5 Other WRC Items

While NASA must be vigilant to protect all existing spectrum provisions from proposals that could affect its operations, there were several specific items of concern. These were: (1) Spectrum allocations for mobile broadband/IMT; (2) MSS uplink and downlink allocations in the 22-26 GHz band; and (3) MMSS uplinks in the 8025-8400 MHz band (*see Table 7.2).*

Bandwidth	Type	Use	Study Results
1400-1427 MHz	EESS (Passive)	Critical passive band for Earth observing Satellites	A relevant combination of channel arrangements, guard bands and/or improved filters and other measures would be needed to allow the design of mobile systems in adjacent bands that are compliant with the specified OOBE values.
2025-2110 MHz **2200-2290 MHz**	SRS	Provides vital command and control uplinks and important data return downlinks as well as links to NASA's TDRS system.	Sharing is not feasible between IMT systems and the forward and return (space-to-space) links of incumbent data relay satellites operating in these frequency bands.
5350-5470 MHz	EESS (active)	Active Earth observing systems include SARs and altimeters	Given assumed RLAN parameters, studies were made under the general assumption that the RLANs would be limited to indoor use only. Sharing between RLANs and the EESS (active) systems in this band would not be feasible.
22-26 GHz	MMS	NASA uses SRS (Earth-to-space) band 22.55-23.15 GHz and EESS/SRS (space-to-Earth) band 25.5-27.0 GHz; the Inter-satellite bands 22.55-23.55 GHz and 25.25-27.5 GHz; EESS (passive) band 23.6-24 GHz as well as 22.21-22.5 GHz.	Any mobile satellite services will be impacted planned NASA use of these bands.
7-8 GHz	MMSS	Space science data downloads occur at 8025-8400 MHz EESS (space-to-Earth) and 8400-8450 MHz SRS (space-to-Earth) (deep space).	Ship operating in the vicinity of Earth stations near coasts could cause interference; enforcement of large exclusion zones would not be feasible in practice and interference would be difficult to track due to the mobile nature of the ships.

Table B2: NASA WRC-15 Spectrum Concerns

B5.1 Mobile Broadband/IMT

Mobile communications, including mobile broadband communications contribute positively to the economic and social developments of both developed and developing countries. Many administrations are investigating a wide range of applications and systems to bridge the digital divide using IMT and other terrestrial mobile broadband applications.

The ITU is working towards realizing the future vision of mobile broadband communications. In early 2012, the ITU-R embarked on a program to develop "IMT for 2020 and beyond"; and it has described a timeline towards "IMT-2020". In 2015, the ITU-R finalized its vision of the "5G" mobile broadband connected society. This view of the horizon for the future of mobile technology was considered at WRC-15, where deliberations on additional spectrum took place in support of the future growth of IMT. In the next phase, in the 2016-2017 timeframe, the ITU-R expects that its Working Party 5D will define in detail the performance requirements, evaluation criteria and methodology for the assessment of a new IMT radio interface.

It is anticipated that the timeframe for Administration proposals will be focused in 2019. In 2019-2020 the evaluation by independent external evaluation groups and definition of the new radio interfaces to be included in "IMT-2020" will take place. The process is planned to be completed in 2020 when a draft new ITU-R Recommendation with detailed specifications for the new radio interfaces will be submitted for approval within ITU-R.

WRC-12 called for studies on future spectrum requirements and potential candidate frequency bands below 6 GHz for IMT and other terrestrial mobile broadband applications. Several bands under consideration at WRC-15 included spectrum vital to current and planned NASA operations: 1400-1427 MHz; 2025-2110/2200-2290 MHz; and 5350-5470 MHz.

WRC-15 made a number of spectrum allocations for mobile broadband/IMT. However, no allocation changes were made in the 1350-1400 MHz, 2025-2110 MHz, 2200-2290 MHz and 5350-5470 MHz bands. In addition, NASA successfully obtained inclusion in the RR, mandatory out-of-band emission (OOBE) limits on IMT in the 1427-1452 MHz band to protect EESS (passive) in the adjacent 1400-1427 MHz band at levels sufficient to protect the passive operations.

Given the seemingly endless efforts to find additional spectrum for IMT and related broadband services, NASA will have to continue to be vigilant in protecting spectrum in which it has equities.

B5.2 Mobile-Satellite Service in 22-26 GHz

One AI that raised concerns for NASA at WRC-12 involved the mobile satellite community seeking new allocations within the 4-16 GHz range. WRC-12 considered making additional allocations in several bands between 4 GHz and 16 GHz. Two of the six bands considered as possible candidate bands included the heavily utilized 7145-7235 MHz and 8400-8500 MHz space research service bands. Extensive study prior to WRC-12 had proved that sharing in these bands was not feasible, nor was it found to be feasible in any of the six candidate bands. NASA accomplished its goal to protect the 7/8 GHz space science bands, and WRC-12 decided to make no frequency allocation changes. However, the conference specified a WRC-15 AI that again caused NASA to strive to ensure protection of space science service allocations.

WRC-15 considered spectrum requirements and possible additional spectrum allocations for the mobile-satellite service in the Earth-to-space and space-to-Earth directions, including a satellite component for broadband applications (e.g., IMT) within the frequency range from 22 GHz to 26 GHz. WRC-12 called for sharing and compatibility studies towards additional allocations to the mobile-satellite service within portions of the allocated bands between 22 GHz and 26 GHz, while ensuring protection of existing services within the bands.[xv] Some MSS interests identified the bands 23.15-25.55 GHz, 24.25-24.5 GHz and 25.25-25.5 GHz for possible re-allocation.

For NASA, the main frequency bands at risk were:

- The SRS Earth-to-space band 22.55-23.15 GHz
- The Inter-satellite band 22.55-23.55 GHz and the Inter-satellite band 25.25-27.5 GHz
- The EESS (passive) band 23.6-24 GHz as well as 22.21-22.5 GHz
- The EESS/SRS space-to-Earth band 25.5-27.0 GHz

As happened at WRC-12, WRC-15 decided not to provide any new MSS allocations within the 22-26 GHz band, thus eliminating the risk from MSS to NASA's equities within this frequency range.

B5.3 MMSS at 7/8 GHz

WRC-15 considered the possibility of allocating the bands 7375-7750 MHz and 8025-8400 MHz to the maritime-mobile satellite service, while ensuring compatibility with incumbent services. The potentially affected space science service bands were 8025-8400 MHz EESS (space-to-Earth) and 8400-8450 MHz SRS (space-to-Earth) (deep space).

NASA was concerned about potential interference to EESS reception in 8025-8400 MHz at high latitudes from transmissions from ships operating in proximity to earth stations, as well as out-of-band interference to SRS (deep space) reception in the 8400-8450 MHz band. Large exclusion zones would be needed to avoid interference to existing and future EESS and SRS earth stations from a potentially large numbers of ships. Many of the more than 100 existing EESS and SRS earth stations are located near coastal areas (e.g., Svalbard, McMurdo, Maspalomas, Lannion, and Wallops) could be seriously affected by emissions from vessels navigating in the area up to distances of hundreds of kilometers from the coastline. The enforcement of large exclusion zones would not be feasible in practice, leading to interference that would be very difficult to track due to the mobile nature of the systems. Thus, NASA opposed an allocation to MMSS in 8025-8400 MHz and strived to retain the current allocations.

WRC-15 provided a MMSS downlink in the 7375-7750 MHz band and in alignment with NASA's interests, did not allocate MMSS in the 8025-8400 MHz band.

[xv] It also recognizes that unwanted emissions in the band 23.6-24 GHz will need to be limited to ensure protection of systems of the EESS (passive), SRS (passive) and radio astronomy services

Attachment C - NASA WRC-19 Objectives

The WRC-19 agenda contains 16 individual AIs along with several standing AIs that are included in all WRC's. Of these, NASA has primary interest in three items and concerns with eight items. Each of these AIs is summarized below and the potential impact to NASA is provided for those items of concern.

C1 WRC-19 Items of Interest

AI 1.2 - *In-band power limits for MSS/Metsat/EESS earth stations in 401-403 MHz and 399.9-400.05 MHz*

This item will examine the possible establishment of in-band power limits for earth stations operating in mobile-satellite service (MSS), the meteorological-satellite service (Metsat) and the Earth exploration-satellite service (EESS) in the frequency bands 401-403 MHz and 399.9-400.05 MHz.

AI 1.3 - *Possible upgrade to primary for Metsat (space-to-Earth) allocation and a new primary EESS (space-to-Earth) allocation in 460-470 MHz*

This item is to consider the possibility of upgrading the secondary space-to-Earth Metsat allocation to primary status and adding a primary space-to-Earth EESS allocation in the frequency band 460-470 MHz.

AI 1.7 - *Requirements for SOS TT&C for Non-Geosynchronous Orbit (NGSO) short duration mission satellites*

This item calls for assessing the suitability of using existing Space Operations Service (SOS) allocations below 1 GHz to accommodate the telemetry, tracking and command (TT&C) requirements for non-geostationary satellites with short duration missions and if those allocations are determined to be unsuitable, consider possible new allocations or an upgrade of the existing allocations to the SOS within the frequency ranges 150.05-174 MHz and 400.15-420 MHz while protecting the incumbent services, both in-band as well as in adjacent bands.

C2 WRC-19 Items of Concern

AI 1.5 - *Earth stations in motion communicating with FSS Geosynchronous Orbit (GSO) stations in 17.7-19.7 GHz (s-to-E) and 27.5-29.5 GHz (Earth-to-space)*

This item is to examine the possibility of using the frequency band 17.7-19.7 GHz in the space-to-Earth direction and the frequency band 27.5-29.5 GHz in the Earth-to-space direction by earth stations in motion communicating with geostationary space stations in the FSS. NASA use of the 18.6-18.8 by the EESS (passive) could be impacted, as well as the potential for adjacent band interference into NASA's Tracking and Data Relay Satellite System (TDRSS).

AI 1.6 - *NGSO FSS in (s-to-E): 37.5-39.5 GHz/39.5-42.5 GHz and (Earth-to-space): 47.2-50.2 GHz/50.4-51.4 GHz*

This item will study the technical, operational issues and regulatory provisions for the possibility of allowing non-geostationary FSS satellite systems to operate uplinks in the frequency bands 37.5-39.5 GHz and 39.5-42.5 GHz and downlinks in the frequency bands 47.2-50.2 GHz and 50.4-51.4 GHz. Bands that overlap NASA uses are identified in this item so there is a potential for impacts to NASA data communication and passive remote sensing equities.

AI 1.13 – *Identification of bands for the future development of IMT*

This item is essentially a continuation of the ongoing identification of spectrum for IMT and seeks the additional allocations to the mobile services on a primary basis in portion(s) of the frequency range between 24.25 and 86 GHz for the future development of IMT for 2020 and beyond. Specifically under examination are the frequency bands, which currently have primary MS allocations: 24.25-27.5 GHz, 37-40.5 GHz, 42.5-43.5 GHz, 45.5-47 GHz, 47.2-50.2 GHz, 50.4-52.6 GHz, 66-76 GHz and 81-86 GHz. In addition, the frequency bands 31.8-33.4 GHz, 40.5-42.5 GHz and 47-47.2 GHz may be considered for new allocations to the mobile service on a primary basis.

This item encompasses many bands that overlap NASA uses so there is a great potential for adverse impacts to NASA data communication and passive remote sensing equities.

AI 1.14 – *Broadband delivered by high-altitude platform stations*

This item will examine facilitating access to broadband applications delivered by high-altitude platform stations in frequency band 38-39.5 GHz on a global level and in Region 2, in the frequency bands 21.4-22 GHz and 24.25-27.5 GHz.

NASA equities adjacent to or using the 24.25-27.5 GHz band could be adversely impacted.

AI 1.15 – *Frequency identification for land-mobile and fixed services applications in the range 275-450 GHz*

This item calls for identification for use by administrations for the land-mobile and fixed service applications operating in the frequency range 275-450 GHz.

The NASA passive remote sensing and radio astronomy operations in bands above 275 GHz need to be protected.

AI 1.16 - Radio Local Area Network (*RLANs) in bands between 5150-5925 MHz*

This item is a continuation one segment of the WRC-15 IMT AI 1.1 and seeks to identify potential Wireless Access System (WAS)/RLAN mitigation techniques to facilitate sharing with incumbent systems in the frequency bands 5150-5350 MHz, 5350-5470 MHz, 5725-5850 MHz and 5850-5925 MHz.

NASA passive remote sensing in the frequency band 5350-5470 MHz band could be severely impacted.

AI 9 Issue 1.4 - *Stations on-board suborbital vehicles*

This item calls for studies of stations on board sub-orbital vehicles to identify any required technical and operational measures that could assist in avoiding harmful interference between radiocommunication services, as well as determining the stations' spectrum requirements and, based on the outcome of those studies, consider a possible future AI for WRC-23.

NASA uses many sub-orbital vehicles (e.g., sounding rockets) so has both interests and concerns with this item.

AI 9 Issue 1.9 - *Spectrum needs and possible FSS (Earth-to-space) allocation in 51.4-52.4 GHz band*

This item calls for sharing and compatibility studies with existing services, on a primary and secondary basis, including in adjacent bands as appropriate, to determine the suitability, including protection of fixed and mobile services, of new primary Earth-to-space FSS allocations in the frequency band 51.4-52.4 GHz limited to FSS feeder links for geostationary orbit use, and the possible associated regulatory actions.

NASA systems operating in the passive frequency band 52.6-54.25 GHz must be protected.

Bands Under Consideration WRC-19 AIs			
1.6 NGSO FSS	**1.13 IMT**	**1.14 High Altitude Platform Station**	**9 Issue 1.9**
	24.25-27.5	24.25-27.5 (Region 2)	
37.5-39.5 (space-to-Earth)	37-40.5	38-39.5 (globally)	
39.5-42.5 (space-to-Earth)	40.5-42.5		
47.2-50.2 (Earth-to-space)	47.2-50.2		
50.4-51.4 (Earth-to-space)	50.4-52.6		51.4-52.4 (Earth-to-space)

Table C1: Frequency Overlaps of WRC-19 AIs

Attachment D - List of Acronyms

Acronym	Description
4G	Fourth Generation
5G	Fifth Generation
AI	Agenda Item
ATK	Alliant Technical Systems
BR	Radiocommunication Bureau
CCP	Commercial Crew Program
CITEL	Inter-American Telecommunication Commission
COTS	Commercial Orbital Transportation Services
CPM	Conference Prepatory Meeting
CSMAC	Commerce Spectrum Management Advisory Committee
DoD	Department of Defense
DoS	Department of State
DSN	Deep Space Network
EESS	Earth Exploration Satellite Service
EHF	Extremely High Frequency
FAA	Federal Aviation Administration
FAS	Frequency Assignment Subcommittee
FCC	Federal Communications Commission
GAA	General Access User
GHz	Gigahertz
GOES	Geostationary Operational Environmental Satellite
GSO	Geosynchronous Orbit
HF	High Frequency
Hz	Hertz
IB	International Bureau
IMT	International Mobile Telecommunication
IR	Infrared
IRAC	Interdepartment Radio Advisory Committee
ISS	International Space Station
ITU	International Telecommunication Union
ITU-R	ITU-Radiocommunications
JTG	Joint Task Group
kHz	Kilohertz
LF	Low Frequency
LTE	Long Term Evolution
MF	Medium Frequency
MSS	Mobile-Satellite Service
MMSS	Maritime Mobile-Satellite Service
MOU	Memorandum of Understanding
NASA	National Aeronautics and Space Administration
NEN	Near Earth Network
NGSO	Non-Geosynchronous Orbit

NOAA	National Oceanic and Atmospheric Administration
NOI	Notice of Inquiry
NPD	NASA Policy Directive
NPR	NASA Process Requirements
NPRM	Notice of Proposed Rulemaking
NTIA	National Telecommunications and Information Administration
OCO-2	Orbiting Carbon Observatory-2
OET	Office of Engineering and Technology
OSM	Office of Spectrum Management
PCAST	President’s Council of Advisors on Science and Technology
PNT EXCOM	Space-based Positioning, Navigation and Timing Executive Committee
PPSG	Policy and Plans Steering Group
RAS	Radio Astronomy Service
RCS	Radio Conference Subcommittee
RF	Radiofrequency
RFA	RF Authorizations
RLAN	Radio Local Area Network
RR	Radio Regulations
RRB	Radio Regulations Board
SAR	Synthetic Aperture Radar
SAS	Spectrum Access System
SCaN	Space Communications and Navigation
SDO	Solar Dynamics Observatory
SFCG	Space Frequency Coordination Group
SGs	Radiocommunication Study Group
SHF	Super High Frequency
SLS	Space Launch System
SMAP	Soil Moisture Active Passive
SN	Space Network
SpaceX	Space Exploration Technologies
SRS	Space Research Service
SSD	Spectrum Services Division
STA	Special Temporary Authorization
STS	Space Transportation System
SWAVES	Stereo/Waves
TDRS	Tracking and Data Relay Satellite
TT&C	Tracking, Telemetry, and Commanding
UAVs	Unmanned Aeronautical Vehicles
UHF	Ultra High Frequency
U-NII	Unlicensed National Information Infrastructure
UV	Ultraviolet
VLF	Very Low Frequency
WARC	World Radio Administrative Conference
WRC	World Radiocommunication Conferences
WTB	Wireless Telecommunications Bureau

Attachment E - List of Figures

Attachment F - Tables