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NASA Spectrum Management Program

Spectrum Guidance for NASA Small Satellite Missions

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Abstract

The NASA Spectrum Management Program provides the overall planning, policy, coordination and implementation necessary to ensure adequate access to and protection of electromagnetic (EM) spectrum in support of NASA's present and future programmatic goals. With these responsibilities, the NASA Spectrum Management Program maintains NASA Policy Directives, NASA Procedural Requirements, Spectrum Guidance documents, and other documents as needed.

This Spectrum Guidance, applicable to all NASA small satellite missions (orbiting systems < 180 kg), provides spectrum policy and process guidance for NASA small satellite missions requiring the use of the electromagnetic spectrum for transmission, reception, or both.

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1. Purpose & Overview

The NASA Spectrum Management Program provides the overall planning, policy, coordination and implementation necessary to ensure adequate access to and protection of electromagnetic (EM) spectrum in support of NASA's present and future programmatic goals. With these responsibilities, the NASA Spectrum Management Program maintains NASA Policy Directives, NASA Procedural Requirements, Spectrum Guidance documents, and other documents as needed.

1.1. Purpose of the Spectrum Guidance for NASA Small Satellite Missions

This Spectrum Guidance, applicable to all NASA small satellite missions (orbiting systems < 180 kg), provides spectrum policy and process guidance for NASA small satellite missions requiring the use of the electromagnetic spectrum for transmission, reception, or both.

1.2. Overview

Per NASA Policy Directive (NPD) 2570.5E, it is NASA policy that all NASA satellite missions, including any small satellite missions (orbiting systems < 180 kg), whether directly developed and operated by NASA or those supported through contracts or other financial agreements, that require the use of the electromagnetic spectrum shall follow the United States spectrum regulatory rules and processes as referenced in the documents listed in "Authority Documents" as well as all applicable international spectrum regulations.

All missions and projects requiring the use of the electromagnetic spectrum should contact the associated Center/Facility Spectrum Manager (SM) as early in the mission development process as possible to discuss the electromagnetic spectrum operations concept and the necessary system certification and frequency authorization (licensing) requirements. Please note that all uses of the radio frequency spectrum require an authorization either from the National Telecommunications and Information Administration (NTIA) if it is a Federal Government system or a license from the Federal Communications Commission (FCC) if it is a Non-Federal Government system (discussed in detail in subsequent sections). If access to or use of specific areas of spectrum is a critical component of a mission, then the Spectrum Manager should be contacted during the pre-proposal and proposal phase. As part of the spectrum authorization and licensing process, a mission must work with NASA spectrum management to determine the Federal or Non-Federal status of the system since the status defines which regulatory agency and rules are involved for frequency authorization. A variety of technical rules also apply to small satellites regarding launches, orbital debris, frequency selection, and other matters. This guidance document provides a starting point for small satellite missions to understand and follow spectrum and related regulatory requirements.

2. Documents

As defined by NASA procedures, there are three types of documents referenced in this Guidance: authority documents, applicable documents, and reference documents.

2.1. Authority Documents

The authority documents listed in Table 1 identify the higher level documents that inform the guidance contained in this document.

Table 1: Authority Documents

Number	Title	Date
NPD 2570.5E	NASA Electromagnetic Spectrum Management	11 July 2011
NPR 2570.1C	NASA Radio Frequency Spectrum Management Manual	22 Sep 2014
47 U.S.C.	Communications Act of 1934, as amended	
47 C.F.R. pt. 300	Manual Of Regulations And Procedures For Federal Radio Frequency Management, U.S. Department Of Commerce National Telecommunications and Information Administration	2014

2.2. Applicable Documents

Applicable documents, Table 2, are cited in the body of this document and contain provisions or other pertinent requirements directly related to the performance of the activities referenced by this document.

Table 2: Applicable Documents

Number	Title	Date
NPR 8715.6A	NASA Procedural Requirements for Limiting Orbital Debris	14 May 2009
DA: 13-445	FCC Guidance On Obtaining Licenses For Small Satellites http://www.fcc.gov/document/guidance-obtaining-licenses-small-satellites	15 March 2013

2.3. Reference Documents & Information Sources

The reference documents and information sources in Table 3 provide information referenced in this guidance document.

Table 3: Reference Documents & Information Sources

Number	Title	Date
	U.S. Government Orbital Debris Mitigation Standard Practices	February 2001
	NASA information on orbital debris including standards, analysis software, processes, etc. http://orbitaldebris.jsc.nasa.gov/index.html	
LSP-REQ-317.0	Launch Services Program Program Level Poly-Picosatellite Orbital Deployer (PPOD) and CubeSat Requirements Document	13 October 2011
AFSPCMAN 91-710	*Range Safety User Requirements Manual Volume 3 – Launch Vehicle, Payloads, and Ground Support Systems Requirements*	1 July 2004

3. Policy Overview

Per NASA Policy Directive (NPD) 2570.5E, it is NASA policy that any NASA small satellite mission (orbiting systems < 180 kg), whether directly developed and operated by NASA or those supported through contracts or other financial agreements, that require the use of the electromagnetic spectrum for transmission, reception, or both shall follow the United States and international spectrum regulatory rules and processes as referenced in the documents listed in "Authority Documents" as well as all applicable international spectrum regulations.

The following are policy directives from NPD 2570 that directly affect small satellite projects:

- NASA programs shall use frequency bands that are properly allocated for their intended use unless permission to operate in another band is granted by the Director of Spectrum Policy and Planning;
- All spacecraft shall be equipped with mechanisms to remotely cease EM emissions unless there is a human presence with this direct capability. If the spacecraft has an automatic capability to cease transmissions, a waiver of this requirement may be granted by the Director of Spectrum Policy and Planning, through the applicable Center Spectrum Manager;
- Non-Federal entities placed in control of NASA transmitters operating in Federal bands (e.g., 2200-2290 MHz) shall have sufficient contractual constraints to ensure those transmissions are operated in accordance with NASA direction; and,
- No frequency assignments for NASA space missions shall be approved for devices which are designed or intended to transmit in exclusive passive radio frequency (RF) bands allocated, either nationally or internationally, to the radio astronomy service, the Earth exploration- satellite service (passive), or the space research service (passive);
- Frequency selection for NASA missions requiring use of 2025-2110 MHz or 2200-2290 MHz shall be made by the Goddard Space Flight Center (GSFC) Spectrum Manager in working with the respective mission Center's Spectrum Manager;
- Frequency selection for NASA deep space missions shall be made by the Jet Propulsion Laboratory (JPL) Spectrum Manager in working with the respective mission Center's Spectrum Manager;
- The Center Directors and the JPL Director shall ensure that all federal RF-related procurements are made with the approval of the applicable Center Spectrum Manager and are in compliance with NASA and Federal regulatory policies.

4. Process for Certification, Authorization, and Licensing

All NASA small satellite missions requiring the use of the electromagnetic spectrum for transmission, reception, or both should follow the basic process outlined by this Section.

4.1. Establish Contact with NASA Spectrum Management

As a first step, all missions and projects requiring the use of the electromagnetic spectrum should contact the associated Center/Facility/Program Spectrum Manager to discuss the electromagnetic spectrum operations concept and the necessary system certification and frequency authorization (licensing) requirements. If no clear NASA Center is involved, the mission or project should contact the NASA National Spectrum Program Manager who will designate a responsible Center Spectrum Manager or will take the lead role for the project spectrum management function depending upon the circumstances. The NASA HQ office of Spectrum Policy and Planning can also assist. The current NASA Center Spectrum Managers, NASA National Spectrum Program Manager, and other points of contact are provided on NASA's spectrum website:
http://www.nasa.gov/directorates/heo/scan/spectrum/txt_NASA_Spectrum_Personnel.html.

The Center/Facility Spectrum Manager or NASA National Spectrum Program Manager will provide assistance during all phases of a mission or project from conceptual, pre-proposal efforts through formulation and implementation. The Spectrum Manager will support the project at each review in the project life cycle and assist with design and spectrum considerations such as frequency selection, conformance to regulatory constraints (e.g., emission masks, power flux density (pfd) limits, etc.), and other electromagnetic spectrum parameters. A key element of this support is assisting with or preparing inputs for spectrum certification as early in the acquisition and procurement cycles as possible, the subject of the next sub-sections.[1] Appendix C provides additional information concerning frequency selection and technical spectrum considerations.

In addition, the Center Spectrum Manager or NASA National Spectrum Program Manager can assist, in consultation with NASA and Center contract personnel, with the inclusion of appropriate provisions in contracts or other agreements that note the requirement for a small satellite system to obtain frequency authorization. Additional information concerning contract and other agreement provisions can be found in Section 5 of this Guidance.

4.2. Status: Federal/Non-Federal

The next step in the spectrum authorization and licensing process is the determination of the federal or non-federal status of the system since the status defines which regulatory agency and rules are involved for frequency authorization, see Figure 1. For stations that "belongs to and operated by" (e.g., effectively controlled) by a federal agency (e.g., NASA), the use of radio frequencies is authorized by the National Telecommunications and Information Administration (NTIA), and if a non-federal frequency is involved, NTIA coordinates with the Federal Communications Commission (FCC). For all other situations (i.e., non-federal), stations are licensed by the FCC, and if a federal frequency is involved, the FCC coordinates with NTIA. The determination of the regulatory status is based on the NASA program or NASA Center arrangement including any contractual or other agreement with the system developer and operator. The NTIA Manual, see Table 4, provides guidance for the federal/non-federal status. Table 5 outlines a two criteria model that may also assist in defining the regulatory case. The Center Spectrum Manager and National Spectrum Program Manager, in consultation with the project/mission, should make a recommendation on the federal or non-federal status. Additional guidance for contract and agreement language is provided in Section 5.

[1] Although the NASA Center Spectrum Managers can assist all NASA sponsored projects, the NASA Center Spectrum Managers can only speak on behalf of NASA and cannot directly represent non-federal (non-NASA) systems (see Section 4.2) in FCC proceedings.

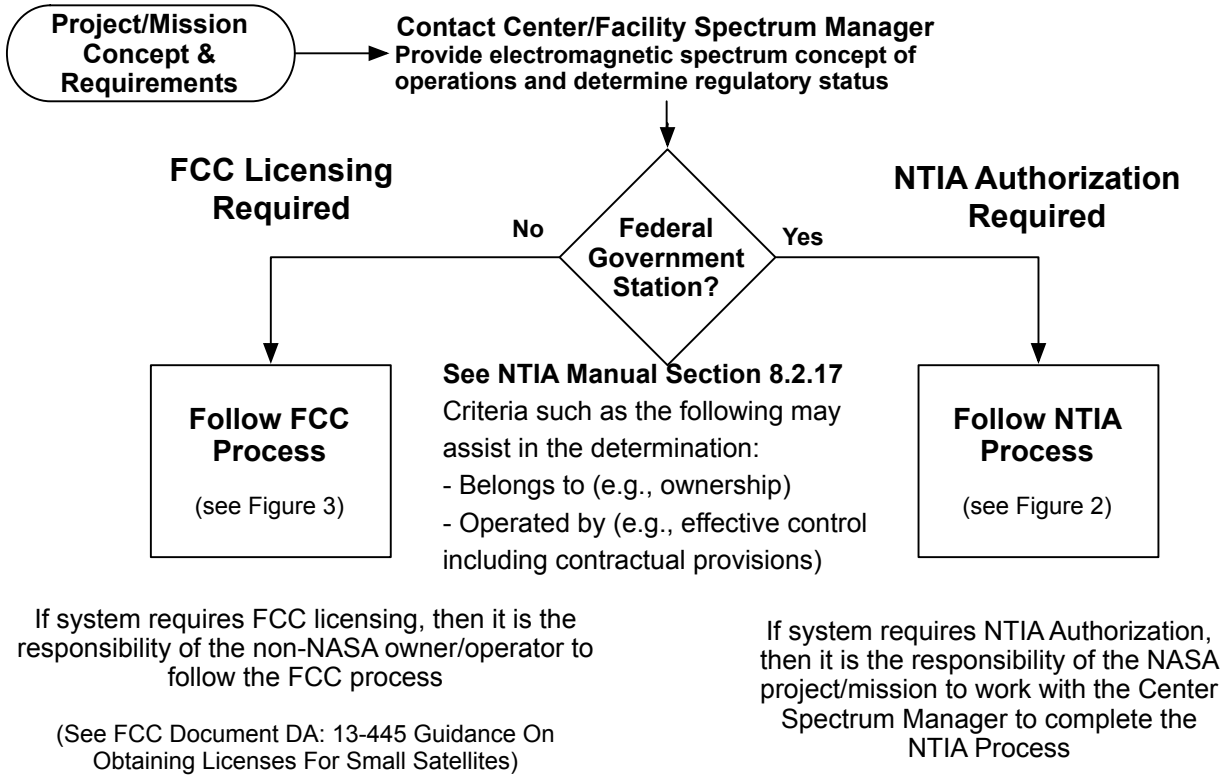

Figure 1: Project/Mission Determination of Spectrum Regulatory Status & Process

Table 4: NTIA Manual: Federal Status Determination

8.2.17 Determining Whether a Station is a Federal Station

1. The following guidelines are to assist in the determination of whether or not a station belongs to and is operated by the United States as specified in Section 305(a) of the Communications Act of 1934:

a. The department or agency concerned should be able to exercise effective control over the radio equipment and its operation; and

b. The department or agency concerned assumes responsibility for contractor compliance with Executive Branch, departmental, or agency instructions and limitations regarding use of the equipment and ensures that such instructions and limitations are met when operating under the authority of an Executive Branch frequency authorization to the department or agency; and

c. The station should be operated by an employee of the department or agency or by a person who operates under the control of the department or agency on a contractual or cooperative agreement basis, and who is under supervision of the department or agency sufficient to ensure that Executive Branch, departmental, or agency instructions and limitations are met.

2. It is recognized that a federal agency may make a contract arrangement for maintenance or operation of a radio station under its control without diminishing the effective control of, or responsibility for, such station, provided the appropriate limitations or requirements are specified.

3. Since the foregoing may not cover every case, or where there may be doubt, the determination will be made by the department or agency concerned after consultation with the NTIA/FCC as appropriate.

Table 5: System Status & Spectrum Authorization-Licensing: Two Criteria Model Approach*

Case	**Belongs To** (e.g., ownership)	**Operated By** (e.g., effective control**)	**Regulatory Agency**	**Frequency Bands & Notes**
1	Federal (NASA)	Federal (NASA)	NTIA	Government and Shared frequency bands are appropriate If a non-government or shared frequency is involved, NTIA coordinates with the FCC—such use by NASA missions is discouraged
2	Federal (NASA)	Non-Federal	FCC	Non-government and Shared frequency bands are appropriate If a government or shared frequency is involved, FCC coordinates with the NTIA—such use by NASA sponsored missions is highly discouraged Proof of FCC Authorization provided to NTIA
3	Non-Federal	Federal (NASA)	FCC	Non-government and Shared frequency bands are appropriate If a government or shared frequency is involved, FCC coordinates with the NTIA—such use by NASA missions is highly discouraged Such a scenario is uncommon
4	Non-Federal	Non-Federal	FCC	Non-government and Shared frequency bands are appropriate If a government or shared frequency is involved, FCC coordinates with the NTIA—such use by NASA missions is highly discouraged

* This approach may assist in defining the regulatory case, but should not be viewed as an explicit definition.
** Effective control may be exercised directly by NASA personnel or through contractual provisions.

In addition, the regulatory status affects the selection of frequencies used since, in the United States, frequency bands are designated as federal, non-federal, or shared. Although systems operating under certain circumstances, such as experimental, may utilize any frequency, the NTIA and FCC must approve and coordinate the frequency selection especially if a system operates under one status (i.e., federal or non-federal) but uses frequencies of the other status. It should also be noted that for federal systems, the command and control communications link must operate on a protected frequency so that cessation of transmissions can be assured. See Appendix C for additional information about frequency status of potential bands.

4.3. Federal System: NTIA Certification and Frequency Authorization

For a federal (e.g., NASA) system, the frequency authorization process is well defined by the NTIA Manual, and the small satellite project should work directly with the Center Spectrum Manager to pursue system spectrum certification and frequency authorization. All small satellite systems, regardless of their classification and use of the formal NASA life-cycle process and reviews (e.g., NPR 7120.5, NPR 7123, etc.), must obtain certification of spectrum support and frequency authorization for each frequency used. Figure 2 illustrates the NTIA spectrum process as an overlay to the NASA life-cycle process highlighting milestones, such as Stage 2 and Stage 4 certification, that are required at various project milestones regardless of NASA system classification. NPR 2570 provides additional information concerning the NTIA regulatory process.

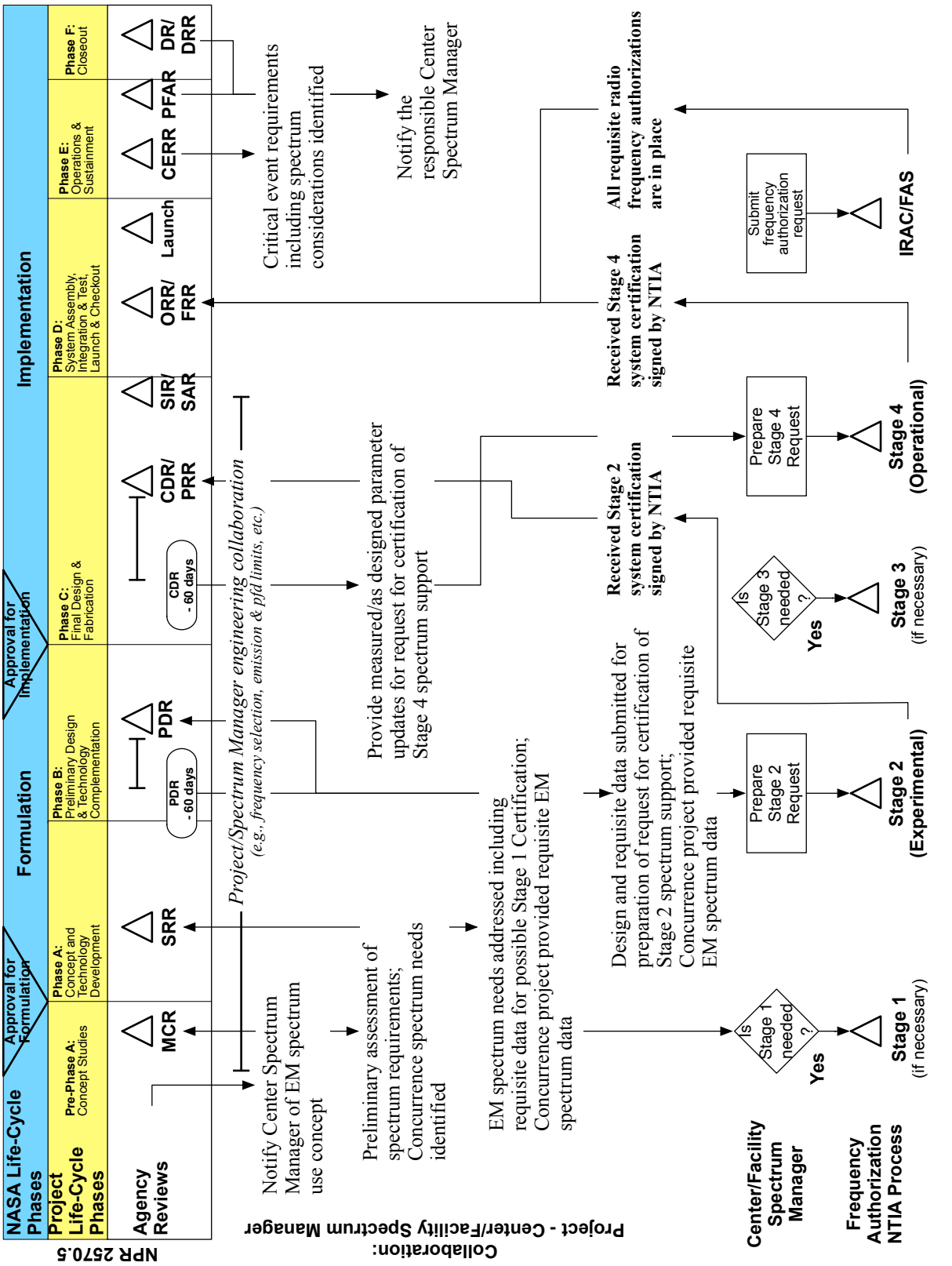

Figure 2: Spectrum Certification Process Overlay on NASA Life-Cycle Process

4.4. Non-Federal System: FCC Licensing

For non-Federal designated systems affiliated with or supported by NASA, a non-Federal entity with ultimate control of the satellite and EM spectrum systems must obtain authorization through the appropriate FCC process. FCC Document DA: 13-445, *Guidance On Obtaining Licenses For Small Satellites* (see http://www.fcc.gov/document/guidance-obtaining-licenses-small-satellites), provides guidance for following the FCC process, and Figure 3 illustrates the basic options associated with that process. For many small satellite missions, a Special Temporary Authority (STA) (lifespans < six (6) months) or an experimental license (lifespans < five (5) years) is appropriate; however, other FCC licensing mechanisms may be appropriate.

For experimental operations (Part 5), there are no specific bands identified in the FCC rules, and operations are on a temporary, non-interference basis, i.e., the operations can neither cause interference nor claim protection from interference. Commercial satellite operations (Part 25) may have additional protections if operated as a primary allocated service in certain frequency bands.

Although the FCC does not guarantee a specific timeline for considering experimental license requests, applicants should expect the FCC to take between 45 and 180 days depending on the complexity of the system and the need to coordinate with Federal or other entities based on the selected frequency band. When submitting license applications, license requesters should be prepared to respond promptly to any questions from the FCC to ensure timely consideration. Specifically, the applicant should be prepared to address questions about arrangements for ownership and operation of the satellite, and ultimate control of the overall mission, particularly where the mission is closely affiliated with a government entity or entities. FCC has increasingly inquired about such information, so it is in the best interest for all to clearly provide that information as early in the process as possible.

The NASA mission and project management should ensure during any formal reviews that the non-Federal entity is progressing with obtaining FCC license authorization. While technical assistance can be provided by NASA, it is the responsibility of the non-Federal entity to obtain licensing from the FCC.

4.5. International Satellite Notification and Coordination

Under international agreement, any spacecraft which will transmit or receive electromagnetic energy of a frequency below 300 GHz shall be filed and, as necessary, coordinated through the International Telecommunication Union (ITU), a specialized agency of the United Nations. This treaty-level obligation does not contain any unique provisions or exemptions for small satellites; it applies regardless of spacecraft size, mass, transmit power, or mission lifetime. These requirements apply to electromagnetic spectrum use for communication, radio science, active sensing, and passive sensing. There is no requirement or procedure for the filing of electromagnetic spectrum use above 300 GHz (*e.g.*, laser communication, infrared imaging, or sensing in the ultra-violet regions).

Under Article 9.1 of the International Radio Regulations, the filing procedure is initiated, "not earlier than seven years and preferably not later than two years before the planned [deployment] of the network or system." The filing procedures for a typical NASA mission may require at least a year to complete. However, the specific filing requirements vary by frequency band and service. Also, backlogs in the processing of satellite filing paperwork at the ITU can and do occur. Therefore, the process could take much longer.

It is understood within the NASA spectrum management office that the relatively quick development time and often short operational time of small satellites is not always commensurate with the timeframe required to properly complete the filing procedure for a spacecraft in the ITU. Parameters (e.g., orbital elements) required for the filing process may not be known until shortly before the mission is deployed. NASA will generally not prohibit a mission from being deployed strictly because the ITU filing procedure has not been completed. However, at a minimum, the initial step, called "Advance Publication" should be initiated. If the operational life of the mission is less than the time required to

complete the ITU filing process, Advance Publication may be the only step completed. Missions which have not fully completed the ITU filing procedure must operate on a non-interference basis; they may neither cause interference to nor claim protection from other systems which are properly filed.

For almost all NASA-related satellite operations, only advance publication and notification will be required. However, there are a few specific situations in which formal ITU satellite coordination may be required. One of these situations includes use of the 450 MHz band for earth-to-space communications, a band used by several small satellite systems. See Appendix C for additional band-related information.

Finally, the ITU as part of the 2015 World Radiocommunication Conference is considering these processes as they relate to small satellite systems, so the specific processes may be modified in the future.

4.5.1 Satellite Notification for NASA Missions

The ITU satellite filing process should largely be transparent to a NASA (federal designated) mission since the requests generated by the responsible Center Spectrum Manager for spectrum certification are also used to generate the corresponding satellite filing material sent to the ITU.

The ITU charges processing fees for each of the satellite notification steps, and for NASA missions these fees are paid directly by the spectrum management office at NASA HQ. These fees are not passed along to the missions themselves.

As the ITU filing procedure is inherently an international process, all earth stations, both U.S. and foreign, and/or service areas are required for filing. Many foreign countries have domestic rules only allowing earth station operations with spacecraft that are filed, or have at least been Advance Published in the ITU and which identify locations within their territory as being associated with that mission. Failure to include this information in the ITU filing material could delay cooperative foreign earth stations from obtaining their own domestic authorizations. Consequently, NASA missions must ensure that both domestic and foreign earth stations and/or service areas are included in the requests for spectrum certification.

NASA's practice is that all NASA space-based missions are filed in the ITU. Additionally, per other NASA international and domestic agreements, all mission frequency selections and planned operations must be notified and coordinated with other space agencies. Thus, when preparing materials and inputs for NTIA or frequency selection by the Spectrum Manager, the small satellite project should:

- Include all needed satellite information necessary for ITU filing as part of the NTIA certification request (Center Spectrum Manager will assist); and,
- Include information about all ground stations, both U.S. and international, in the certification request so that such information can be used by NASA to insure appropriate frequency selection and coordination and to prepare ITU filings.

4.5.2 Satellite Notification for Non-NASA (Non-Federal) Systems

For NASA-supported but non-federal (non-NASA) designated space systems, the mission is responsible to follow the FCC and ITU processes for satellite notification and coordination. These types of systems are typically not eligible to file as Amateur Radio Satellite systems. For non-federal systems, NASA cannot represent or engage in the satellite filing process on behalf of the mission.

The FCC requires that all space-based systems, including small satellite systems, follow the ITU satellite notification processes. For non-federal systems seeking experimental licenses, the situation for most NASA supported, non-federal systems, the FCC will file the necessary information with the ITU based on inputs from the applicant. For all systems including those providing commercial services, amateur radio systems, and experimental systems, the applicant is responsible to prepare a draft notification using the

ITU software "SpaceCap," [2] and to forward it to the FCC as well as to coordinate domestically and internationally if necessary.

When preparing materials and inputs for FCC licenses, the small satellite project should:

- Include needed satellite information, as outlined in the *FCC Guidance On Obtaining Licenses For Small Satellites*, necessary for ITU filing; and,
- Include information about all ground stations, both U.S. and international, in the FCC license application since, even though international ground stations are not licensed by the FCC, such information is required for the ITU filing process.

The ITU charges processing fees for each of the satellite notification steps, and each non-Federal mission is required to cover these costs; the FCC does not pay these fees. Systems operating in the amateur-satellite service may not need to pay these fees; however, it is very unlikely that NASA-supported missions will qualify as amateur systems. The FCC may also request applicants provide a cost recovery letter stating payment was completed or committing the applicant to paying the fees incurred as part of the ITU filing process. Example fees[3] include:

- Advanced Publication for non-geostationary systems not requiring coordination = 570 CHF; and,
- Notification for non-geostationary systems not requiring coordination = 7030 CHF.

As noted in previous sections, non-Federal missions should consult the *FCC Guidance On Obtaining Licenses For Small Satellites* and work with the FCC to ensure the ITU-related satellite notification and coordination requirements are fulfilled.

[2] The "SpaceCap" software can be downloaded from the following link: http://www.itu.int/ITU-R/go/space-software/en specifically item "SpaceCap – Space data capture" (http://www.itu.int/en/ITU-R/software/Pages/spacecap.aspx). Information about using the SpaceCap software can be found at http://www.itu.int/en/ITU-R/space/workshops/2015-prague-small-sat/Presentations/ARS-API_help.pdf and http://www.cubesat.org/images/developers/licensing/spacecap_guide.pdf.

[3] Per ITU Circular Letter CR/295 (19 Dec 2008) (see http://www.itu.int/ITU-R/go/space-cost-recovery/en)

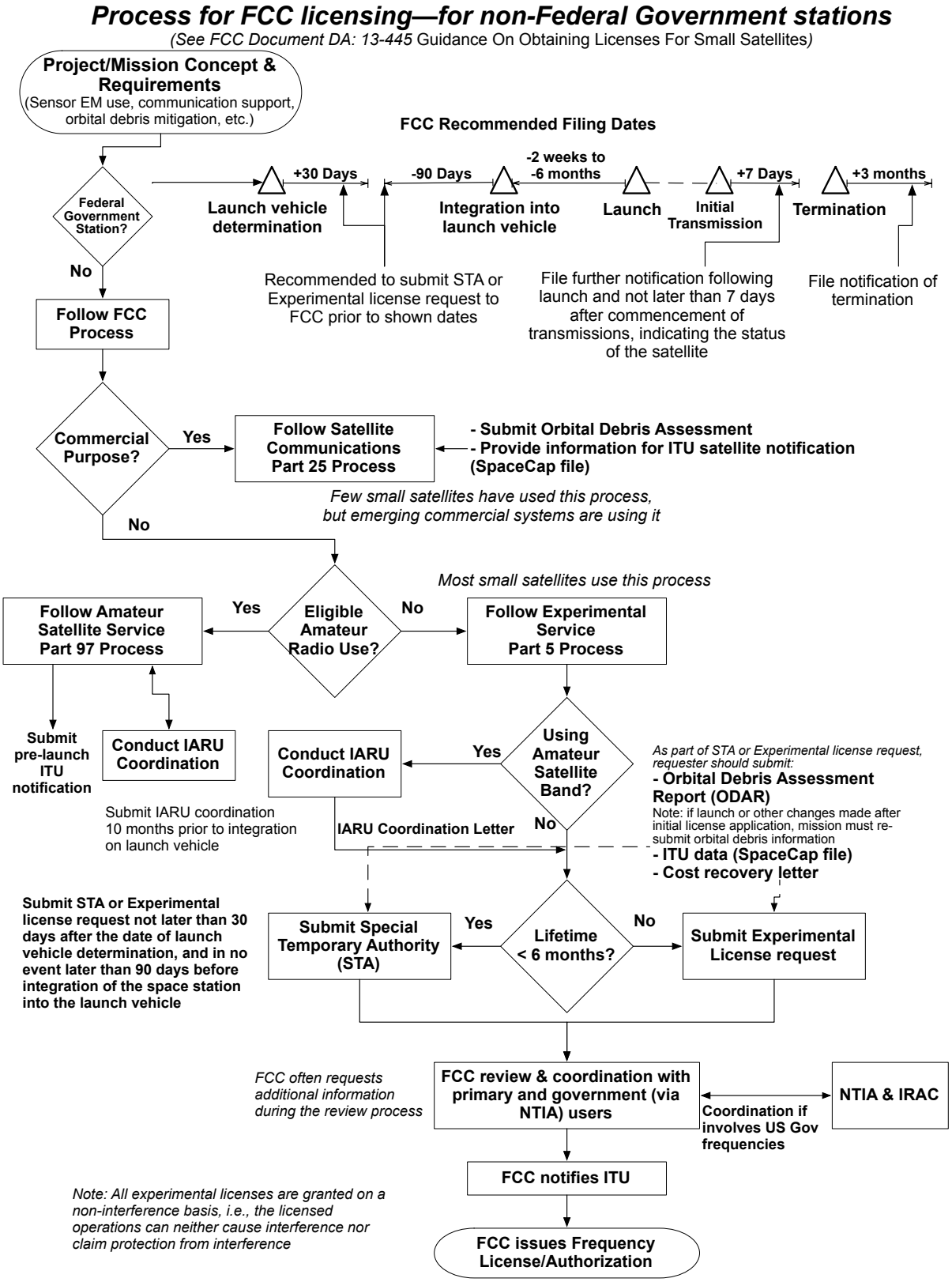

Figure 3: Frequency Authorization Process for Non-Federal Systems – FCC Process

5. Provisions for Contracts, Grants, and Other Agreements and Announcements

To assist NASA in complying with federal spectrum laws and regulations, NASA contracts, grants, and other agreements (e.g., cooperative research and development agreement (CRADA)) should provide clear language associated with spectrum regulatory requirements. Appendix B provides additional information and example language that can be included in contracts, grants, and other agreements.

In addition, any NASA Announcement of Opportunity, Request for Proposal (RFP), or other such solicitation should indicate that any system that uses the electromagnetic spectrum for transmission, reception, or both shall follow the United States spectrum regulatory rules and processes as referenced in the documents listed in "Authority Documents" as well as all applicable international spectrum regulations.

Two items, spectrum authorization and ownership/operations, should be addressed in NASA contracts, grants, and other agreements that involve the use of the electromagnetic spectrum for transmission, reception, or both.

5.1. Contracts/Agreements: Require Spectrum Authorization

Any NASA contract, grant, or other agreement should clearly state that spectrum authorization is required for all systems using the electromagnetic spectrum for transmission, reception, or both;

- As noted by NPR 2570 (Section 3.5), for NASA-funded but non-Federal designated systems, NASA requires that the contractor or grantee obtain spectrum licensing through the appropriate FCC processes;
- Appendix B provides specific example contract clauses and example agreement language.

5.2. Contracts/Agreements: Indicate Ownership & Operator (Effective Control)

Any NASA contract, grant, or other agreement that involves the use of the electromagnetic spectrum for transmission, reception, or both should explicitly indicate the following:

a) Ownership of equipment: Agreement should state whether the system, specifically the radiocommunication (transmitter, receiver) system, is owned by NASA (Federal Government) or not.

- For NASA ownership, cases may include equipment developed by a contractor, government procured or developed systems provided to a contractor (i.e., Government Furnished Equipment (GFE)) but claimed as NASA (Federal Government) property. NASA ownership may also include a sub-system that is included as a hosted payload on a non-NASA platform or spacecraft. Other cases may also exist.
- For non-NASA (non-Federal Government), cases may include systems developed under contract or systems procured by NASA but formally transferred to a non-NASA entity. Other cases may also exist.

b) Operations (effective control): Agreement should identify the organization that has effective control of the operations of the system specifically the radiocommunication system and the capability to conduct or cease transmissions;

- For NASA (Federal) operations, the effective control may be exercised in several ways including, but not limited to, a NASA civil servant with direct control of the systems conducting radiocommunications or a contract directing a contractor conducting operations to follow instructions from NASA.
- For non-NASA (non-Federal) operations, the contractor or other entity exercises sole authority, without direction from NASA (Federal Government), over the operations of the system specifically the radiocommunications transmissions.

6. Launch and Deployment Related Requirements: Launch Services and ISS

In addition to the core frequency authorization processes, a small satellite system must also follow launch, launch range, International Space Station (ISS), or other launch services spectrum-related requirements including timelines and milestones. Such requirements may include obtaining frequency licensing/authorization prior to integration on the launch vehicle, safeguards to prevent RF emissions until a set time after deployment, exposure or associated electromagnetic interference (EMI) limits, and other factors.

This section provides information concerning launch services processes and typical requirements; however, each small satellite mission will need to work with the appropriate launch service organization to identify the specific requirements for its launch.

6.1. Launch Requirements: Expendable Launch Vehicles (ELVs)

NASA Launch Services Program (LSP), including services through the CubeSat Launch Initiative (CSLI) (where manifests for each launch opportunity uses the designation "ELaNa [number]" (ELaNa = Educational Launch of Nanosatellites)), and other launch and range integration activities often require several items associated with electromagnetic emissions to ensure that the small satellite secondary and auxiliary payloads do not increase the baseline mission risk. Each launch event is unique, and the rules governing secondary and auxiliary payloads are defined by the specific launch vehicle customer, ELV developer, and the launch range.

Typically, these launch-related requirements will be stated in a contract or CRADA, launch vehicle Interface Control Document (ICD), or other launch-specific document. Each small satellite mission will need to work with NASA/LSP or other launch and range integration organization to identify the specific launch-related requirements. As an example, an auxiliary payload to be deployed by the future NASA Space Launch System (SLS) vehicle, which has the capability to accommodate up to 11 6U cubesats, would need to comply with the SLS Interface Definition Requirements Document (IDRD).

Launch-related requirements may include:

- Frequency Licensing/Authorization: The mission must obtain frequency licensing/authorization prior to integration on the launch vehicle. The required date prior to launch or launch vehicle will be set for each mission and may vary depending upon on the specific launch vehicle integration process;
- Inhibit and Delayed Communications: The small satellite (e.g., cubesat) shall not generate or transmit any signal from the time of integration into the launch container (e.g., PPOD) through a specified time period (e.g., 45 minutes) after on-orbit deployment (Note: time period depends on launch vehicle or system); and,
- Permissible Exposure Limit (PEL) & Electromagnetic Interference (EMI) Compatibility: Some launch systems and ranges may require compliance with PEL and EMI standards or requirements (e.g., ANSI/IEEE C95.1) to ensure that personnel and equipment are not exposed to hazardous energy levels.

Other types of requirements (e.g., limits on propulsion systems, hazardous materials, etc.) may also apply, so each small satellite developer is encouraged to work with the launch integration and range activities as soon as known since launch-related requirements will affect the specification and design of the small satellite systems. The NASA/LSP Poly-Picosatellite Orbital Deployer (PPOD) and CubeSat Requirements Document (LSP-REQ-317.0) provides an example set of requirements. Appendix C provides additional information concerning these and related design considerations.

6.2. ISS Deployment Requirements

For any small satellite systems (e.g., cubesat) to be deployed from the ISS such as those deployed by Nanoracks or the Cyclops system, the small satellite system must work with the ISS payload manager, follow the ISS risk assessment processes, and work with the Progrm (ISS) Spectrum Manager, currently the JSC Spectrum Manager, in regards to the system requirements imposed by ISS.

Required actions include:

- ISS Safety Review Process: The mission must work with the ISS payload integration office and the ISS spectrum management activity to conduct two analyses:
  - EM Hazard/Keep out Zone (e.g., human exposure, equipment EMI) [NASA-STD-3000 116, NASA-STD-3001, section 5, SSP 30237, SSP 50237];
  - EM Compatibility to ensure no RFI to ISS EM systems [Various RF system performance specifications, including SSP 30237 and SSP 50237];
- Frequency Licensing/Authorization: The mission must obtain frequency licensing/authorization prior to integration on the launch vehicle. Preferably, the mission should obtain its frequency licensing/authorization prior to integration in the deployment mechanism (e.g., NanoRacks). [SSP 57000, 57003, 57004]
- Inhibit and Delayed Communications: The small satellite (e.g., cubesat) shall not generate or transmit any signal from the time of integration into the launch container (e.g., NanoRacks) through [45] minutes after on-orbit deployment.

Appendix C provides additional information concerning these and related design considerations.

7. Processes Affiliated with Spectrum Authorization

Small satellite systems must follow other regulatory processes associated with space systems and such processes may also be a requirement for spectrum licensing and authorization. Although details for orbital debris mitigation and remote sensing licensing are not covered in this Guidance, these processes are cited as they are applicable for NASA-affiliated small satellite systems.

7.1. Orbital Debris Mitigation

Several standards and practices address orbital debris mitigation:

- Federal/NASA Systems: Per U.S. Government Orbital Debris Mitigation Standard Practices, "Programs and projects will assess and limit the amount of debris released in a planned manner during normal operations;" (NASA Standard 8719.14A, NASA Handbook 8719.14)
- NASA Systems: Per NPR 8715.6A, NASA Procedural Requirements for Limiting Orbital Debris, NASA's objective is "to limit the generation of debris in Earth," and, thus, the "NASA Program/Project Manager shall ensure that all NASA and NASA-funded or NASA-controlled spacecraft and launch vehicles are designed to be disposed of in accordance with" various activities and standards, as outlined in the NPR;
- Non-NASA (non-Federal) systems: As part of the FCC licensing process, small satellite systems must provide information and analysis concerning orbital debris mitigation. Guidance for such information is discussed in the FCC Rules and Document DA: 13-445, *Guidance On Obtaining Licenses For Small Satellites* (see http://www.fcc.gov/document/guidance-obtaining-licenses-small-satellites). In addition, as part of the NOAA authorization of remote sensing, NOAA also requires non-Federal systems to address orbital debris standards—see subsequent section on Remote Sensing Licensing;

NASA provides useful information concerning orbital debris mitigation standards and also provides software for missions, including small satellite missions, to assess their potential for orbital debris: see http://orbitaldebris.jsc.nasa.gov/index.html.

Although not explicitly required by policy or licensing rules at this time, missions may be asked by the FCC or other organizations to designate a contact for receiving conjunction messages and other operational information and to register with U.S. Strategic Command's (USSTRATCOM) Joint Space Operations Center (JSpOC) at: https://www.space-track.org/documentation#odr.

All missions should check on the latest NASA and other organization's orbital debris-related standards and policies as many of them are under review and subject to change.

7.2. Private Remote Sensing Space System Licensing

Pursuant to the National and Commercial Space Programs Act (NCSPA or Act), 51 U.S.C. § 60101, et seq,, private space-based remote sensing systems require licensing, and such licensing responsibilities have been delegated from the Secretary of Commerce to the National Oceanic and Atmospheric Administration (NOAA). Per requirements in NCSPA, NOAA also requires imaging system licensees to assess and minimize the amount of orbital debris released during the post-mission disposal of their satellite(s).

For specific information, see:

- http://www.nesdis.noaa.gov/CRSRA/index.html; and,
- http://www.nesdis.noaa.gov/CRSRA/licenseHome.html.

Federally owned remote sensing systems are not required to follow this remote sensing licensing process; however, all systems should review the NOAA guidance in making the determination whether or not such licensing is required.

Appendix A. Acronyms and Definitions

AP	Advanced Publication
CRADA	Cooperative Research and Development Agreement
CSLI	CubeSat Launch Initiative
ELaNa	Educational Launch of Nanosatellites
EM	Electromagnetic
EMI	Electromagnetic Interference
FAR	Federal Acquisition Regulation
FAS	Frequency Assignment Subcommittee
FCC	Federal Communications Commission
GSFC	Goddard Space Flight Center
HEOMD	Human Exploration and Operations Mission Directorate
GFE	Government Furnished Equipment
IARU	International Amateur Radio Union
ICD	Interface Control Document
IRAC	Interdepartment Radio Advisory Committee
ISS	International Space Station
ITU	International Telecommunication Union
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
JSpOC	Joint Space Operations Center
KSC	Kennedy Space Center
LSP	Launch Services Program
NCSPA	National and Commercial Space Programs Act
NOAA	National Oceanic and Atmospheric Administration
NPD	NASA Policy Directive
NPR	NASA Procedural Requirements
NTIA	National Telecommunications and Information Administration
ODAR	Orbital Debris Assessment Report
PEL	Permissible Exposure Limit
pfd	Power Flux Density
PPOD	Poly-Picosatellite Orbital Deployer
RFI	Radio Frequency Interference
RFP	Request for Proposal
RR	Radio Regulations
SCaN	Space Communications and Navigation
SFCG	Space Frequency Coordination Group
SM	Spectrum Manager
SMD	Science Mission Directorate
SPS	Spectrum Planning Subcommittee
SSS	Space Systems Subcommittee
USSTRATCOM	U.S. Strategic Command

Appendix B. Spectrum-Related Provisions for Contracts and Other Agreements

As discussed in Section 5, to assist NASA in complying with federal spectrum laws and regulations, NASA contracts, grants, and other agreements (e.g., cooperative research and development agreements (CRADAs)) should provide clear language associated with spectrum regulatory requirements. The following sub-sections provide example language that can be included in contracts, grants, and other agreements.

B.1 Language for Spectrum Authorization/Frequency Licensing

Given that any NASA contract, grant, or other agreement should clearly state that spectrum authorization is required for all systems using the electromagnetic spectrum for transmission, reception, or both, the following identifies existing contract clauses and example language.

a. Contracts

The following Federal Acquisition Regulation (FAR) clauses within the NASA FAR supplement[4] are available for inclusion in contracts explicitly highlighting the requirement to obtain spectrum authorization:

> Subpart 1823.71—Frequency Authorization
>
> 1823.7101 Contract clause.
>
> The contracting officer shall insert the clause at 1852.223–71, Frequency Authorization, in solicitations and contracts calling for developing, producing, constructing, testing, or operating a device for which a radio frequency authorization is required.
>
> 1823.7102 Procedures.
>
> The contracting officer shall obtain the necessary frequency authorization and other procedural details from the installation's spectrum manager.
>
> 1852.223-71 Frequency Authorization.
>
> As prescribed in 1823.7101, insert the following clause:
>
> FREQUENCY AUTHORIZATION (DECEMBER 1988)
>
> (a) Authorization of radio frequencies required in support of this contract shall be obtained by the Contractor or subcontractor in need thereof.
>
> (b) For any experimental, developmental, or operational equipment for which the appropriate frequency allocation has not been made, the Contractor or subcontractor shall provide the technical operating characteristics of the proposed electromagnetic radiating device to the Contracting Officer during the initial planning, experimental, or developmental phase of contractual performance. Procedures furnished by the Contracting Officer shall be followed in obtaining radio frequency authorization.
>
> (c) This clause, including this paragraph (c), shall be included in all subcontracts that call for developing, producing, testing, or operating a device for which a radio frequency authorization is required.

If the contract does not need to use the pre-defined FAR clauses, a statement such as the following may be sufficient:

---

[4] Referenced at http://www.hq.nasa.gov/office/procurement/regs/nfstoc.htm and specifically at http://www.hq.nasa.gov/office/procurement/regs/1823.htm#23_71 (as of 27 April 2015)

"The Contractor shall arrange for radio frequency licensing in advance of launch date. The Contractor shall provide a copy of the frequency license prior to launch."

The example language from the following "Other Agreements" section can also serve as models for contract requirements.

b. Other Agreements

The NASA/CSLI program has a template CRADA[5] and Statement of Work that provide a model for any NASA grant or other agreement highlighting the need to obtain spectrum authorization:

1. CRADA Clause (with minor modification):

RADIOFREQUENCY AUTHORIZATION

##.1 Compliance. The Parties agree that use of radiofrequencies for any purpose, such as spacecraft tracking and control, information (data) transmission to and from the spacecraft, or sensors with active radiofrequency emissions, will be in accordance with all U.S. laws and regulations, and with the International Radio Regulations promulgated by the International Telecommunication Union (ITU). The COLLABORATOR shall obtain radiofrequency authorization from the Federal Communications Commission (FCC) in accordance with the Rules and Regulations, Title 47, of the Code of Federal Regulations.

2. Appendix in Statement of Work

##. RESPONSIBILITIES AND MILESTONES

##. COLLABORATOR will use reasonable efforts to perform the following tasks:

##. COLLABORATOR shall provide to NASA documentation required to demonstrate compliance with regulatory obligations regarding radiofrequency authorization. Specifically, the COLLABORATOR shall provide: (1) A detailed technical description of the spacecraft, including description of its communications system; (2) a copy of the application for radiofrequency authorization as submitted to the FCC, and a copy of the radiofrequency authorization when obtained; (3) a copy of the information specified in Appendix 4 of the International Radio Regulations, which is required by the FCC for compliance with the frequency assignment notification and recording procedures of the International Radio Regulations; and (4) if amateur satellite service frequencies are employed, a copy of the Amateur Satellite Frequency Coordination Request as submitted to the International Amateur Radio Union (IARU), and a copy of the IARU response when obtained.

B.2 Language for Ownership and Operation (Effective Control)

Noting that any NASA contract, grant, or other agreement that involves the use of the electromagnetic spectrum for transmission, reception, or both should explicitly indicate the ownership and operator (effective control) of the radiocommunication (transmitter, receiver) system, the following provide example language for inclusion in contracts and other agreements.

a. Ownership of equipment – Contracts & Other Agreements

Besides standard contract language concerning government property, the following example clauses may be helpful to explicitly state the ownership of equipment:

1. Government Owned: "Any experimental, developmental, or operational equipment that involves the use of the electromagnetic spectrum for transmission, reception, or both that is developed, procured, or furnished by the Government under this [contract/agreement] shall be owned by NASA";

[5] See http://www.nasa.gov/627971main_2012_02_13_CubeSat_CRADA_Template.docx (as of 27 April 2015)

2. Non-Government Owned: “NASA does not claim ownership of any experimental, developmental, or operational equipment that involves the use of the electromagnetic spectrum for transmission, reception, or both that is developed or procured under this [contract/agreement].”

b. Operations (effective control) – Contracts & Other Agreements

Contract and agreement language needs to express which organization, NASA or a supporting organization, has effective control whether via direction from NASA or whether the NASA-supported organization retains sole control without direction from NASA. Such language may include:

1. Government Operated: “Any experimental, developmental, or operational equipment that involves the use of the electromagnetic spectrum for transmission, reception, or both as part of this [contract/agreement] shall be operated by NASA personnel”;

2. Government Directed (NASA retains effective control): “Any experimental, developmental, or operational equipment that involves the use of the electromagnetic spectrum for transmission, reception, or both that is operated under this [contract/agreement] shall be operated per direction from NASA whereby NASA retains effective control including the right to direct the shut down of any transmission, reception, or both in the event that there are any problems, such as radio communication interference issues”;

3. Non-Government Operated: “the [contracting organization’s] use of any experimental, developmental, or operational equipment that involves the use of the electromagnetic spectrum for transmission, reception, or both that is operated under this [contract/agreement] shall be under [contracting organization’s] discretion and control; NASA does not claim any authority over the operations of the electromagnetic spectrum systems.”

c. Communications with Regulatory Agencies

If necessary, the regulatory agencies (NTIA, FCC) may require a letter from NASA and the contracting organization indicating the ownership or operator (effective control) for the small spacecraft, such a letter may consider using the following language when the operations are conducted by a non-government operator:

> “The purpose of this letter is to confirm [Operating Organization’s] role in operating the [mission name] spacecraft, currently manifested for launch in [date]. [Operating Organization] is the contracted mission control organization for the [mission name]. This letter acknowledges that the mission operations team at [Operating Organization] will exercise full control of the operational aspects of these experiments/mission. This includes the ability – without seeking permission from or consulting with NASA – to shut down any experimental, developmental, or operational equipment that involves the use of the electromagnetic spectrum for transmission, reception, or both in the event that there are any problems, such as radio communication interference issues.
>
> Please contact [Point of Contact] if you have any questions or comments regarding [Operating Organization’s] role. [Operating Organization] looks forward to continued operation as per all FCC requirements and regulations.”

Appendix C. Design Considerations and Potential Frequency Bands

[Note: The following section is organized, essentially, as a concise "handbook" for a mission developer and, as such, provides details beyond what is necessary for frequency authorization.]

The design and operation of small satellite communication and sensors (i.e., any system that involves the use of the electromagnetic spectrum for transmission, reception, or both) need to consider a variety of factors including spectrum regulations, network services, spaceflight equipment availability, and others depending upon the mission needs. Descriptions of the functionality and emission characteristics (e.g., emission levels both in-band and out-of-band, etc.) of systems may also be required as part of the frequency licensing and authorization processes. This section provides guidance on several of the spectrum-related items including potential frequency bands. This section is provided for information only and should not be viewed as a requirements document.

C.1 Mission Operations Planning

Mission developers are encouraged to: i) Prepare a mission operations plan to guide and define needed access to the electromagnetic spectrum; and, ii) Seek spectrum guidance (as noted in Section 4), before designing or procuring any spectrum dependent systems. Such preliminary planning is essential to avoid spectrum regulatory challenges that have affected a number of small satellite missions.

Such planning includes understanding a mission's basic operational needs, including data and communication needs, such as:

- What type of radiofrequency sensors (if any) will the mission need? (Such systems could be passive sensors (e.g., radiometers) or active sensors (e.g., altimeters, radars, etc..)
- How often does the mission need to receive telemetry from the spacecraft and instruments?
- How often does the mission need to command the spacecraft and instruments?
- How much data (data volume) and how quickly (latency) does the mission need to transport data from the spacecraft to final locations (e.g., Mission Operations Center, Science Operations Center, etc.)?

Further, a mission should understand several other factors:

- What type of mission is the system? Is the mission performing:
  - Earth remote sensing (e.g., Earth Exploration Satellite Service, Meteorological Satellite Service), or
  - Exploration of the sun, planetary bodies, or universe (e.g., Space Research Satellite Service), or
  - Technology demonstrations (e.g., Space Research, Space Operation Services or experimental).
- Is the mission Federal or Non-Federal? (See Section 4)

As part of the design process, a mission will need to consider whether it will operate its own communication support systems (e.g., ground sites) or use space relay or ground network services from other organizations (e.g., NASA's SCaN networks, commercial networks, etc.) which will also dictate which frequency bands are available.

Given an understanding of these needs and status, a mission should then seek guidance from the spectrum community and, if a NASA-affiliated mission, from NASA Center Spectrum Managers, before designing or procuring any spectrum dependent systems.

C.2 Network Support and Spaceflight Hardware Availability

For mission operations, systems typically need to connect with supporting ground or space-based communication stations and networks. A system designer needs to consider the desired services, available earth station equipment, space communication network support, and available spaceflight hardware. Mission support for small satellites has ranged from a single mission-procured earth station to use of NASA's space communication networks.

Use of NASA's space communication assets are covered by NASA policy and practices, and are outside the scope of this guidance. However, NASA's Space Communication and Navigation (SCaN) networks and the NASA GSFC Wallops Flight Facility (WFF) range ground station, can support small satellite systems, and those missions with some level of NASA sponsorship may wish to contact these systems to explore possible operational support:

- SCaN Networks including the Deep Space Network (DSN), Near Earth Network (NEN), and the Space Network (SN) (i.e., TDRSS). Point of Contact:
  Gary Morse, SCaN Mission Commitment Manager
  202.358.0504
  gary.a.morse@nasa.gov
- GSFC WFF Range Ground Station. Point of Contacts:
  Tom Johnson
  757.824.2560
  thomas.e.johnson@nasa.gov

Table 6 and Table 7 indicate frequency bands supported by NASA network systems.

C.3 Operational Considerations

As part of a mission's design and implementation, a variety of operational considerations for radiofrequency systems need to be considered, as outlined in this section.

a. Inhibit and Delayed Communications

Most launch vehicle and associated services, including small satellite launches provided on the ISS, require small satellites, including cubesats, to inhibit any radiofrequency emissions until a period of time after deployment from the launch vehicle or ISS. To satisfy this requirement, a small satellite (e.g., cubesat) may use different mechanisms such as a deployment switch to physically cut off the cubesat batteries from the rest of the satellite or other mechanism. Since there is typically no access to the small satellites at the launch site, there are no radiated emissions from the small satellites at the launch site.

Each small satellite mission will need to work with the launch services and range organization associated with its launch to identify the specific requirements. Example requirements include:

- The small satellite shall not generate or transmit any signal from the time of integration into the deployment mechanism (often months in advance of launch) through 45 minutes after on-orbit deployment;
- RF Inhibits: The small satellite shall be designed to meet at least one of the following requirements to prohibit inadvertent RF transmission:
  - Transmission Power Limit: The small satellite will have one RF inhibit and have a RF power output of no greater than 1.5W at the transmitting antenna's RF input;
  - Dual Independent RF Inhibits: The small satellite will have two independent RF inhibits.

b. Control and Cessation of Emissions

The U.S. regulatory agencies, FCC and NTIA, require, as does NASA policy, that all space systems, including small satellites, maintain control of transmissions including the capability to cease transmissions. For example, per NTIA Manual (Section 8.2.32), "The use of frequencies by space stations will be authorized only in those cases where such stations are equipped so as to ensure the ability to turn on or to provide immediate cessation of emissions by telecommand." Similarly, per No. 22.1 of the ITU Radio Regulations, "Space stations shall be fitted with devices to ensure immediate cessation of their radio emissions by telecommand, whenever such cessation is required under the provisions of these Regulations." Consequently, the design of any communication or active sensor system on a small satellite must include such a capability and report on that capability in the frequency licensing or authorization application. Several methods exist that can satisfy this requirement including:

- Telecommand (via an uplink command process) that can schedule or directly command transmission and cessation of emissions (a requirement for all Federal and NASA space systems);
- A "fail-safe" operating mode where the satellite can transmit only while an uplink is active and detected; (to accomplish this, a system could wire the transmitter directly to the satellite TT&C link carrier detect, that way when the TT&C link is lost at the satellite (either by going out of view or by turning off the ground station radio) then the satellite transmitter immediately ceases, with no delay); and,
- Indirect methods (e.g., battery life, timing devices, etc.) that will ensure definite cessation of emissions.

In addition, space systems may not transmit when not in view of an associated earth station or service area, as per No. 15.1 of the ITU Radio Regulations, "All stations are forbidden to carry out unnecessary transmissions…" Consequently, the operational plans for small satellite systems should follow this directive.

Each small satellite project will need to work with the Center Spectrum Manager or other spectrum advisor to discuss the documentation of such capabilities in the licensing or authorization process.

c. Permissible Exposure Limit (PEL) & Electromagnetic Interference (EMI) Compatibility

Some launch systems and ranges may require compliance with PEL and EMI standards or requirements to ensure that personnel and equipment are not exposed to hazardous energy levels. For example, a system may be required to meet range requirements, such as those defined in AFSPCMAN 91-710, *Range Safety User Requirements Manual Volume 3 – Launch Vehicle, Payloads, and Ground Support Systems Requirements*. As specified in the range document, an example requirement is limiting exposure as defined in ANSI/IEEE C95.1, *Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz*.

As noted in previous sections, each launch event is unique, and the rules governing secondary and auxiliary payloads are defined by the specific launch vehicle customer, ELV developer, and the launch range; thus, each small satellite mission needs to engage the launch and range activities as soon as known to establish the specific PEL and EMI requirements for its mission.

d. Security

Each mission, considering the mission goals and associated mission-level requirements, needs to determine its link and data security requirements especially in regards to commanding and controlling the spacecraft. Devices, such as encryption systems, exist and are compatible with small satellite form factors and are often implemented in-line with the command and data handling and communication systems. Such security systems, although not necessary for regulatory requirements in controlling

spacecraft emissions, may be useful to demonstrate control. As noted, each mission needs to make it's own determination in implementing security systems.

C.4 Frequency Band Selection & Technical Parameter Constraints

As with all systems using the electromagnetic spectrum, the choice of a specific frequency will depend on the desired service (e.g., communications, active sensor, etc.), spectrum regulations including the status (e.g., Federal, non-Federal) and service designation of a system, the characteristics of a frequency band (e.g., bandwidth, propagation), the availability of network services whether via ground apertures or space-based relays, spaceflight equipment availability and physical constraints (e.g., size, mass, power), and cost. To date, small satellites have used many different frequency bands; however, the long-term viability for some of the bands is not guaranteed, so careful consideration should be made in selecting a frequency. Each small satellite project should work with the Center Spectrum Manager or other spectrum representative to help select the specific frequency band.

Spectrum regulations affecting frequency selection include:

- The need for (or not) regulatory protection (see below for additional information); and,
- Constraints on emissions (e.g., out-of-band emissions, power flux density (pfd) limits, etc.) (see below for additional information).

Table 6 and Table 7 list a variety of potential frequency bands that may be or have been used for small satellite operations and communications. This listing should only be viewed as informational and does not indicate recommendations or requirements.

Many frequency bands are available for passive and active sensors; projects are encouraged to work with Center Spectrum Managers to assist with identifying appropriate bands for sensors.

a. Regulatory Protection and Status

To date, most small satellite systems operate with an experimental license on a secondary non-interference basis. That is, the system must accept any interference from and must not cause interference to systems that operate on a primary basis. While such secondary operations may be appropriate for experimental or demonstration projects, such secondary status operations may not be acceptable or permitted for long-term exploration or science missions. Also:

- For experimental licensed operations (i.e., non-primary), there are no specific bands identified in the FCC rules, and operations are on a temporary, non-interference basis, i.e., the operations can neither cause interference nor claim protection from interference; and,
- For Federal systems, per NTIA 8.2.53, command and control must be accomplished in frequency bands allocated on a primary basis for this purpose (e.g., and Earth-to-space allocation for an appropriate space service) and for which fully protected operations are approved. "The tracking, telemetry, and telecommand operations of a satellite network shall have Stage 4 NTIA spectrum certification and frequency assignments with operational station class(es) before the launch of the spacecraft."

b. Technical Parameter Constraints

Spectrum regulations often limit space system emissions to facilitate operations of other systems operating in the band or in adjacent bands. Such limits may include spectral masks for emissions outside of the needed bandwidth and power flux density (pfd) limits for emission received at the earth (often specified per an elevation angle from the horizon). These limits, defined in the international ITU Radio Regulations and in U.S. FCC and NTIA regulations, are often specified depending upon the specific

frequency band or mission service designation. Each small satellite project will need to work with the Center Spectrum Manager or other representative to identify these emission requirements.

Example technical constraints include:

- Earth Station Power Limits: To protect other systems, some bands limit an Earth station's equivalent isotropically radiated power (EIRP) toward the horizon and specified antenna elevation angles above the horizontal plane;
- Power flux density (pfd) limits: To protect terrestrial system operations, many frequency bands have limits on the power incident on the Earth for a reference bandwidth
  - Example: For 460-470 MHz, the power flux density produced at the Earth's surface by any space station in this band shall not exceed -152 dBW/m²/4 kHz;
- Out of band emissions (spectral masks): To protect systems operating in adjacent bands, many system types and frequency bands have limits on out of band emissions (Filtering and other signal shaping techniques may be required);
- Bandwidth constraints: some frequency bands constrain transmission bandwidths or follow channel plans
  - Example: Per U.S. policy, signals in the 2200-2290 MHz band are limited to 5 MHz or less;
  - Example: Per international space agency agreement, signals (space research service) in the 8450-8500 MHz band are limited to 10 MHz or less.

Table 6: Potential Frequency Bands for Small Satellite Communications – Below 2 GHz (selected bands only, others possible)

Band-Lower (MHz)	Band-Upper (MHz)	Status	Uplink (Earth-to-space)	Downlink (space-to-Earth)	Considerations	Applicable US Allocations & Footnotes
137	138	Gov & Non-Gov		X		SPACE OPERATION (space-to-Earth) METEOROLOGICAL-SATELLITE (space-to-Earth) MOBILE-SATELLITE (space-to-Earth) SPACE RESEARCH (space-to-Earth)
144	146	Non-Gov	X	X	IARU no longer coordinating "experimental" license use; thus, only amateur systems permitted	AMATEUR SATELLITE
148	149.9		X		subject to coordination under RR Art. 9 Sect. II & shared terrestrially	
235	322	Gov Only	X	X	Not available for NASA or non-Federal systems	MOBILE-SATELLITE via US footnote Military services only
335.4	399.9	Gov Only	X	X	Not available for NASA or non-Federal systems	MOBILE-SATELLITE via US footnote Military services only
399.9	400.05	Gov & Non-Gov	X		NASA ground support possible for qualifying missions Federal systems limited to ground stations operating with non-Federal space systems	MOBILE-SATELLITE (Earth-to-space) (non-voice, LEO systems)
400.15	401	Gov & Non-Gov		X	NASA ground support possible for qualifying missions	METEOROLOGICAL-SATELLITE (space-to-Earth) MOBILE SATELLITE (space-to-Earth) SPACE RESEARCH (space-to-Earth) Space Operation (space-to-Earth)
401	402	Gov & Non-Gov	X	X	NASA ground support possible for qualifying missions	SPACE OPERATION (space-to-Earth) EARTH EXPLORATION-SATELLITE (Earth-to-space) METEOROLOGICAL-SATELLITE (Earth-to-space)
402	403	Gov & Non-Gov	X		NASA ground support possible for qualifying missions	EARTH EXPLORATION-SATELLITE (Earth-to-space) METEOROLOGICAL-SATELLITE (Earth-to-space)
435	438	Non-Gov	X	X	Must coordinate with IARU Possible use for beacon "services"	Amateur Satellite (via footnote)
449.75	450.25	Gov & Non-Gov	X		NASA ground support possible for qualifying missions International coordination/nofication required	Space operation service (Earth-to-space) Space research service (Earth-to-space) (via footnote)
460	470	Gov & Non-Gov		X	NASA ground support (WFF range) possible for qualifying missions; PFD Limits apply	Meteorological-satellite (space-to-Earth) Earth exploration-satellite service (via footnote)
902	928	Non-Gov	X	X	Numerous unlicensed operations, so ground support may encounter interference depending upon location	No allocation; available for experimental use only
1615	1617.5	Gov & Non-Gov	X (via space relay)	X (via space relay)	Commercial service (Globalstar); experimental use only	MOBILE-SATELLITE (Earth-to-space) Mobile-satellite (space-to-Earth)
1618.7	1626.5	Gov & Non-Gov	X (via space relay)	X (via space relay)	Commercial service (Iridium); experimental use only	MOBILE-SATELLITE (Earth-to-space) Mobile-satellite (space-to-Earth)

Table 7: Potential Frequency Bands for Small Satellite Communications – Above 2 GHz (selected bands only, others possible)

Band-Lower (MHz)	Band-Upper (MHz)	Status	Uplink (Earth-to-space)	Downlink (space-to-Earth)	Considerations	Applicable US Allocations & Footnotes
2025	2110	Gov & Non-Gov	X		NASA communication support possible for qualifying missions (NASA Space Communication Networks) Non-Federal subject to conditions on a case-by-case basis	SPACE OPERATION (Earth-to-space) (space-to-space) EARTH EXPLORATION-SATELLITE (Earth-to-space) (space-to-space) SPACE RESEARCH (Earth-to-space) (space-to-space)
2110	2120	Gov Only	X (deep space)		NASA communication support possible for qualifying missions (NASA Space Communication Networks) Non-Federal subject to conditions on a case-by-case basis	SPACE RESEARCH (deep space) (Earth-to-space) (Goldstone, CA)
2200	2290	Gov Only		X	NASA communication support possible for qualifying missions (NASA Space Communication Networks) pdf limits apply	SPACE OPERATION (space-to-Earth) (space-to-space) EARTH EXPLORATION-SATELLITE (space-to-Earth) (space-to-space) SPACE RESEARCH (space-to-Earth) (space-to-space)
2290	2300	Gov & Non-Gov		X (deep space)	NASA communication support possible for qualifying missions (NASA Space Communication Networks) pdf limits apply	SPACE RESEARCH (deep space) (space-to-Earth)
2400	2450	Non-Gov	X	X	Ubiquitous unlicensed operations, so ground support may encounter interference depending upon location	Amateur Satellite (via footnote)
3400	3410	Non-Gov	X	X	Secondary	Amateur Satellite (via footnote)
7145	7190	Gov & Non-Gov	X (deep space)		Non-Federal use on a Secondary basis; Limited to Goldstone, CA	SPACE RESEARCH (deep space) (Earth-to-space)
7190	7235	Gov Only	X			SPACE RESEARCH (Earth-to-space)
8025	8400	Gov & Non-Gov		X	NASA communication support possible for qualifying missions (NASA Space Communication Networks) Non-Federal subject to conditions on a case-by-case basis pdf limits apply	EARTH EXPLORATION-SATELLITE (space-to-Earth) METEOROLOGICAL-SATELLITE (Earth-to-space) Mobile-satellite (Earth-to-space) (no airborne transmissions)
8400	8450	Gov & Non-Gov		X (deep space)	NASA communication support possible for qualifying missions (NASA Space Communication Networks) Non-Federal subject to conditions on a case-by-case basis pdf limits apply	SPACE RESEARCH (deep space) (space-to-Earth)
8450	8500	Gov & Non-Gov		X	Civilian space agencies' policy to limit bandwidth to 10 MHz pdf limits apply	SPACE RESEARCH (space-to-Earth)
14800	1535	Gov & Non-Gov	X	X	NASA communication support possible for qualifying missions (NASA Space Communication Networks) Non-Federal subject to conditions on a case-by-case basis	Space research (Primary in US)
22550	23550	Gov & Non-Gov			NASA communication support possible for qualifying missions (NASA Space Communication Networks) Future Space Research/EESS earth-to-space allocation likely	INTER-SATELLITE
25500	27000	Gov & Non-Gov		X	NASA communication support possible for qualifying missions (NASA Space Communication Networks) Non-Federal subject to conditions on a case-by-case basis Inter-satellite service 25.25-27.5 GHz	EARTH EXPLORATION-SATELLITE (space-to-Earth) INTER-SATELLITE SPACE RESEARCH (space-to-Earth)
31800	32300	Gov & Non-Gov		X (deep space)	NASA communication support possible for qualifying missions (NASA Space Communication Networks) Non-Federal subject to conditions on a case-by-case basis	SPACE RESEARCH (deep space) (space-to-Earth)
34200	34700	Gov & Non-Gov	X (deep space)		NASA communication support possible for qualifying missions (NASA Space Communication Networks) Non-Federal subject to conditions on a case-by-case basis	SPACE RESEARCH (deep space) (Earth-to-space)

Note: other frequency bands above 35 GHz are possible for use.