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NASA's Management of Electromagnetic Spectrum

March 9, 2017

Report No. IG-17-012

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NASA Office of Inspector General
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RESULTS IN BRIEF

NASA's Management of Electromagnetic Spectrum

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IG-17-012 (A-16-012-00)

WHY WE PERFORMED THIS AUDIT

NASA relies on radio waves and other portions of the electromagnetic spectrum to communicate with the spacecraft that carry out the Agency's space and science missions and to conduct day-to-day operations. However, the radio portion of the electromagnetic spectrum (radio spectrum) is a finite resource, and an ever-growing number of communications devices has increased the demand for usable radio spectrum. To avoid interference, multiple users generally cannot transmit radio signals at the same frequencies, at the same time, to the same location. Accordingly, several domestic and international organizations manage radio spectrum among users, including Federal agencies and commercial entities.

In light of this growing demand, and because the radio spectrum and other portions of the electromagnetic spectrum are vital to NASA's missions, we initiated this audit to review the Agency's efforts to manage its electromagnetic spectrum allocation. To complete this work, we visited five NASA Centers and NASA Headquarters; interviewed NASA, U.S. Air Force, Federal Communications Commission, and National Telecommunications and Information Administration officials; and reviewed relevant policies, procedures, laws, and regulations.

WHAT WE FOUND

Overall, NASA is effectively managing challenges to its radio spectrum access. NASA missions operate in a constantly evolving electromagnetic spectrum environment, and the Agency faces several challenges in ensuring its current and future missions have adequate access to the radio spectrum. NASA must comply with Federal initiatives designed to make additional radio spectrum available to the mobile broadband industry and share radio spectrum historically reserved for Federal users with the emerging commercial space launch industry. In addition, the proliferation of small satellites (SmallSats) for educational or technology development projects is straining already congested radio spectrum resources. Finally, future NASA missions are expected to require higher data transmission rates, which could overwhelm the frequency band allocations NASA currently uses.

NASA has addressed these challenges by collaborating with other Federal agencies and commercial industry users and regulators worldwide, pursuing new technologies, and issuing guidance to Agency radio spectrum users. However, NASA's space flight program management policies do not include key electromagnetic spectrum requirements, which increases the risk project developers, particularly SmallSat developers who may be unfamiliar with NASA processes, will not incorporate electromagnetic spectrum requirements into their development plans in a timely manner. This in turn increases the risk a project will have to make costly design changes or miss a planned launch date. Indeed, NASA's experience with the Space Launch System – which is relying on waivers to meet the radio spectrum needs for its first two launches – illustrates the need for timely consideration of electromagnetic spectrum requirements.

WHAT WE RECOMMENDED

To ensure NASA programs and projects are aware of electromagnetic spectrum requirements and submit a request for radio spectrum certification early in a mission's development cycle, we recommended the Agency clarify its program management policies. NASA concurred with our recommendations and described planned actions. We find the actions responsive and will close the recommendations upon verification the Agency has taken the action.

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Acronyms

EM-1	Exploration Mission-1
FCC	Federal Communications Commission
GAO	Government Accountability Office
GHz	Gigahertz
GPS	Global Positioning System
ISS	International Space Station
ITU	International Telecommunication Union
JWST	James Webb Space Telescope
LLCD	Lunar Laser Communication Demonstration
LADEE	Lunar Atmosphere and Dust Environment Explorer
Mbps	Megabits per second
MHz	Megahertz
NISAR	NASA-Indian Space Research Organisation Synthetic Aperture Radar
NPD	NASA Policy Directive
NPR	NASA Procedural Requirements
NTIA	National Telecommunications and Information Administration
OIG	Office of Inspector General
PACE	Plankton, Aerosol, Cloud, ocean Ecosystem
SCaN	Space Communications and Navigation
SFCG	Space Frequency Coordination Group
SLS	Space Launch System
STA	Special Temporary Authorization
UHF	Ultra High Frequency
VHF	Very High Frequency
WFIRST	Wide Field InfraRed Survey Telescope

INTRODUCTION

Government agencies and commercial entities utilize radio frequency in the electromagnetic spectrum to transmit and communicate information. For example, cell phone companies transmit signals allowing users to communicate via voice and text, and first responders communicate via radio during emergencies. At NASA, personnel rely on radio waves and other portions of the electromagnetic spectrum to communicate with the spacecraft carrying out the Agency's space and science missions, as well as for day-to-day operations.

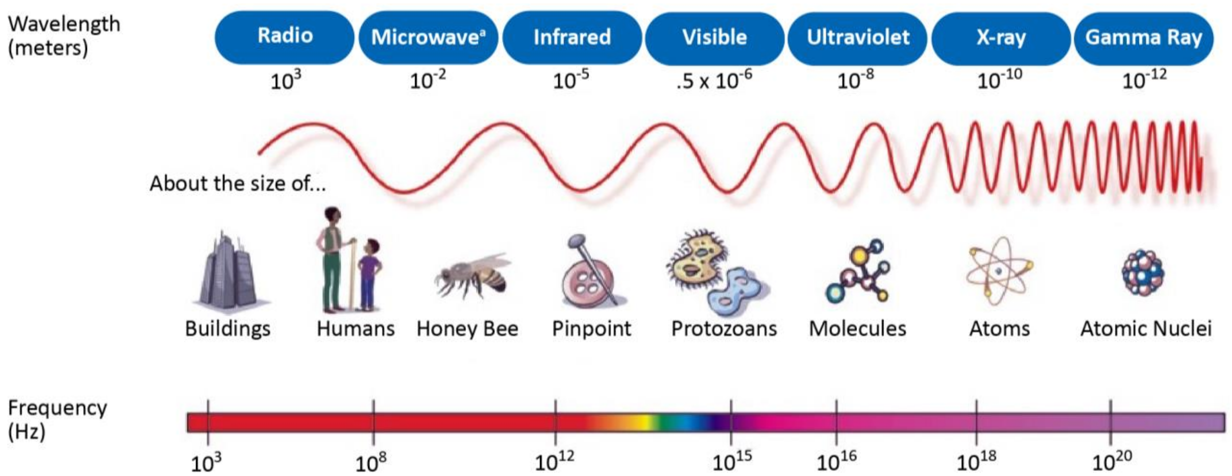
The radio waves of the electromagnetic spectrum – also known as the radio spectrum – are a finite resource. Generally, to avoid interference multiple users cannot transmit radio signals at the same frequencies, at the same time, to the same location. Accordingly, several national and international organizations manage use of radio spectrum for use by Federal agencies and commercial entities. However, as the number of communications devices has dramatically increased in the public and private sectors over the past several decades, the demand for radio spectrum has similarly increased.

In light of this growing demand, and because radio spectrum and other portions of the electromagnetic spectrum are vital to NASA's missions, we initiated this audit to review the Agency's efforts to manage its radio spectrum allocation. This is the fourth in a series of audits by the Office of Inspector General (OIG) examining the various projects managed by NASA's Space Communications and Navigation (SCaN) Program. See Appendix A for details of the audit's scope and methodology.

Background

The electromagnetic spectrum includes radio and microwave waves, infrared light, visible light, ultraviolet light, x-rays, and gamma rays, each of which transmit at different wavelengths (see Figure 1).

Figure 1: Types of Electromagnetic Spectrum and Comparison of Wavelength Sizes



Source: NASA.

[a] Microwaves are considered part of the radio wave spectrum.

Radio waves naturally propagate outward in all directions and are able to coexist in the same physical space with other radio spectrum.[1] To avoid interference, transmitters and receivers operate in specific frequency ranges. Once a particular user stops transmitting signals over a portion of the radio spectrum, it is immediately available to other users.

NASA uses almost every component of the electromagnetic spectrum in its various missions. For example, the Agency uses microwaves that penetrate clouds to make observations of the Earth, infrared waves to view and track hurricane paths, visible waves to take color pictures of the Earth, ultraviolet waves to study the Sun from its core to its outermost layer, x-rays to photograph the Sun, and gamma rays to study the universe. All of these activities and virtually every other NASA undertaking require communications or data transfer via the radio spectrum.

Domestic and International Regulation of the Radio Spectrum

Management of the radio spectrum is governed by both domestic and international regulations.

Domestic Regulation and Coordination

In the United States, responsibility for managing the radio spectrum is divided between two agencies: the Department of Commerce's National Telecommunications and Information Administration (NTIA), which regulates the Federal Government's use of the radio spectrum, and the Federal Communications Commission (FCC), which regulates non-Federal use of the radio spectrum.

- *National Telecommunications and Information Administration.* The NTIA serves as the President's principal advisor on telecommunications and information policy issues, assigns radio frequencies, and allocates the radio spectrum used by the Federal Government, including NASA. Within the NTIA, the Interdepartment Radio Advisory Committee assists NTIA in assigning frequencies to Government radio stations and in developing policies, programs, and technical criteria for radio spectrum allocation. NASA is a member of this Advisory Committee and in that capacity reviews proposals for new radio stations and services, such as broadcasting, meteorological, mobile, radio navigation, and satellite, from other Federal users to determine if they will have an adverse impact on the Agency's existing and planned systems.[2]
- *Federal Communications Commission.* The FCC is an independent Federal agency that regulates interstate and international communications by radio, television, wire, satellite, and cable by assigning radio frequencies and issuing licenses to non-Federal entities. NASA requires commercial entities with which it does business, such as Space Exploration Technologies Corporation (SpaceX), to have an FCC license to transmit or receive data from Agency Tracking and Data Relay Satellites and other Agency assets.

The NTIA and the FCC regulate their respective constituents' use of the radio spectrum and work together to ensure policy decisions affecting radio spectrum use are consistent with Federal

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[1] Radio waves have a wavelength – the distance between wave crests – and a frequency, which is the number of wave crests passing a point in a unit of time. Radio frequency is defined in units known as hertz, which is the number of cycles that occur in one second.

[2] Other members of the Interdepartment Radio Advisory Committee include the Departments of Agriculture, Commerce, Energy, Homeland Security, Interior, Justice, State, Transportation, Treasury, and Veterans Affairs; the Federal Aviation Administration; Broadcasting Board of Governors; National Science Foundation; the U.S. Postal Service; and the U.S. Air Force, Army, Coast Guard, and Navy.

Government user requirements and U.S. economic interests. The NTIA and the FCC have divided the usable radio spectrum into about 800 frequency bands, which are allocated to different types of radio services including broadcasting, Earth exploration, mobile communications, space operation, and space research.[3] For ease of identification, scientists have named the different bands of the radio spectrum according to their wavelengths (see Table 1). Although NASA does not have exclusive use of any of the radio frequency bands, the Agency utilizes parts of nearly all of the bands for different purposes.

Table 1: Letter Designation of Radio Frequency Bands and their Respective Wavelengths

Band	Frequency Range	Wavelength
High Frequency	3–30 megahertz (MHz)	10010 meter
Very High Frequency	30–300 MHz	10–1 meter
Ultra High Frequency	300–1000 MHz	100–30 centimeter
L	1–2 gigahertz (GHz)	30–15 centimeter
S	2–4 GHz	30–15 centimeter
C	4–8 GHz	15–7.5 centimeter
X	8–12 GHz	7.5–3.75 centimeter
Ku	12–18 GHz	3.75–2.5 centimeter
K	18–27 GHz	1.67–1.11 centimeter
Ka	27–40 GHz	11.1–7.5 millimeter
V	40–75 GHz	7.5–4 millimeter
W	75–110 GHz	4–2.73 millimeter

Source: NASA OIG.

International Regulation and Coordination

More than 160 nations work together to develop standards for managing the radio spectrum. Since 1947, the International Telecommunication Union (ITU) has served as the United Nations' agency responsible for issues involving radio frequency bands. The Department of State represents the United States at the ITU and is responsible for international negotiations concerning radio spectrum usage with input from the NTIA and the FCC and with participation and support from domestic Federal agencies. ITU member nations develop global radio frequency management regulations and designate radio spectrum allocations consistent with the international treaty commonly referred to as the Radio Regulations. The Regulations govern the use of the radio spectrum, radio frequency band assignments, allocation plans, and satellite orbits and are revised every 3 to 4 years at the World Radiocommunication Conference.

Formed in January 1980, the Space Frequency Coordination Group (SFCG) provides a forum to discuss and solve radio frequency management problems encountered by space organizations.[4] The SFCG focuses on the use and management of radio frequency bands allocated to space research, space

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[3] Frequency bands have specific technical and operating rules that govern the use of spectrum within those allocations.

[4] In addition to NASA, members include space agencies from Argentina, Australia, Canada, China, France, Germany, India, Italy, Japan, Korea, Russia, South Africa, Ukraine, and the United Kingdom. Additionally, the National Oceanic and Atmospheric Administration is a member along with the European Organisation for the Exploration of Meteorological Satellites and the European Space Agency.

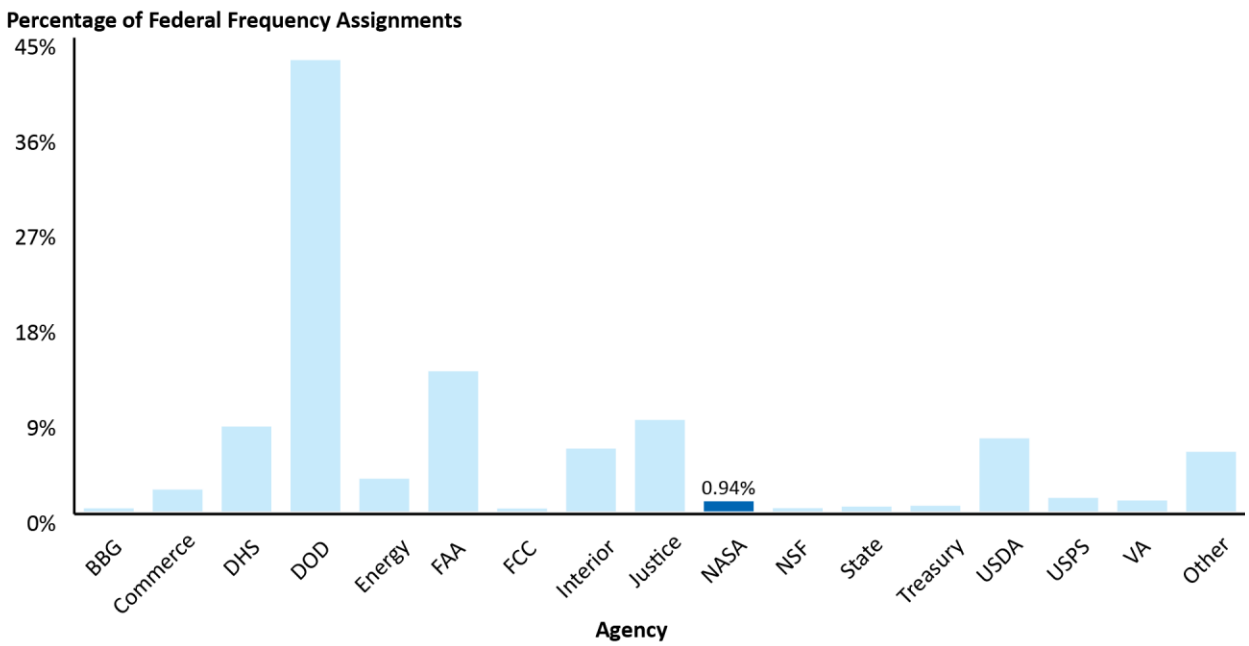
operations, Earth exploration- and meteorological-satellite services, as well as radio navigation satellites, radar astronomy, and radio astronomy. Additionally, SFCG adopts technical and administrative agreements to help make effective use of allocated radio frequency bands and avoid interference.[5]

NASA Radio Spectrum Authorization

Prior to activating a radio transmitter, Federal agencies must obtain a radio frequency authorization. Authorization – via frequency assignments – is the process by which users are licensed to access a frequency or a set of frequencies in the radio spectrum. The authorization sets forth the frequency, location, and power level in which the transmitter may operate.

At the end of fiscal year 2016, the NTIA was tracking more than 240,000 Federal frequency assignments, almost half of which were assigned to the Department of Defense. NASA accounted for 2,261 frequency assignments, or less than 1 percent of all Federal frequency assignments (see Figure 2).[6]

Figure 2: Comparison of Federal Radio Frequency Assignments by Agency, as of September 2016



Source: NASA OIG representation of NASA data.

Note: Broadcasting Board of Governors (BBG), Department of Commerce (Commerce), Department of Homeland Security (DHS), Department of Defense (DOD), Department of Energy (Energy), Federal Aviation Administration (FAA), Department of the Interior (Interior), Department of Justice (Justice), National Science Foundation (NSF), Department of State (State), Department of the Treasury (Treasury), U.S. Department of Agriculture (USDA), U.S. Postal Service (USPS), Department of Veterans Affairs (VA), and non-Interdepartment Radio Advisory Committee Federal agencies (Other).

[5] In June 2016, we attended the SFCG's annual meeting in Mainz, Germany, where we met with spectrum officials from across the globe and observed coordination activities between domestic and international space agencies.

[6] Approximately 70 percent of NASA's radio frequency licenses are for non-space communication. For example, many frequencies are used for aircraft communications or assigned to the handheld radios maintenance crews use.

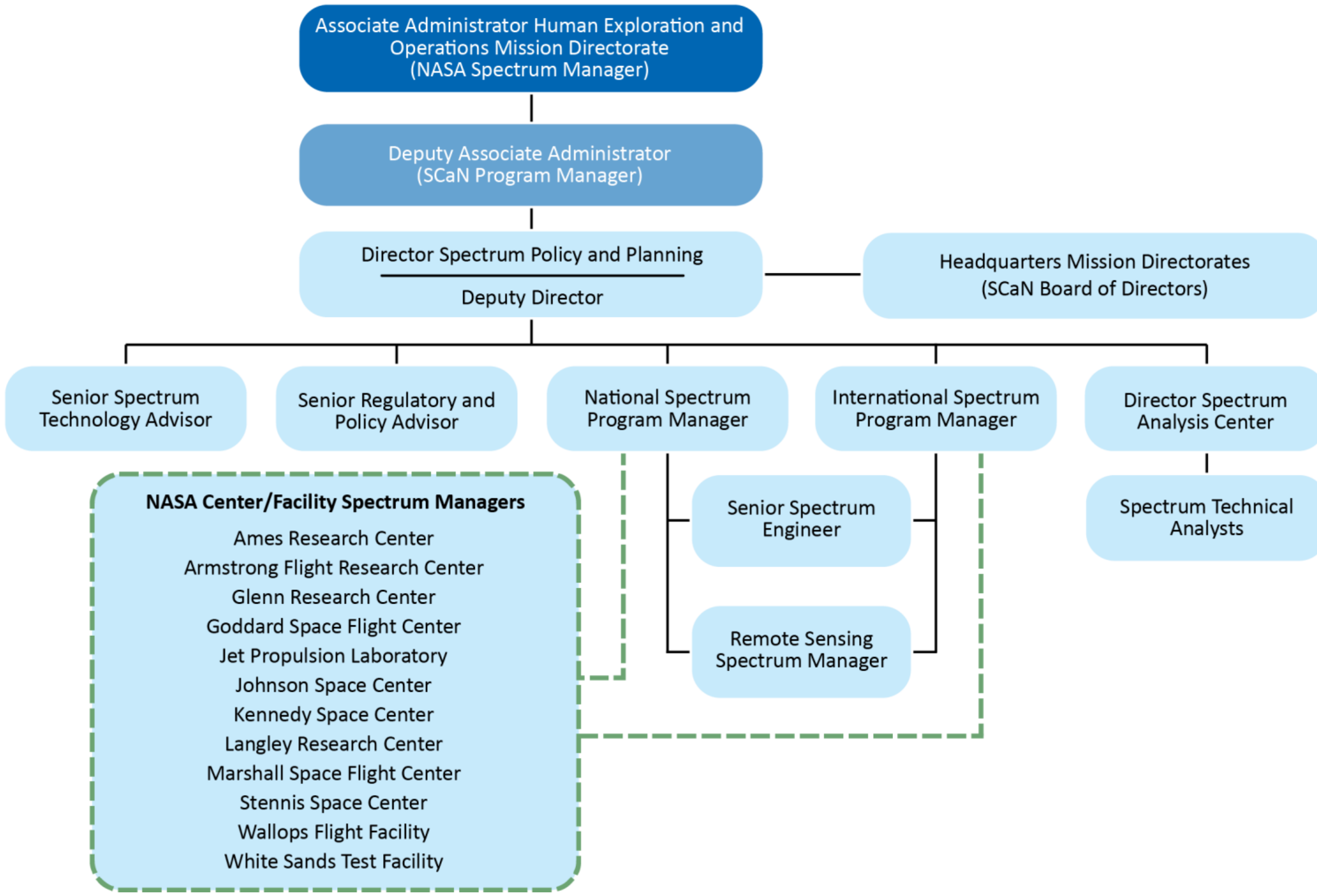
In addition to obtaining its own licenses, which can take weeks or even months to prepare and process, NASA reviews license proposals from other Federal agencies to ensure they will not conflict with Agency operations. During fiscal year 2016, NASA reviewed more than 124,000 such proposals.

NASA's Spectrum Management Responsibilities

NASA's SCaN Program manages both electromagnetic spectrum use at the Agency and the three communications networks the Agency uses to communicate with spacecraft: the Deep Space Network, Near Earth Network, and Space Network. The Deputy Associate Administrator for SCaN oversees the overall planning, policy development, and administration of NASA's Spectrum Management Program. The Director of the Spectrum Policy and Planning Division oversees Agency efforts to obtain adequate national and international allocations of radio frequency bands, coordinates proposed NASA frequency use with other domestic and foreign users, and seeks approval of NASA radio frequency assignments by the NTIA. The Director is also responsible for planning the Agency's long-term national and international electromagnetic spectrum management initiatives. The SCaN Program Office also includes a National Spectrum Program Manager and an International Spectrum Program Manager responsible for implementing electromagnetic spectrum management initiatives and day-to-day electromagnetic spectrum management activities and representing NASA in national and international meetings. In addition, each NASA Center and some Agency facilities have a spectrum manager responsible for obtaining frequency assignments for projects at their locations (see Figure 3).[7]

[7] Some Center spectrum managers also have Agency-wide responsibilities. For example, the Johnson Space Center manager is responsible for frequency selection and protection requirements for all NASA human spaceflight activities, the Goddard Space Flight Center (Goddard) manager for radio frequency selections and protection for all NASA activities requiring use of the S-band, and the Jet Propulsion Laboratory manager for radio frequency selection and protection for all NASA and U.S. deep space missions.

Figure 3: NASA Electromagnetic Spectrum Management Organization



Source: NASA OIG presentation of Spectrum Management Program information.

NASA Policy Directive (NPD) 2570.5E requires any Agency activity directly operated by NASA or supported through Agency contracts or other financial agreements that requires use of the radio spectrum follow U.S. and international radio spectrum management regulations.[8] Every such activity is also required to discuss radio spectrum requirements at each project life-cycle review and submit to the appropriate spectrum manager a request for radio spectrum certification as early in the acquisition and procurement cycles as possible. The purpose of the policy is to ensure radio spectrum requirements are considered early enough in the project's development process to secure needed certifications and ensure compliance with regulatory requirements, thereby avoiding the possibility of costly changes later in the development cycle.

[8] NPD 2570.5E, "NASA Electromagnetic Spectrum Management - Revalidated 9/13/16," July 11, 2011.

NASA Use of Electromagnetic Spectrum

Nearly every NASA mission requires the electromagnetic spectrum for communication or data transfer. Below we discuss in more detail the ways in which the different types of NASA missions use radio and other types of electromagnetic spectrum.

Aerospace and Technology Development

NASA is developing technology solutions for space transportation and to support a safe and efficient national aviation system. In addition to flight test and research operations for experimental aircraft, NASA also operates unmanned aeronautical vehicles and scientific balloons. The Agency requires access to the radio spectrum in order to test new technology endeavors. For example, NASA uses the radio spectrum to send command and control information to unmanned vehicles and to receive video and other data generated from experimental and remotely piloted aircraft and scientific balloons.

Earth Science

Aura, the Soil Moisture Active Passive, and other NASA Earth science missions use the electromagnetic spectrum to transmit data from spacecraft and satellites to ground stations.[9] The Agency uses two primary types of Earth observation sensors – active and passive. Active sensors emit radiation in the direction of the target to be investigated and detect and measure the radiation reflected or "backscattered" from the target. The majority of active sensors operate in the microwave portion of the electromagnetic spectrum, which allows them to penetrate the atmosphere. Passive sensors detect radiation emitted or reflected by the object being observed. Most passive systems used in remote sensing applications operate in the microwave, infrared, and visible portions of the electromagnetic spectrum. The data collected by these sensors is then transmitted by radio link to facilities back on Earth.

Human Space Flight

NASA's human space exploration programs, including the International Space Station (ISS), the Orion Multi-Purpose Crew Vehicle (Orion), and the Space Launch System (SLS) all require access to radio frequencies to support their operations.[10] For example, the ISS utilizes the S and Ku bands for vital command and control transmissions. Orion and SLS will also rely on the S-band for primary command and control transmissions, as well as the C, L, and Ultra High Frequency bands to support other functional requirements. See Appendix B for a sample of frequency assignments associated with Orion and SLS.

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[9] The satellite Aura, launched in 2004, studies the chemistry of the Earth's atmosphere by taking measurements that enable scientists to investigate questions about ozone trends and air quality changes and their link to climate change. Launched in 2015, the Soil Moisture Active Passive mission was designed to help scientists understand the links between Earth's water, energy, and carbon cycles and to enhance the ability to monitor and predict natural hazards such as floods and droughts.

[10] Orion will provide NASA with the capability to transport astronauts beyond low Earth orbit. The SLS is NASA's next generation launch vehicle.

Space Science

Cassini, Voyager 1 and 2, and other NASA space science missions that travel to the outer edges of the solar system require highly reliable communications over great distances for long periods of time.[11] Accordingly, NASA uses high power transmitters and sensitive receivers at Earth-based stations to communicate with these missions. Because multiple deep-space missions may operate simultaneously for a dozen or more years, NASA uses the radio frequency bands allocated for these missions nearly continuously. Spectrum in the S, X, and Ka bands has been allocated to support these missions.

NASA Communications Networks Use of the Radio Spectrum

NASA uses three communications networks to communicate with spacecraft: the Deep Space Network, Near Earth Network, and Space Network.[12] The Deep Space Network is a central component of the Agency's space communications and navigation capability, providing deep space missions with tracking, telemetry, and command services needed to control spacecraft and transmit data. The Deep Space Network uses antennas in the United States, Spain, and Australia, which operate on the S, X, and Ka bands, to communicate with spacecraft operating beyond low Earth orbit.[13] The Near Earth Network supports missions through a mixture of NASA-owned tracking stations, other Federal Government agencies' stations, and domestic and foreign commercial service providers. The Near Earth Network relies primarily on the S and X bands but supports downlink capabilities via the Ka-band. The Near Earth Network also provides emergency voice communication for ISS and the Soyuz spacecraft via the Very High Frequency (VHF) -band.[14] The Space Network uses a combination of ground stations and space-based Tracking and Data Relay Satellites to transmit information between Earth and spacecraft owned by NASA, other Federal agencies, and commercial entities.[15] In addition to the S and Ka bands, the Space Network uses the Ku-band to communicate with the ISS and other spacecraft. See Figure 4 for more information on the three networks.

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[11] Cassini, launched in 1997, is studying Saturn, its rings, and moons. Since launching in 1977, Voyager 1 and Voyager 2 have explored many of our solar system's planets and continue its journey through interstellar space.

[12] The OIG has published reports on each of the Networks: "Audit of NASA's Management of the Near Earth Network" (IG-16-014, March 17, 2016); "Audit of NASA's Management of the Deep Space Network" (IG-15-013, March 24, 2015); and "Space Communications and Navigation: NASA's Management of the Space Network" (IG-14-018, April 29, 2014).

[13] Spacecraft launched in the 1960s communicated on the S-band, while the X-band came into use in the 1970s and the Ka-band in the 2000s. Many spacecraft have dual frequency capability (e.g., S/X and more recently X/Ka). The use of higher frequencies for data transmission allows larger bandwidths, which enables faster transmission of larger amounts of data and better tracking capability.

[14] Since retirement of the Space Shuttle in 2011, the Russian Federal Space Agency (Roscosmos) has been transporting astronauts to the ISS on the Soyuz spacecraft.

[15] Tracking and Data Relay Satellites relay data to a designated spacecraft and return data from the spacecraft to a NASA Space Network ground station, which in turn sends the data to a location designated by the spacecraft owner or customer.

Figure 4: NASA Networks and the Radio Frequency Bands they Support

	Deep Space Network		Near Earth Network		Space Network	
						
Description	• Three-station global network of large-scale antennas (34- and 70-meter) • Focused on detecting and differentiating faint signals from stellar noise • Optimized for data capture from deep space distances orders of magnitude above near Earth		• World-wide network of stations • Utilizes NASA-owned assets and commercial services • Back-up capability through partnerships		• Global orbital satellite communications fleet with ground control stations • Optimized for continuous, high data rate communications • Critical for human space flight safety and critical event coverage	
Radio Frequency Bands Supported by the Networks						
Data Transmission/ Band	Up/Forward Link	Down/Return Link	Up/Forward Link	Down/Return Link	Up/Forward Link	Down/Return Link
S	✓	✓	✓	✓	✓	✓
X	✓	✓		✓		
Ku					✓	✓
Ka	✓	✓		✓	✓	✓

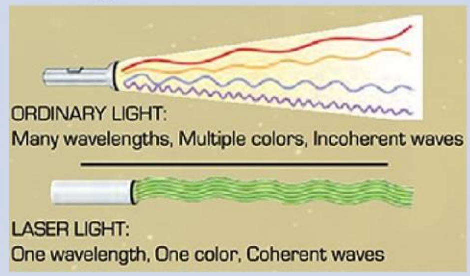
Source: NASA OIG presentation of NASA information.

The radio spectrum capabilities of the Deep Space, Near Earth, and Space Networks have inherent limitations. For example, the lower radio frequency bands (S and X bands used for space science missions) provide limited bandwidth and low data transfer rates and are becoming heavily congested. Radio spectrum below 10 gigahertz is heavily used by Earth and human exploration programs and faces increasing pressure to reallocate some bandwidth for commercial wireless broadband. Accordingly, NASA is working to increase its communication capabilities by encouraging greater use of the less congested and higher capacity Ka-band for both near Earth and deep space missions. The Agency is also testing optical communications that use two-way lasers located in space and have data transmission rates 10 to 1,000 times faster than traditional radio frequencies. For example, it would take 9 years to transmit the data needed to create a Google map of Mars using the best radio frequency technology available today. Using laser technology, that same data could be transmitted from Mars in 9 weeks.

Lunar Laser Communication Demonstration

For decades NASA's space communications networks have relied on the radio spectrum to transmit critical science data from spacecraft to Earth. While the radio spectrum has been the most reliable form of communication across the vast distances of space, it has struggled to meet the data rate demands of current science missions. Another motivation for exploring laser communications is the development of more efficient, cost-effective space communications equipment. Because radio-frequency wavelengths are longer, the size of their transmission beam covers a wider area; therefore, receiving antennas for radio-frequency data transmissions must be very large, such as the 34-and 70-meter antennas used by the Deep Space Network. Laser wavelengths are 10,000 times shorter, allowing data to be transmitted across narrower, tighter beams. The narrow wavelengths of laser-based communications are also harder to intercept and therefore more secure. However, the smaller collecting antennas are also more susceptible to atmospheric interference. This reduction in antenna size applies for both ground and space receivers, which reduces satellite size and mass. Laser communication terminals can support higher data transmission rates with lower mass, volume, and power requirements and represent a cost savings for future missions.

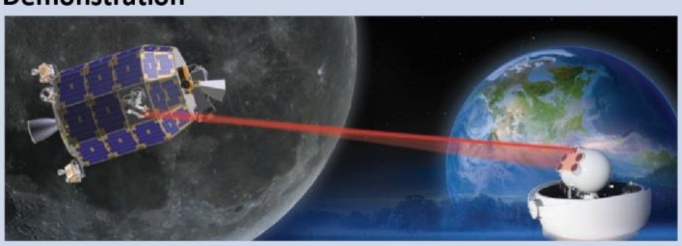
Comparision of Ordinary Light and Laser Light



Source: NASA.

The Lunar Laser Communication Demonstration (LLCD) – launched aboard the Lunar Atmosphere and Dust Environment Explorer (LADEE) mission in September 2013 and completed in April 2014 – was the first NASA mission to demonstrate two-way, high-rate laser communications from Lunar orbit. The main goal of LLCD was to prove the fundamental concepts of laser communications and maintain a data transfer rate of 622 megabits per second (Mbps). For example, using S-band communications the LADEE spacecraft would normally take 639 hours to download an average-length, high-definition movie. Using LLCD technology, download times would be reduced to less than 8 minutes. LLCD made history by using a pulsed laser beam to transmit data the 239,000 miles from the Moon to the Earth at a download rate of 622 Mbps. In addition, scientists transmitted at an error-free data upload rate of 20 Mbps from the primary ground station in New Mexico to LADEE.

NASA's First Space Laser Communication System Demonstration


Source: NASA.

Growing Demands on NASA's Radio Spectrum

NASA's access to the radio spectrum is being challenged both by increasing demand from the Agency's own missions and growing demand from outside users.

More Complex NASA Missions

Future NASA missions are expected to generate more data than their predecessors, which could overwhelm the radio frequency band allocations NASA missions currently share. Missions such as the James Webb Space Telescope (JWST), Wide Field InfraRed Survey Telescope (WFIRST), and NASA-Indian Space Research Organisation Synthetic Aperture Radar (NISAR) will demand higher bandwidths to transmit increasing amounts of science and engineering data.[16] For example, as JWST studies every phase in the history of our universe, it will produce approximately 235 gigabits of science and engineering data every day. Similarly, WFIRST is being designed to answer questions about dark energy, exoplanets, and infrared astrophysics and will downlink science data at a rate up to 300 Mbps. Finally, at a downlink data rate of 1.5 gigabits per second in the Ka-band, NISAR will acquire radar images of changes to the Earth's surface and produce images to detect local changes and measure regional trends.

National Broadband Plan

In June 2010, President Obama directed the Secretary of Commerce, through the NTIA, to collaborate with the FCC to develop a 10-year plan for making 500 megahertz (MHz) of Federal and non-Federal radio spectrum available for the wireless broadband industry through a combination of Federal and non-Federal radio spectrum sharing and reallocation of Federal radio spectrum for the exclusive use of non-Federal entities.[17] In response, in October 2010 the FCC released its National Broadband Plan.[18] The Plan recommended that the FCC establish incentive auctions to free up radio spectrum and provide a portion of the auction revenues to incumbents as an incentive for giving up radio spectrum entirely or giving up a portion of licensed channels and sharing the remaining capacity.[19] Although sharing among Federal agencies is already widely practiced, sharing between Federal and non-Federal entities in bands currently dedicated to Federal use marks a point of departure from past practices and is largely untested in many bands.

Commercial Space

NASA's Spectrum Management Program has also been challenged by the Agency's agreements with commercial companies to transport cargo and, in the near future, crew to the ISS.[20] Even though these companies are working on NASA's behalf, they are considered a commercial operation under the

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16 JWST is NASA's follow-on to the Hubble Space Telescope and is scheduled to launch in late 2018 from French Guiana and will orbit the Sun 1 million miles away from the Earth. WFIRST, currently in its early development phase, is planning for a mid-2020 launch, while NISAR is preparing for a 2021 launch.

17 White House, "Presidential Memorandum: Unleashing the Wireless Broadband Revolution," June 28, 2010.

18 Department of Commerce, "Plan and Timetable to Make Available 500 Megahertz of Spectrum for Wireless Broadband," October 2010.

19 In 2012, Congress authorized the FCC to utilize incentive auctions and use the proceeds to reimburse agencies for repurposing costs, meet deficit reduction goals, and provide funding for a planned national first responder network. The incentive auction was held in 2015 and generated almost $45 billion.

20 To date, NASA has agreements with Orbital ATK, Sierra Nevada Corporation, and SpaceX for cargo transportation and The Boeing Company and SpaceX for crew transportation.

jurisdiction of the FCC. NASA worked jointly with the NTIA, FCC, and other Federal agencies to reach an agreement to allow use of a specific portion of the Federal-only radio spectrum for each NASA cargo resupply mission through the FCC-issued, single-mission Special Temporary Authorization (STA) license grant.[21] Before an STA license is issued, the FCC must coordinate with the NTIA to determine the likely impact on existing and planned Federal radio spectrum use.

SmallSats

NASA's radio spectrum resources have been affected by the emerging market for small satellites (SmallSats) – spacecraft with a mass of less than 180 kilograms (approximately 400 pounds).[22] CubeSats – the most common type of SmallSats – provide a cost effective platform for science investigations and technology demonstrations (see Figure 5).[23] To date, most SmallSats operate with an experimental license on a noninterference basis and therefore must accept any interference from and not cause interference to systems that operate in the frequency band on a primary basis.[24] According to Agency officials, the primary concerns regarding SmallSats use of spectrum are that they sometimes operate in radio frequency bands outside of their allocated uses or fail to coordinate spectrum needs prior to operation. Both of these issues could result in interference or performance degradations to NASA missions.

Figure 5: CubeSat Example

Lunar IceCube

Description: $7.9 million	
Goals: Search for water ice and other resources on the lunar surface	
Science Area: Planetary	
Status: In development	

Source: NASA OIG presentation of National Academies of Sciences information.

21 STA licenses generally are valid for 6 months or less.

22 SmallSats include minisatellites, which typically weigh between 100 and 180 kilograms; microsatellites, which weigh between 10 and 100 kilograms; nanosatellites, which weigh between 1 and 10 kilograms; picosatellites, which weigh between 0.01 and 1 kilograms; and femtosatellites, which weigh between 0.001 and 0.01 kilograms.

23 CubeSats standards were originally developed in 1999 by professors from California Polytechnic State University at San Luis Obispo and Stanford University to provide a platform for education and space exploration. The standard CubeSat size uses one unit, or 1U, measuring 10x10x10 centimeters but is expandable to larger sizes.

24 The FCC's experimental licensing rules are designed to make it easier for users such as higher education institutions and manufacturers to develop, test, and bring new radio frequency devices to market. An experimental license is granted for less than 5 years for a specific project or a series of related experiments or for a product development or market trial.

Numerous private organizations and Federal agencies including NASA are working with SmallSats, primarily through educational or technology development projects. Between 2003 and 2015, more than 520 SmallSats were launched, including 200 supported and facilitated by NASA through funding, launch support, or deployment from the ISS. As the science objectives of SmallSats become more ambitious, their bandwidth requirements – and associated regulatory challenges – are also expected to grow. Indeed, NASA is participating in domestic and international studies on a possible new radio frequency for short duration missions (up to 3 years on-orbit life) to be discussed at the next World Radiocommunication Conference.

This complex and competitive environment for electromagnetic spectrum presents challenges and opportunities that are redefining how NASA manages this essential but finite resource.

NASA IS EFFECTIVELY MANAGING CHALLENGES TO ITS RADIO SPECTRUM ACCESS

NASA faces several challenges in ensuring its current and future missions have adequate access to the radio spectrum. First, the Agency must comply with Federal initiatives designed to make additional radio spectrum available to the mobile broadband industry. Second, NASA must share the radio spectrum historically reserved for Federal users with the emerging commercial space launch industry. Third, the proliferation of SmallSats is straining already congested radio spectrum resources. Finally, future NASA missions are expected to require higher data transmission rates, which could overwhelm the radio frequency band allocations the Agency currently uses. NASA has been proactive in addressing each of these challenges by collaborating with other Federal Government and commercial space launch industry users and regulators worldwide, pursuing new technologies, and issuing guidance to Agency radio spectrum users. However, the Agency could clarify its policies to ensure Agency programs and projects consider radio spectrum requirements at appropriate times in their development life cycles to avoid later costly design changes or, in extreme cases, a launch delay.

Radio Spectrum Management is Complex and Constantly Changing

NASA uses the radio spectrum to facilitate communications and data transfer. As the complexity and number of uses for the radio spectrum has grown, the responsibilities for coordinating radio spectrum management have also become increasingly complex.

Growth of Mobile Broadband

The growth of commercial wireless broadband services, including smart phones and tablet computers, are crowding radio frequency bands and prompting Federal initiatives to identify federally allocated portions of the radio spectrum that could be shared or reallocated. However, sharing and reallocating the radio spectrum could adversely impact NASA operations, result in loss of frequency allocations, or necessitate costly modifications to existing communications networks. In 2010, the Department of Commerce released its National Broadband Plan, which seeks to make available to commercial entities 500 MHz of the radio spectrum through sharing or reallocation. In June 2016, the Department of Commerce reported it had achieved nearly half of its goal at the end of fiscal year 2015 by making available 245 MHz of radio spectrum for wireless broadband technologies, of which 140 MHz came from Federal or shared radio spectrum.[25] As part of this plan, NASA relinquished one radio frequency band and performed technical studies to demonstrate the impact reallocation of other bands would have on the Agency.

[25] Department of Commerce, "Sixth Interim Progress Report on the Ten-Year Plan and Timetable," June 2016. The Department of Commerce further reported that 205 MHz of additional radio spectrum is being studied and 955 MHz of radio spectrum has been identified for potential future study (https://www.ntia.doc.gov/files/ntia/publications/ntia_6th_interim_progress_report_on_ten-year_timetable_june_2016.pdf, last accessed February 15, 2017).

Increased Sharing

In July 2012, the President's Council of Advisors on Science and Technology addressed concerns related to the effectiveness of reallocating and auctioning Federal radio spectrum to meet the President's goal of freeing up 500 MHz and recommended the Government identify and share 1,000 MHz of "underutilized Federal spectrum to the maximum extent possible."[26] Radio spectrum sharing among Federal agencies, including NASA, is already widely practiced to gain efficiencies from crowded Federal radio spectrum bands. As congestion increases, NASA requires its missions to use the radio spectrum as efficiently as practical. This can be accomplished through mission design, advanced coding, software-defined radios, cognitive radios, and smart antennas.[27] However, policymakers are pressing forward with assessing how radio frequency bands, including frequencies in the 5 gigahertz range, can be shared between Federal users and new commercial wireless applications on an unlicensed use basis.[28] According to NASA officials, shared use of this portion of the radio spectrum has already impacted operations because the Agency uses these radio frequency bands for test and launch range instrumentation radars to track launch vehicles and for downlink transmissions of data to ground control receivers to operate unmanned aerial vehicles.

Although radio spectrum sharing initiatives have yet to negatively affect NASA, a 2015 radio spectrum incentive auction with the private sector has reinvigorated the FCC's search to identify, clear, and reallocate radio spectrum needs to meet demand.

Reallocation

In 2013, the NTIA notified the FCC that a portion of the L-band previously allocated to Federal users was available to be reallocated toward the 500 MHz goal. As part of the process, NASA identified one project that would be impacted by the reallocation: an antenna at Langley Research Center (Langley) used to uplink data, video, and commands to research aircraft and unmanned aerial vehicles. NASA determined it could upgrade the antenna system and move future transmissions onto the C-band without impacting operations. The entire process is expected to cost $1 million and take approximately 5 years, with completion of the new antenna targeted for June 2017. To finance the changes, NASA received money from the FCC's 2015 incentive auction.

Criticality of Protection

NASA has gone to great lengths to ensure other radio frequency bands critical to its operations are not reallocated. For example, the 2200 to 2290 MHz radio frequency in the S-band was targeted for consideration; however, this band is the Agency's "backbone spectrum band" that supports communication for the ISS and other projects. Many of the world's space agencies also operate communications networks in this range. The Agency's effort to protect this band began in 2010,

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[26] The President's Council of Advisors on Science and Technology is an advisory group of scientists and engineers appointed by the President. The Council makes recommendations to the President on a wide range of science, technology, and innovation issues and is used to augment the science and technology advice available from inside the White House and other Federal agencies.

[27] Software-defined radios can be programmed to transmit and receive on multiple frequencies within the limits of their hardware designs. Cognitive radios sense unused frequencies and can adapt in real-time to automatically make use of those frequencies. Smart antennas can direct transmissions towards specific receivers thereby reducing interference.

[28] Unlicensed use allows users to operate without an operator-specific FCC license but must still use FCC certified radio equipment and comply with technical requirements. However, the users may cause interference to licensed users or equipment and are subject to interference.

involved numerous studies, and culminated at the November 2015 World Radiocommunication Conference, where International Telecommunication Union (ITU) parties agreed not to change the Radio Regulations, thus ensuring protection of the band.

NASA was also able to successfully defend the L-band, which the Agency uses for the Global Positioning System (GPS).[29] The L-band frequencies used by GPS are also considered ideal for mobile communications because the transmissions are not as susceptible as higher frequencies to weather conditions. NASA has a number of GPS-dependent applications, including ground-based, airborne, and space-based receivers used to support Earth science research, weather forecasting, disaster monitoring, ground calibration of instruments on orbit, and precision navigation for aircraft and spacecraft. For example, spacecraft approaching the ISS use GPS for positioning and navigation during critical rendezvous and docking operations. A degradation or interference in the signal could disrupt the precision of the spacecraft's orientation.[30]

In November 2010, LightSquared Subsidiary LLC (LightSquared) filed a petition with the FCC requesting permission to create what the company billed as the first-ever, nationwide 4G-LTE wireless broadband network.[31] The company's proposal concerned NASA, the Department of Defense, and other GPS users because the bandwidth assigned to LightSquared would abut the radio spectrum reserved for GPS devices, and its proposed technology might interfere with and overwhelm signals used by GPS devices. In 2011, NASA and other Federal agencies and industry conducted tests to determine if LightSquared's planned use would interfere with GPS devices that receive signals on the neighboring band. These tests concluded there would be significant and harmful interference to terrestrial- and space-based GPS receivers were the plan permitted to proceed.[32] Subsequently, the FCC barred the company from launching its network as planned, and in 2012 LightSquared filed for Chapter 11 bankruptcy protection. In 2015, after exiting bankruptcy under a different set of owners and new name – Ligado Networks – the company proposed a new plan in the hopes of mitigating interference concerns. This plan permanently foregoes use of the frequencies closest to the GPS range and reduces the power of its signals. New studies led by the Department of Transportation are underway to determine if the revised plan would interfere with existing GPS frequencies.[33] The LightSquared/Ligado example underscores the challenges NASA faces in balancing concerns about protecting mission critical NASA operations from interference and meeting Federal requirements to provide capacity for new commercial mobile broadband services.

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[29] GPS is a space-based navigation system that uses a network of satellites in orbit around the Earth to provide positioning, navigation, and timing 24 hours a day. GPS is owned and operated by the Federal Government, paid for by taxpayers, and managed at a national level as a multi-use asset. Like FM radios, GPS is a one-way broadcast and can accommodate an unlimited number of users with free access to civilian GPS signals.

[30] Harmful radio frequency interference is defined by the ITU as "interference which endangers the functioning of a radio-navigation service or of other safety services or seriously degrades, obstructs, or repeatedly interrupts a radio-communication service operating in accordance with Radio Regulations."

[31] LightSquared sought authorization from the FCC to augment its existing satellite mobile phone service with 40,000 ground-based cell towers to expand its mobile phone operations. LightSquared claimed that the additional cell towers would allow American consumers to stay connected to the Internet and make telephone calls anywhere in the United States regardless of their proximity to existing towers.

[32] NASA OIG "Report of Investigation into Allegations that Members of a NASA-Supervised Advisory Committee Violated Federal Conflict of Interest Laws," August 2, 2012.

[33] NASA has determined the proposed system would still cause harmful interference to its operations that utilize GPS.

Radio Spectrum Allocations for the Emerging Commercial Space Sector

As non-Federal entities, SpaceX and NASA's other commercial space flight partners may only operate as secondary users on a case-by-case basis in radio frequency bands allocated for Federal use. This means they may be permitted to use the radio spectrum but must accept any interference from and not cause interference to the Federal systems that operate there on a primary basis.[34] In addition, because they are commercial companies, the FCC is the regulatory agency responsible for issuing their licenses. In the case of an application for access to the Federal-only portion of the radio spectrum, the FCC is required to obtain NTIA approval prior to granting a license for commercial application and then issues a STA to NASA's partners to allow them to use federally allocated frequencies.

To prevent interference to ongoing operations, the FCC routes the STA license application through the NTIA to allow primary Federal users the opportunity to place conditions on the applicant's use of the radio spectrum. The conditions placed on a license, which may include limitations on a particular radio frequency band, bandwidth, power, operating locations, or a real-time coordination request prior to transmission, are recorded on the NTIA's formal evaluation response to the FCC. The FCC then sends the approved license, caveated with specific NTIA conditions, to the applicant. The agreed minimum timeframe for the NTIA review and approval process is 14 business days, and STA licenses are valid for approximately 6 months. For NASA's commercial space flight partners, an FCC license for both the launch vehicle and the spacecraft are required prior to launch. NASA's Spectrum Managers are involved in the application evaluation process to ensure protection of NASA mission requirements.

In May 2013, the FCC issued a Notice of Inquiry and a Notice of Proposed Rulemaking seeking comments from the public on the allocation of Federal-only radio spectrum for non-Federal space launch operations (excluding spacecraft).[35] The May 2013 Notices offered several alternatives for providing Federal-only radio spectrum for launch vehicle use during commercial space launches. However, as of February 2017, the FCC has not promulgated new regulations. Given the importance of NASA's commercial space flight partners in providing cargo and crew transportation to the ISS, it is imperative the Agency continue to work with Federal regulators as they restructure the regulatory and licensing oversight of commercial space activities.

[34] Systems operating under a primary allocation are granted priority of use and have the right to be protected from interference from other potential users. Systems operating under a secondary allocation must protect all systems operating under primary allocations in the same band and must not cause harmful interference to but must accept interference from primary users. Current U.S. regulations allow for commercial use of NASA's Tracking and Data Relay Satellites within a small portion of the S-band. NASA commercial cargo and crew vehicle partners designed their space communications to utilize the Federal-only allocation of the S-band in order to leverage communication support from NASA's Tracking and Data Relay Satellites.

[35] The FCC will issue a Notice of Inquiry to ask the public to comment on specific questions about an issue. The responses will help the FCC to determine if further action is warranted. The FCC will issue a Notice of Proposed Rulemaking to seek comments on proposed new rules or changes to existing rules.

Growth of SmallSats

NASA's involvement with SmallSats continues to grow. For example, the Agency is planning to provide a launch opportunity for 13 U.S. and foreign private and government SmallSats on Exploration Mission-1 (EM-1) – the first launch of the combined Orion-SLS planned for November 2018.[36] In October 2016, NASA announced creation of the Small Spacecraft Systems Virtual Institute to promote innovation, identify emerging technology opportunities, and provide communication about SmallSat systems with industry, academia, and other Federal agencies.

According to NASA spectrum management officials, SmallSats have a relatively short development and operational period and sometimes there is not enough time to secure the necessary radio frequency license before launch. To this end, NASA has allowed some SmallSats to be launched to the ISS before they received approval for Federal-only radio spectrum use provided they met all NASA safety requirements and accepted the risk they may not deploy if the license could not be obtained.[37]

NASA officials told us that the growth of SmallSats has increased Spectrum Managers' workload. If the SmallSat is NASA-sponsored, the Spectrum Manager works with Agency officials to obtain the NTIA authorization. If the SmallSat is operated by a commercial entity but will be launched on an Agency vehicle, the Spectrum Manager is required to analyze the SmallSats' communication requirements to ensure they will not conflict with the needs of NASA missions and have secured the required regulatory license for on-orbit operations.

Demand for High Data Rates

Future Earth observing missions are expected to generate more data than past missions, which could overwhelm the capacity of radio frequency band allocations NASA missions currently share. Most of NASA's current missions rely on the heavily congested S and X bands, which are also limited by bandwidth, particularly for space science. For instance, as of 2016 the Mars Reconnaissance Orbiter had sent back to Earth more than 200,000 gigabits of data.[38] Even at its top data transmission rate of 5.2 Mbps, the Mars Reconnaissance Orbiter requires 7.5 hours to empty its onboard recorder and 1.5 hours to send a single, high-resolution image back to Earth for processing. By comparison, JWST will produce approximately 235 gigabits of science and engineering data every day and will require a bandwidth higher than 10 Mbps. To keep up with demand, the Agency must find ways to more efficiently use electromagnetic spectrum, including upgrading its network infrastructure or utilizing less crowded radio frequency bands.

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[36] Secondary payloads on EM-1, the 13 SmallSats will carry science and technology experiments related to future human exploration in deep space, including a possible mission to Mars. While most SmallSats are limited to low Earth orbit, these 13 SmallSats are intended for Lunar and deep space orbits.

[37] For example, launched in 2015 onboard a cargo resupply mission to the ISS, the Satlet Initial-Mission Proofs and Lessons (SIMPL) cubesat is in a nonoperational status because it does not have an approved FCC license to transmit on the S-band frequency. Despite having submitted a license request multiple times, the FCC denied the developer a license because of concerns about frequency interference with existing users. The FCC license was expected in September 2016 after NASA concurrence. Until the license issue is resolved, the SIMPL radio is disconnected from the antenna and power.

[38] Mars Reconnaissance Orbiter, launched in August 2005, entered Martian orbit in March 2006 to map the planet's landscape and study its climate, atmosphere, and geology.

NASA is Proactively Responding to Challenges but Needs to Clarify Policies

NASA has been proactive in addressing the challenges posed by the expansion of commercial wireless communications by collaborating with radio spectrum users and regulators and pursuing technological advances to address the needs of missions requiring higher data transmission rates. In addition, the Agency has developed policies to provide guidance and support to programs and projects that require radio spectrum. However, NASA's program management policies do not include key radio spectrum requirements, which increases the risk that project developers – especially SmallSat developers who may be unfamiliar with NASA processes – will not incorporate radio spectrum requirements in a timely manner. This in turn increases the risk a project will have to make costly design changes or miss a planned launch date. Indeed, NASA is relying on waivers to meet the data rate needs for the first two launches of SLS because the system's design does not conform to NTIA spectrum requirements.

Collaboration across the Spectrum Community

The NASA Spectrum Management Office routinely engages in formal and informal collaboration and coordination activities with stakeholders to advance the Agency's long-term objectives. NASA officials coordinate radio spectrum use not only within the Agency, but also with Federal agencies and private entities, the commercial space industry, and other space-faring nations.

Through the Agency's participation with the Interdepartment Radio Advisory Committee, NASA reviews proposals for new radio services and stations from Federal and non-Federal users in bands where regulatory jurisdiction is shared by the NTIA and the FCC to determine if the new proposals will have an adverse impact on the Agency's existing and planned missions. Affected users can negotiate directly with the Federal agency involved and develop technical resolutions to potential problems. NASA's participation in ITU allows for detailed coordination between space system and ground station users. For example, the Agency's involvement in ITU led NASA to identify the need to change the Radio Regulations to mitigate interference between space research service ground stations and mobile aircraft stations operating in the S-band. NASA's participation in the Space Frequency Coordination Group (SFCG) is especially important as it provides the opportunity for a unified position for space science interests that can be presented at ITU conferences. For example, SFCG member agencies identified the need for an Earth-to-space radio spectrum allocation for future space research service missions that will explore the solar system and operate from both low Earth orbit and deep space. Based primarily on the efforts of the SFCG at the 2015 World Radiocommunication Conference, ITU members agreed to this allocation to enable communication with future missions.

NASA also coordinates with multiple internal, domestic, and international radio spectrum management stakeholders, and internal coordination efforts between programs is especially crucial to effectively manage the Agency's use of radio spectrum. For example, both the Orion and SLS vehicles require radio frequency assignments for their communication systems and both Programs worked with the Johnson Space Center (Johnson) Spectrum Manager to resolve conflicts and obtain frequency assignments. Moreover, since Orion and SLS will be launched as an integrated system, it is also imperative the two communication systems do not interfere with one another. Collaboration between the Orion and SLS Programs revealed that a SLS transmitter and antenna shared Orion's primary telemetry frequency. The SLS Program was able to change its transmitter and antenna frequency to avoid interfering with Orion.

NASA is in the process of addressing interference concerns related to contacting the Russian Soyuz capsule in case of an emergency en route to the ISS. The Russian Space Agency uses the VHF-band to provide two-way voice communications between its Soyuz spacecraft and its ground station during crew transportation to the ISS, and as such the flight is routinely handled using Russian ground station coverage. In 2014, a Soyuz vehicle carrying NASA astronauts to the ISS experienced an anomaly requiring the spacecraft to extend its mission and continue orbiting the Earth.[39] Although the Russian Space Agency was in control of the flight, NASA wanted to talk directly to its astronauts from Mission Control at Johnson but was not authorized to do so because the portion of the VHF-band used by the Soyuz is authorized for civil aviation safety operations in the United States and would have caused harmful interference to American Airlines' operations. To prevent similar scenarios in the future, NASA coordinated with the Federal Aviation Administration; American Airlines; and the Aviation Spectrum Resource, Inc., a group that manages radio communication licensing for the U.S. aviation industry. This effort developed an annual test between NASA ground stations and the ISS-docked Soyuz for emergency preparedness exercises and emergency procedures for communicating with astronauts traveling on a Soyuz while minimizing impacts to American Airline's operations.

Advancements in Technology Development

Crowded and limited radio frequency bands have prompted NASA to search for ways to more efficiently use the electromagnetic spectrum. For example, the Agency is building spacecraft that will operate on less crowded radio frequency bands, upgrading existing infrastructure at each of the NASA Networks, and investing in optical communication capabilities. According to NASA spectrum management officials, without new innovations current radio-spectrum-based communication links could be overwhelmed by the amount of data sent by current and future missions.

As discussed earlier, JWST will downlink 235 gigabits of science data every day at a rate of 10 Mbps utilizing the Ka-band. However, JWST's initial operational concept planned for an 8 Mbps downlink utilizing the X-band, which would require 8 hours per day of contact time with antennas on the Deep Space Network. At the time, Deep Space Network officials were reluctant to commit to 8 hours of coverage because that duration would reduce the Deep Space Network's ability to support future missions and the 8 Mbps downlink rate over the X-band would cause interference to other Agency missions. Accordingly, NASA asked the JWST Project to conduct a study on moving from the X-band to the Ka-band, which would support a higher data downlink rate. The study concluded the Ka-band was a viable option and the Project agreed to move its downlink. The Agency also agreed to spend $13 million upgrading the 34-meter antennas at its three Deep Space Network complexes to support the use of the new frequency allocation.[40] By opting to use another radio frequency band, JWST has reduced the likelihood of limited transmission capability during operation.

Similarly, the WFIRST, Plankton, Aerosol, Cloud, ocean Ecosystem (PACE), and other low Earth orbit missions are driving updates to the Near Earth Network in support of their communication needs.[41] Currently, the Near Earth Network's Ka-band capability is an 18-meter antenna at NASA's White Sands

[39] While the three-man crew was not in danger, the Soyuz spacecraft unexpectedly skipped a planned engine maneuver in orbit, forcing the crew to circle the Earth for 2 days instead of the planned 6-hour flight.

[40] The Deep Space Network consists of three primary complexes located at Goldstone, California; Madrid, Spain; and Canberra, Australia.

[41] PACE is a satellite mission to study Earth's aquatic ecology and chemistry. PACE will allow scientists to see the colors of the ocean, from the ultraviolet to near infrared, and obtain more accurate measurements of biological and chemical ocean properties such as phytoplankton biomass and the composition of phytoplankton communities.

Test Facility used by the Lunar Reconnaissance Orbiter to downlink data from lunar orbit at 130 Mbps.[42] Beginning around 2022, before WFIRST is launched, the Near Earth Network will need to support PACE and NISAR, missions that will also utilize the Ka-band. As such, the Near Earth Network is planning to invest about $32 million in the near term to upgrade its ground system. WFIRST's communication design is based on two Ka-band transmitters that will downlink science data up to 300 Mbps and will require a single 18-meter antenna with cryogenically cooled low noise amplifiers. To support WFIRST, the Near Earth Network is conducting a study to determine whether it makes more sense to upgrade an existing 18-meter antenna, build a new antenna, or both. While the 18-meter antenna at the White Sands Test Facility would provide baseline coverage to WFIRST, additional antennas may be needed to extend coverage and increase data transmission rates. A decision on a new 18-meter antenna – estimated between $12 million and $16 million – is planned for later in fiscal year 2017.

NASA also plans to build upon advancements in technology to increase radio spectrum efficiency in existing systems. For example, NASA uses the Ku-band to transmit data and video from the ISS to a NASA Tracking and Data Relay Satellite for downlink to Mission Control at Johnson. In 2008, the ISS was capable of transmitting at an information rate of about 130 Mbps. By April 2013, that capability had doubled following upgrades of the ISS's onboard communications equipment at a cost of $17 million. NASA is investing an additional $24.4 million to make further upgrades planned for completion in 2018.[43]

The Agency is also considering satellite communication services such as laser inter-satellite links that offer an alternative to radio frequency bands with virtually unlimited potential and an unregulated portion of the electromagnetic spectrum – flexibilities NASA will need for its future Mars missions. For example, by leveraging technology from its 2013 LADEE mission, NASA plans to launch the Laser Communication Relay Demonstration in 2019, which will be the Agency's first long-duration optical communications mission.[44] This demonstration project hopes to mature concepts and deliver technologies applicable to both near Earth and deep space communication network missions using optical communications.

NASA Program Management Policies Do Not Reference Electromagnetic Spectrum Requirements

NASA Procedural Requirements (NPR) 7120.5E and 7123.1B do not reference the Agency's electromagnetic spectrum policy.[45] In our view, this increases the risk a project may need to make costly design changes or, in extreme cases, miss a launch because electromagnetic spectrum issues were not considered at the appropriate time in the development cycle.

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[42] Launched in 2009, the Lunar Reconnaissance Orbiter has mapped the Moon's surface and continues to provide detailed information about the Moon's environment.

[43] The 2018 ISS Ku-band upgrade leverages advanced modulation and coding techniques without changing the authorized maximum output power, necessary bandwidth, and antenna design.

[44] The Laser Communication Relay Demonstration is a technology demonstration mission funded through NASA's Space Technology Program and SCaN Program. Led by Goddard with partners Jet Propulsion Laboratory and Massachusetts Institute of Technology's Lincoln Laboratory, the Laser Communication Relay Demonstration is expected to fly as a hosted payload on a commercial communications satellite.

[45] NPR 7120.5E, "NASA Space Flight Program and Project Management Requirements," August 14, 2012, and NPR 7123.1B, "NASA Systems Engineering Processes and Requirements," April 18, 2013.

NPR 7120.5E provides overall direction to managers for formulating and implementing space flight programs and projects and stipulates the documentation required at each life-cycle review. Life-cycle reviews provide a periodic assessment of a program or project's technical and programmatic health and enables the project to demonstrate that it has completed the work required at a particular point in the life cycle and is ready to move to the next stage. These reviews are essential elements of conducting, managing, evaluating, and approving space flight projects and an important part of the Agency's system of checks and balances. NPR 7123.1B defines a process for programs and projects to complete technical work, reduce program and technical risk, and improve mission success. For example, the policy provides criteria a program or project should meet before it enters a life-cycle review and on accomplishments that need to be satisfactorily demonstrated to meet the objectives of the review.

Although NPD 2570.5E and NPR 2570.1C require all programs and projects that will use the electromagnetic spectrum to discuss spectrum considerations at each life-cycle review, there is no link to this policy in NPR 7120.5E or NPR 7123.1B.[46] According to Spectrum Managers, this omission increases the risk electromagnetic spectrum requirements will not be incorporated into a project's development cycles in a timely manner, which may cause costly design changes or the project to miss its launch date.

We also found the Agency's electromagnetic spectrum policy does not include guidance regarding SmallSats. Instead, this guidance is provided in a separate document: "Spectrum Guidance for NASA Small Satellite Missions."[47] Although this guidance is accessible on the SCaN Program's website, it is not codified in formal policy or available via the NASA Online Directive Information System library – NASA's web-based document management system for approved directives and related policy documents governing the Agency. Given the growth in SmallSats, assuring developers have ready access to Agency electromagnetic spectrum requirements would help ensure those requirements are followed.

Agency Relying on Waivers to Meet SLS Requirements

NASA is relying on waivers to meet the data rate needs for the first two launches of SLS. The SLS Program designed its communication system to provide 20 MHz downlink on the S-band; however, NTIA regulation limits the S-band downlink bandwidth to 5 MHz in order to maximize use of this crowded band. SLS designed its communication architecture using hardware from a predecessor space flight program known as Constellation, which itself did not conform to NTIA regulations.[48] In fact, during the Constellation Program, the NTIA advised NASA to pursue alternatives other than requesting a waiver. In response, the SLS Program conducted a review that found the Program would face an $18 million cost increase and a 6-month schedule slip were it not allowed to exceed the 5 MHz limit. As a result, NASA worked with the NTIA to resolve the discrepancy and the NTIA granted the Agency a waiver for the first two SLS flights contingent on the Program moving out of the band on subsequent flights. Moving forward, the SLS Program is changing the communication architecture from the S-band to the C-band where a 20 MHz downlink is allowed. The Agency's experience with waivers to SLS spectrum use highlights the importance of ensuring electromagnetic spectrum requirements are considered throughout a project's development process to minimize cost and schedule impacts.

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[46] NPR 2570.1C, "NASA Radio Frequency (RF) Spectrum Management Manual," September 22, 1014.

[47] NASA, "Spectrum Guidance for NASA Small Satellite Missions," August 27, 2015.

[48] The Constellation Program was cancelled in 2010.

CONCLUSION

NASA missions operate in an electromagnetic spectrum environment that is constantly evolving as a result of expanding Agency requirements and escalating demands for increased bandwidth for the commercial wireless broadband sector. To meet these challenges, the Agency is using a multi-prong approach that includes actively participating in domestic and international regulatory organizations, addressing user demands, and fostering innovation with new technology. NASA could help ensure its projects and programs consider electromagnetic spectrum requirements and involve Spectrum Managers at appropriate stages in the development life cycle by clarifying program management policies.

RECOMMENDATIONS, MANAGEMENT'S RESPONSE, AND OUR EVALUATION

To ensure programs and projects are aware of electromagnetic spectrum requirements, the requirements are discussed at each life-cycle phase, and a request for electromagnetic spectrum certification is submitted early in the acquisition cycle, we recommended NASA's Associate Administrator for Human Exploration and Operations, in conjunction with the Office of the Chief Engineer

1. incorporate NPD 2570.5E, "NASA Electromagnetic Spectrum Management - Revalidated 9/13/16," and NPR 2570.1C, "NASA Radio Frequency Electromagnetic Spectrum Management Manual," in its next update of NPR 7120.5E, "NASA Space Flight Program and Project Management Requirements," and NPR 7123.1B, "NASA Systems Engineering Processes and Requirements."

To ensure SmallSat projects are aware of electromagnetic spectrum requirements and submit a request for electromagnetic spectrum certification early in the acquisition cycle, we recommended NASA's Associate Administrator for Human Exploration and Operations

2. incorporate the "Spectrum Guidance for NASA Small Satellite Missions" into formal NASA electromagnetic spectrum policies NPD 2570.5E, "NASA Electromagnetic Spectrum Management - Revalidated 9/13/16," and NPR 2570.1C, "NASA Radio Frequency Electromagnetic Spectrum Management Manual."

We provided a draft of this report to NASA management who concurred with our recommendations and described planned actions to address them. We consider the proposed actions responsive to our recommendations, but are concerned about the proposed timetable for implementing them – August 2018 for recommendation 1 and November 2019 for recommendation 2. We believe NASA should take interim steps to incorporate the suggested revisions sooner than the proposed dates. We will monitor NASA's response and will close the recommendations upon verification and completion of the actions. Management's full response to our report is reproduced in Appendix C. Their technical comments have been incorporated, as appropriate.

Major contributors to this report include Ridge Bowman, Space Operations Director; Loretta Atkinson, Project Manager; Linda Hargrove; Barbara Moody; and Dimitra Tsamis.

If you have questions about this report or wish to comment on the quality or usefulness of this report, contact Laurence Hawkins, Audit Operations and Quality Assurance Director, at 202-358-1543 or laurence.b.hawkins@nasa.gov.

PaKMa

Paul K. Martin
Inspector General

Appendix A: Scope and Methodology

We performed this audit from April 2016 through January 2017 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Our overall audit objective was to assess how NASA is managing the electromagnetic spectrum the Agency uses to enable communication and sensing capabilities for its missions and is responding to increasing external demand for spectrum sharing. During our audit, we visited Glenn Research Center, Goddard Space Flight Center (Goddard), Jet Propulsion Laboratory, Johnson, Kennedy Space Center (Kennedy), and NASA Headquarters.

To assess to what extent NASA's key communication networks are meeting electromagnetic spectrum requirements for missions, we met with officials from the SCaN Program Office, Spectrum Management Division, and Advanced Communication and Navigation Division. We also interviewed the Project Managers for the Deep Space Network, Near Earth Network, and Space Network. Furthermore, we interviewed personnel from the Deep Space Services Commitment Office and toured the Goldstone Deep Space Communications Complex to gain an understanding of the equipment used to transmit and receive data over the electromagnetic spectrum. We also examined each Network's radio frequency capabilities and the missions they support or plan to support. Additionally, we benchmarked with other Federal electromagnetic spectrum users, to include several organizations within the Department of Defense, as well as commercial space flight entities operating in Federal radio frequency bands in order to conduct their operations.

To assess to what extent NASA is complying with Federal, Agency, and domestic and international regulations, directives, policies, procedures, and plans regarding the electromagnetic spectrum, we interviewed personnel from NASA's Spectrum Management Division, including the Domestic and International Spectrum Managers, and Center Spectrum Managers from Goddard, Jet Propulsion Laboratory, Johnson, Kennedy, Langley, and Marshall Space Flight Center. We interviewed the Patrick Air Force Base/Eastern Range Spectrum Manager to gain an understanding of U.S. Air Force electromagnetic spectrum management and coordination of launch related activities affecting NASA.

To assess what impact U.S. policies requiring the fostering of commercial space and the meeting of consumer demand for broadband have on NASA's management of the electromagnetic spectrum, we met with officials from the NTIA and the FCC. We also interviewed personnel from SpaceX and The Boeing Company. Additionally, we spoke to representatives from NASA's Educational Launch of Nanosatellites Program, the ISS Research Integration Office, and the SLS Secondary Payloads team. We also reviewed Presidential memoranda, Notices of Proposed Rulemaking, Notices of Inquiry, and other reports and documents, as applicable.

To assess to what extent NASA programs and projects, as well as NASA-sponsored activities, are effectively incorporating electromagnetic spectrum requirements into their mission development, we met with NASA Spectrum Management personnel and officials from NASA's ISS Program, JWST Program, Orion Program, SLS Program, and Science Mission Directorate. We also interviewed personnel from the Goddard Procurement Operations Division and examined pertinent acquisition documents, forms, and regulations.

In addition, we met with officials from the NTIA and the FCC. In June 2016, we attended the SFCG annual meeting in Mainz, Germany, where we had access to electromagnetic spectrum officials from across the globe and witnessed coordination activities between various domestic and international agencies operating in space, including the U.S. National Oceanic and Atmospheric Administration, European Space Agency, Japan Aerospace Exploration Agency, and United Kingdom Space Agency.

Finally, we reviewed and evaluated applicable Presidential memoranda, laws, regulations, policies, procedures, guidance, and other information, including the following:

- Title 14 Code of Federal Regulations, Part 1215, "Tracking and Data Relay Satellite System (TDRSS)," January 1, 2016
- NTIA "Manual of Regulations and Procedures for Federal Radio Frequency Management," May 2014
- "Presidential Memorandum: Expanding America's Leadership in Wireless Innovation," June 14, 2013
- "Presidential Memorandum: Unleashing the Wireless Broadband Revolution," June 28, 2010
- President's Council of Advisors on Science and Technology, "Report to the President: Realizing the Full Potential of Government-Held Spectrum to Spur Economic Growth," July 2012
- Office of Management and Budget Circular No. A-11, "Preparation, Submission, and Execution of the Budget," July 2016
- NPD 2570.5E, "NASA Electromagnetic Spectrum Management - Revalidated 9/13/16," July 11, 2011
- NPD 8074.1, "Management and Utilization of NASA's Space Communication and Navigation Infrastructure - Revalidated 2/27/15," August 11, 2009
- NPR 2570.1C, "NASA Radio Frequency (RF) Spectrum Management Manual," September 22, 1014
- NPR 7120.5E, "NASA Space Flight Program and Project Management Requirements w/Changes 1-15," August 14, 2012
- NPR 7123.1B, "NASA Systems Engineering Processes and Requirements," April 18, 2013
- NASA Federal Acquisition Requirement Supplement, 1823.71, "Frequency Authorization," December 28, 2015
- NASA, "NASA Grant and Cooperative Agreement Manual," revised September 16, 2016
- NASA Summary Report, "2015 World Radiocommunication Conference," December 15, 2015
- NASA, "Space Launch System (SLS) Secondary Payload User's Guide (SPUG)," January 15, 2015

- NASA, "NASA Long Range EM [Electromagnetic] Spectrum Forecast," October 17, 2007
- Marshall Procedural Requirements 2800.2, Revision H, "MSFC [Marshall Space Flight Center] Information Technology Services," January 11, 2016
- Various architectural documents, trade studies, and white papers

Use of Computer-Processed Data

We used limited computer-processed data from various databases to analyze NASA assigned radio frequencies and SmallSats. Those databases included the NASA Electronic Radio Database System, Spectrum XXI, Equipment Location Certification Information Database, and the NTIA Government Master File. Additionally, we analyzed CubeSat data maintained by the Saint Louis University. Although we did not independently verify the reliability of all this information, we compared it with other available supporting documents to determine data consistency and reasonableness. From these efforts, we believe the information we obtained is sufficiently reliable for this report.

Review of Internal Controls

We reviewed and evaluated internal controls related to NASA's management of the electromagnetic spectrum management. This included assessing compliance with requirements such as applicable Federal laws, regulations, directives, and NASA policies and procedures. We concluded the controls were generally adequate, except in specific circumstances, as discussed in the body of this report. Our recommendations, if implemented, should correct the weaknesses identified.

Prior Coverage

During the last 6 years, the NASA OIG and the Government Accountability Office (GAO) have issued 12 reports of significant relevance to the subject of this report. Unrestricted reports can be accessed at http://oig.nasa.gov/audits/reports/FY17 and http://www.gao.gov respectively.

NASA Office of Inspector General

Audit of NASA's Management of the Near Earth Network (IG-16-014, March 17, 2016)

Audit of NASA's Management of the Deep Space Network (IG-15-013, March 26, 2015)

Space Communications and Navigation: NASA's Management of the Space Network (IG-14-018, April 29, 2014)

Report of Investigation into Allegations that Members of a NASA-Supervised Advisory Committee Violated Federal Conflict of Interest Laws (August 2, 2012)

Government Accountability Office

Spectrum Management: FCC's Use and Enforcement of Buildout Requirements (GAO-14-236, February 26, 2014)

Spectrum Management: Preliminary Findings on Federal Relocation Costs and Auction Revenues (GAO 13-563T, April 24, 2013)

Spectrum Management: Federal Relocation Costs and Auction Revenues (GAO 13-472, May 22, 2013)

Spectrum Management: Further Consideration of Options to Improve Receiver Performance Needed (GAO-13-265, February 22, 2013)

Spectrum Management: Incentives, Opportunities, and Testing Needed to Enhance Spectrum Sharing (GAO-13-7, November 14, 2012)

Spectrum Management: Federal Government's Use of Spectrum and Preliminary Information on Spectrum Sharing (GAO-12-1018T, September 13, 2012)

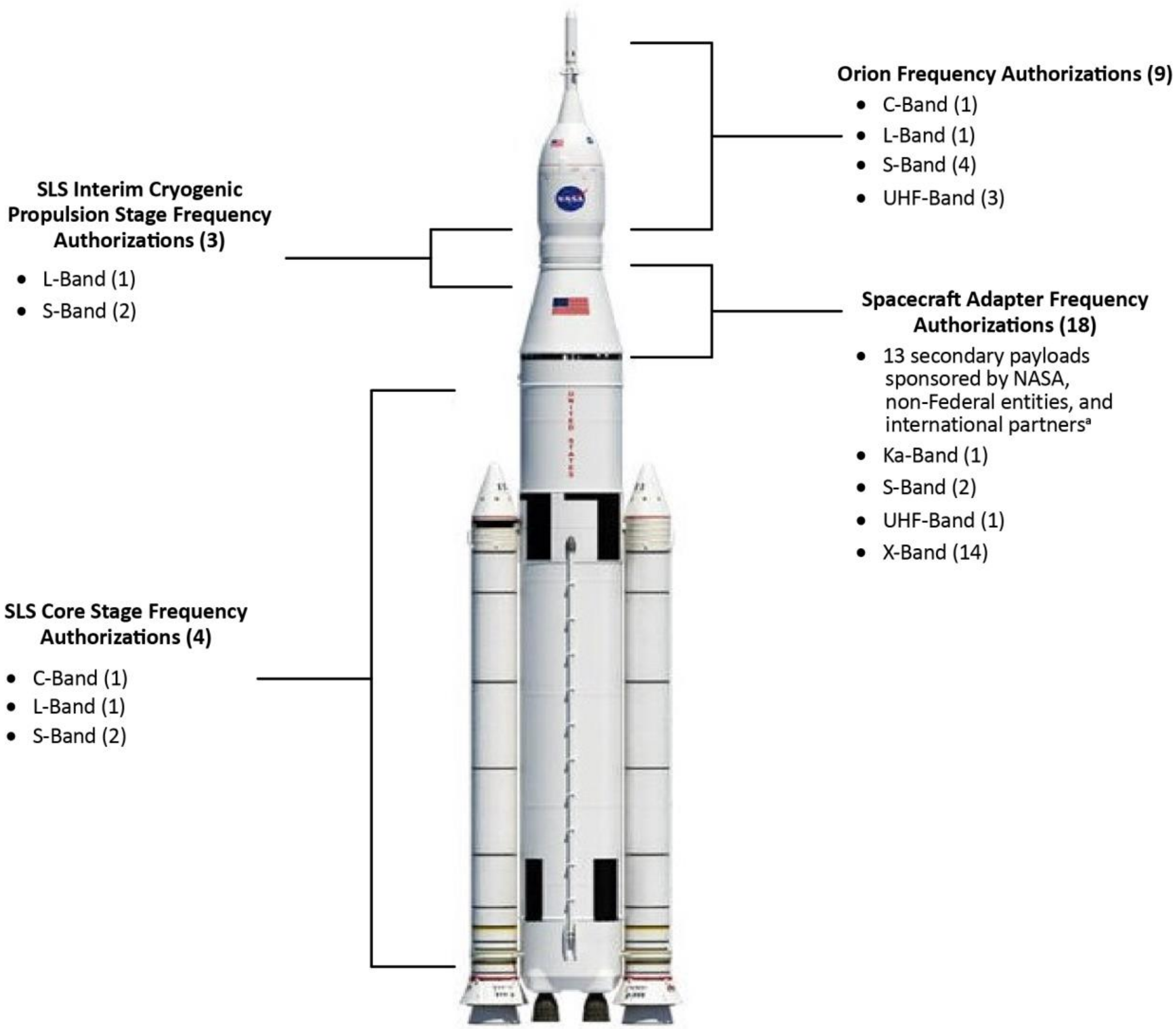
2012 Annual Report: Opportunities to Reduce Duplication, Overlap and Fragmentation, Achieve Savings, and Enhance Revenue (GAO-12-342SP, February 28, 2012)

Spectrum Management: NTIA Planning and Processes Need Strengthening to Promote the Efficient Use of Spectrum by Federal Agencies (GAO-11-352, April 12, 2011)

Appendix B: Sample of Radio Frequency Bands Associated with EM-1

NASA's electromagnetic spectrum officials must ensure all requests for radio spectrum use are compliant with NASA and Federal regulatory policies and receive the proper authorization to operate. In preparation for the launch of EM-1, electromagnetic spectrum officials have been involved in at least 34 future radio frequency authorizations, not including the radio frequency use associated with the ground support at Kennedy. Figure 6 provides a sample of radio frequency bands planned for use by Orion and SLS during EM-1. It is imperative that each of these radio spectrum requirements are coordinated to prevent interference and ensure safe operations.

Figure 6: Possible EM-1 Frequency Authorizations



Source: OIG representation of NASA data.

[a] Each payload requires a frequency authorization; however, several of the payloads have yet to define their radio spectrum needs.

APPENDIX C: MANAGEMENT'S COMMENTS

National Aeronautics and Space Administration
Headquarters
Washington, DC 20546-0001

March 6, 2017

Reply to Attn of: Human Exploration and Operations Mission Directorate

TO: Assistant Inspector General for Audits

FROM: Associate Administrator for Human Exploration and Operations

SUBJECT: Agency Response to OIG Draft Report, "NASA's Management of the Electromagnetic Spectrum" (A-16-012-00)

NASA appreciates the opportunity to review and comment on the Office of Inspector General (OIG) draft report entitled, "NASA's Management of the Electromagnetic Spectrum" (A-16-012-00), dated February 13, 2017.

In the draft report, the OIG makes two recommendations intended to ensure that programs and projects consider electromagnetic spectrum requirements and involve Spectrum Managers at appropriate stages in the development life cycle by clarifying program management policies.

Specifically, the OIG recommends the following:

To ensure programs and projects are aware of electromagnetic spectrum requirements, the requirements are discussed at each life-cycle phase, and a request for electromagnetic spectrum certification is submitted early in the acquisition cycle, the OIG recommends the Associate Administrator for Human Exploration and Operations Mission Directorate (HEOMD), in conjunction with the Office of the Chief Engineer (OCE):

> **Recommendation 1:** Incorporate NASA Policy Directive (NPD) 2570.5E, "NASA Electromagnetic Spectrum Management - Revalidated 9/13/16," and NASA Procedural Requirements (NPR) 2570.1C, "NASA Radio Frequency Electromagnetic Spectrum Management Manual," in its next update of NPR 7120.5E, "NASA Space Flight Program and Project Management Requirements," and NPR 7123.1B, "NASA Systems Engineering Processes and Requirements."
>
> **Management's Response:** Concur. HEOMD will work, in conjunction with the OCE, to incorporate both NPD 2570.5E and NPR 2570.1C into NPR 7120.5E and NPR 7123.1B as recommended. Additionally, Spectrum-related criteria will be added at certain milestone reviews outlined within NPR 7123.1. These changes are estimated to occur during the next revision of NPR 7120.5 and NPR 7123.1 in the summer of 2018.

Estimated Completion Date: August 31, 2018. (NPR 7120.5 expires on August 14, 2017 and NPR 7123.1 expires on April 18, 2018, and spectrum policy [NPD 2570.5] and procedures [NPR 2570.1] will be incorporated into the system engineering NPRs by the summer of 2018 during the revision of the NPRs).

To ensure SmallSat projects are aware of electromagnetic spectrum requirements and submit a request for electromagnetic spectrum certification early in the acquisition cycle, the OIG recommends that the Associate Administrator for HEOMD:

Recommendation 2: Incorporate the "Spectrum Guidance for NASA Small Satellite Missions" into formal NASA electromagnetic spectrum policies NPD 2570.5E, "NASA Electromagnetic Spectrum Management - Revalidated 9/13/16," and NPR 2570.1C, "NASA Radio Frequency Electromagnetic Spectrum Management Manual."

Management's Response: Concur. NASA's "Spectrum Guidance for NASA Small Satellite Missions" covers many of the topics addressed by NPR 2570.1C. However, the guidance also addresses topics of particular interest to small satellite projects, including small satellite projects using grants or cooperative agreements that often involve organizations, such as universities, with limited experience in flight systems. NASA Spectrum will be issuing an update to the "Spectrum Guidance for NASA Small Satellite Missions" by the summer of 2017 that will reflect changes in the Spectrum regulatory processes that have occurred since the Guidance was first issued in August 2015. These topics, along with any feedback received during the update of the Guidance, will be incorporated into the next revision of NPR 2570.1C during the fall of 2019.

Estimated Completion Date: November 30, 2019. NPR 2570.1C expires on September 22, 2019, and the Guidance will be incorporated into the NPR by the fall of 2019 during the revision of NPR 2570.1C.

We have reviewed the draft report for information that should not be publicly released. As a result of this review, we have not identified any information that should not be publicly released.

Once again, thank you for the opportunity to review and comment on the subject draft report. If you have any questions or require additional information regarding this response, please contact Michelle Bascoe on (202) 358-1574.

William H Gerstenmaier

William H. Gerstenmaier

cc:
Office of the Chief Engineer/Mr. Roe

Appendix D: Report Distribution

National Aeronautics and Space Administration

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House Committee on Appropriations
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    Subcommittee on Space

(Assignment No. A-16-012-00)