# SPECTRUM MANAGEMENT

# Key Practices Could Help Address Challenges to Improving Receiver Performance

Report to Congressional Committees

**July 2024**
**GAO-24-106325**
**United States Government Accountability Office**

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# GAO Highlights

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Highlights of GAO-24-106325, a report to congressional committees
**July 2024**

## Spectrum Management

## Key Practices Could Help Address Challenges to Improving Receiver Performance

### Why GAO Did This Study

Spectrum enables a wide range of critical services in the U.S., such as mobile phone service and wireless services used by the military. Nearly all usable spectrum has been allocated by FCC for nonfederal use or by NTIA for federal use. Yet the demand for spectrum continues to grow due to ongoing innovations such as 5G networks. Improving receiver performance can help increase the available spectrum.

GAO was asked to review issues related to receiver performance. This report examines key challenges that selected stakeholders and experts identified to improving receiver performance, and how FCC and NTIA consider receiver performance as part of their spectrum management efforts.

GAO reviewed relevant statutes, regulations, and FCC and NTIA guidance and documentation. GAO interviewed FCC and NTIA officials, experts, and relevant stakeholders, such as spectrum users and industry associations. GAO compared FCC's and NTIA's spectrum management to key practices for managing and assessing the results of federal efforts.

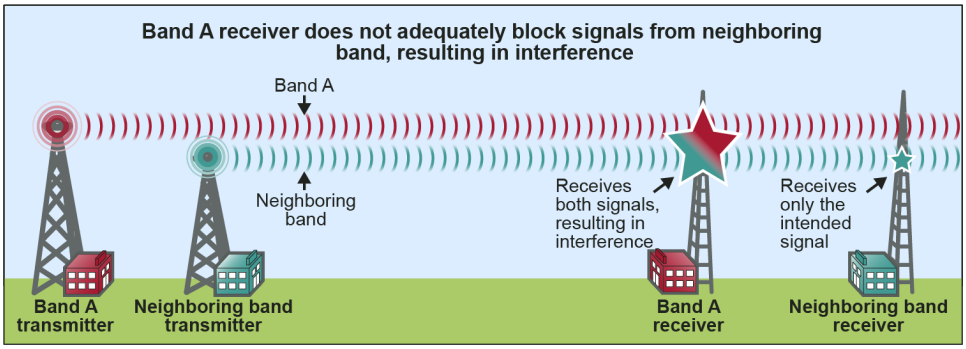
### What GAO Recommends

GAO is making three recommendations to FCC related to implementing its principles for spectrum management: (1) define goals, (2) identify strategies to achieve these goals, and (3) identify barriers to these goals. GAO is also making a recommendation to NTIA to identify and assess current information sources related to federal receiver performance. FCC and NTIA agreed with the recommendations.

### What GAO Found

Equipment that receives radio signals (receivers) can be susceptible to unwanted signals from new services and users entering the radio frequency spectrum environment. Some receivers may not be able to reject unwanted signals that are transmitted in adjacent and nearby spectrum bands, resulting in interference (see figure). Having more robust receivers can help promote spectrum efficiency by enabling different services to operate closer together. However, stakeholders and experts that GAO interviewed noted several challenges to improving receiver performance. For example, they said that it can be difficult to design, procure, or modify receivers that can accommodate the rapidly evolving spectrum environment.

**Example of a Receiver Unable to Reject Unwanted Signals Transmitted from Nearby Services**




Source: GAO. | GAO-24-106325

In 2023, as a part of its broader efforts to improve spectrum efficiency, the Federal Communications Commission (FCC) established nine principles for spectrum management that set expectations for users of nonfederal receivers. Specifically, the principles establish policy and technical considerations for receivers including that users should design receivers to reduce unwanted signals from nearby services. However, in implementing the principles, FCC has not applied key practices that GAO has found could help an agency better manage for results, including identifying goals, strategies, and barriers. Taking such steps could help FCC address challenges to improving receiver performance by providing more direction and certainty for spectrum users.

The National Telecommunications and Information Administration (NTIA) collects information and mandates performance standards for certain federal receivers. While the information NTIA currently collects is helpful for preventing instances of harmful interference, it may not provide insight into other aspects of receiver performance that could promote spectrum efficiency. Assessing its information sources to identify and address any information gaps related to federal receiver performance could help NTIA ensure that is has the evidence needed to address broader spectrum efficiency efforts. For example, knowing more about the robustness of federal receivers and the extent to which receiver performance is being optimized could be helpful to effectively manage spectrum moving forward.

# Contents

**Abbreviations**

| | |
|---|---|
| AM | amplitude modulation |
| DOD | Department of Defense |
| FAA | Federal Aviation Administration |
| FCC | Federal Communications Commission |
| FM | frequency modulation |
| GHz | gigahertz |
| GPS | Global Positioning System |
| IRAC | Interdepartment Radio Advisory Committee |
| kHz | kilohertz |
| MHz | megahertz |
| MOU | memorandum of understanding |
| NASA | National Aeronautics and Space Administration |
| NTIA | National Telecommunications and Information Administration |

U.S. GOVERNMENT ACCOUNTABILITY OFFICE
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July 18, 2024

The Honorable Cathy McMorris Rodgers
Chair
The Honorable Frank Pallone, Jr.
Ranking Member
Committee on Energy and Commerce
House of Representatives

The Honorable Robert E. Latta
Chair
The Honorable Doris Matsui
Ranking Member
Subcommittee on Communications and Technology
Committee on Energy and Commerce
House of Representatives

Radio-frequency spectrum is a scarce natural resource that provides a variety of services critical to the U.S. economy and government, including mobile telecommunications, broadband, GPS, and radar.[1] Spectrum is divided into frequency "bands" that the federal government allocates for particular services or operations, such as mobile or satellite services.[2] Nearly all usable spectrum has been allocated either by the Federal Communications Commission (FCC) for nonfederal use, or by the National Telecommunications and Information Administration (NTIA) for federal use. Yet, the demand for spectrum continues to grow due to ongoing innovations in wireless technologies, including commercial 5G mobile networks and beyond.

One of the ways FCC and NTIA can make more spectrum available is through repurposing—changing spectrum from an existing use to a new use.[3] However, accommodating the growing demand for spectrum while accounting for existing uses can be a challenging and complex task. For instance, introducing new services and operations into the spectrum environment can also increase the risk of interference to existing services in shared or adjacent and nearby bands, that, in some cases, can rise to the level of harmful

[1]The radio-frequency spectrum is the part of the natural spectrum of electromagnetic radiation lying between the frequency limits of 3 kilohertz (kHz) and 300 gigahertz (GHz).

[2]The frequency bands have different characteristics that make them more or less suitable for specific purposes. Currently, the federal government has allocated frequency bands between 8.3 kHz and 275 GHz. *See* 47 C.F.R. § 2.106.

[3]For the purposes of this report, spectrum repurposing means changing the allocation of specific frequencies from one radiofrequency service or set of services to another, or changing the service rules associated with an allocation, such that the frequencies can be used by different entities and in different ways than previously. The federal government may allocate the repurposed spectrum for either federal or nonfederal use, or both. *See* U.S. Department of Commerce, *Annual Report on the Status of Spectrum Repurposing and Other Initiatives*, (Washington, D.C.: Mar. 2023).

interference.[4] Recently, stakeholders have raised questions about 5G signals potentially causing harmful interference to existing devices operating in adjacent and nearby bands. These existing devices include GPS and aviation radar altimeters—a critical safety-of-life device that measures the distance between an aircraft and the terrain immediately below.

Historically, FCC and NTIA have managed instances of harmful interference by focusing on regulating the transmitter—the equipment that emits signals. But the receiver—the equipment that captures a transmitted signal—also plays a role. For example, a receiver's ability to filter out or reject unwanted signals can prevent or reduce harmful interference.[5] In addition to regulating transmitter performance, improving a receiver's resistance to interference could promote spectrum efficiency by enabling services to operate closer together, freeing up valuable spectrum that the federal government could repurpose for other uses.[6]

In general, FCC has not directly imposed receiver performance requirements on nonfederal spectrum users, while NTIA has mandated receiver performance standards for certain federal operations. We previously reported that stakeholders—including both federal and nonfederal spectrum users, commercial licensees, and manufacturers—have taken steps to improve receiver performance but faced challenges, including difficulty accommodating a changing spectrum environment.[7]

You asked us to review issues related to improving receiver performance. This report examines: (1) key challenges that selected stakeholders and experts identified to improving receiver performance; (2) how FCC considers the performance of receivers as part of its spectrum management; and (3) how NTIA considers the performance of receivers as part of its spectrum management.

To address these objectives, we reviewed relevant statutes, regulations, and FCC and NTIA guidance and documentation. We also reviewed literature on receiver performance, standards, and interference, including white papers and reports issued by FCC's Technological Advisory Council and the National Academies of Sciences, Engineering, and Medicine.[8]

Additionally, we selected two case studies for review involving instances where stakeholders claimed adjacent-band interference and wherein receiver performance played or could have played a role. These case studies involved: (1) potential interference between commercial wireless communication and aviation services in the C-Band, and (2) potential interference between mobile satellite and GPS services in the L-Band. We selected

[4]Harmful interference is interference that endangers a radionavigation service's or other safety services' functioning or seriously degrades, obstructs, or repeatedly interrupts a radiocommunication service operating in accordance with the International Telecommunications Union Radio Regulations. The International Telecommunications Union is an international organization within the United Nations System where governments and the private sector coordinate global telecom networks and services. 47 C.F.R. § 2.1(c).

[5]Federal Communications Commission, Technological Advisory Council, Spectrum and Receiver Performance Working Group, *Basic Principles for Assessing Compatibility of New Spectrum Allocations* (Dec. 11, 2015).

[6]For the purposes of this report, we refer to improving a receiver's resistance to interference as improving receiver performance.

[7]GAO, *Spectrum Management: Further Consideration of Options to Improve Receiver Performance Needed*, GAO-13-265 (Washington, D.C.: Feb. 22, 2013).

[8]Technological Advisory Council, *Basic Principles;* National Academies of Sciences, Engineering, and Medicine, *Analysis of Potential Interference Issues Related to FCC Order 20-48* (2023).

these case studies to ensure variation in application or use (e.g., communications, navigation), and a mix of federal and nonfederal users, among other characteristics.

For each case study, we reviewed documentation and interviewed FCC and NTIA officials, as well as relevant stakeholders. Stakeholders included federal spectrum users; nonfederal spectrum users (i.e., commercial licensees); industry associations; and device manufacturers. We identified stakeholders based on their involvement in our selected case studies and through comments submitted in response to FCC's Notice of Inquiry regarding efficient spectrum use and improved receiver performance.[9] Due to their roles in our selected case studies, we focused on FCC, NTIA, the Department of Defense (DOD), and the Federal Aviation Administration (FAA) as the cognizant agencies and agency components in our review.

With regard to stakeholders, we selected four additional federal spectrum users through their membership in NTIA's Interdepartment Radio Advisory Committee (IRAC). We selected 13 nonfederal stakeholders representing various commercial licensees, industry associations, and device manufacturers based on their involvement in our two selected case studies or on their relevant interests in 5G networks, GPS, and aviation equipment. To provide additional context, we interviewed 12 experts in spectrum management-related topics, including receiver performance and interference. We identified these experts with the assistance of the National Academies of Sciences, Engineering, and Medicine. See appendix I for a list of experts we interviewed and how they were identified.

We compared FCC and NTIA efforts related to receivers against key practices we previously identified to help manage and assess the results of federal efforts.[10] Specifically, we focused on key practices, as applicable, for federal evidence-building and performance-management activities, including planning for results and assessing and building evidence. We assessed the extent to which FCC and NTIA applied key practices, when applicable, by analyzing FCC and NTIA documentation. This documentation included NTIA's *Manual of Regulations and Procedures for Federal Radio Frequency Management* (commonly referred to as the Redbook), and agency-specific policies, procedures, and spectrum-management directives and manuals.[11] See appendix I for a detailed description of our objectives, scope, and methodology, including a list of interviewees.

We conducted this performance audit from October 2022 to July 2024 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.

[9]*Promoting Efficient Use of Spectrum through Improved Receiver Interference Immunity Performance*, Notice of Inquiry, 37 FCC Rcd. 5337 (2022).

[10]In our prior work, we identified 13 key practices that can help federal leaders and employees develop and use evidence to effectively manage and assess the results of federal efforts. These 13 key practices can be viewed as four interrelated topic areas including: (1) plan for results; (2) assess and build evidence; (3) use evidence; and (4) foster a culture of learning and continuous improvement. *See* GAO, *Evidence-Based Policymaking: Practices to Help Manage and Assess the Results of Federal Efforts,* GAO-23-105460 (Washington, D.C.: Jul. 12, 2023).

[11]U.S. Department of Commerce, National Telecommunications and Information Administration, *Manual of Regulations and Procedures for Federal Radio Frequency Management* (Jan. 2023 rev).

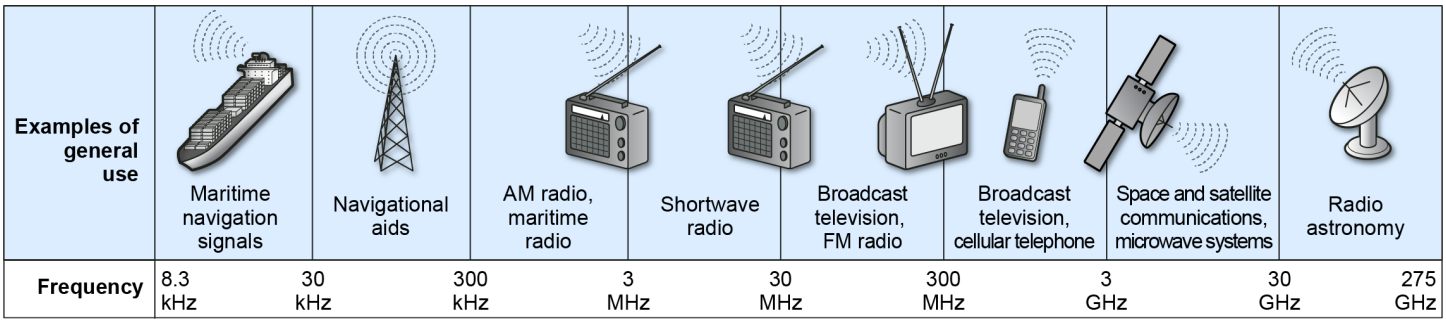
# Background

## Spectrum Management

Within the United States, spectrum is jointly managed by FCC—an independent agency within the executive branch—and NTIA—an administration within the Department of Commerce. FCC manages spectrum use for nonfederal users, including commercial, private, and state and local government users. NTIA manages spectrum for federal government users and advises the President on telecommunications issues.

FCC and NTIA manage spectrum through actions to "allocate" and "assign" it. Allocation involves segmenting spectrum into bands of frequencies designated for use by particular services or operations (such as mobile or satellite services). (Fig. 1 illustrates examples of services by frequency band.) Assignment, which occurs after allocation, involves providing spectrum users with a license or authorization to operate within a specific band allocated for a particular use. In allocating and assigning spectrum, FCC and NTIA specify service rules or regulations, including limits on the operations of equipment using the band. Depending on the allocation, use of bands may be limited to one type of user or may be shared between and among users (such as both federal and nonfederal users) for different services.

**Figure 1: Examples of Services by Frequency Band**




Source: GAO. | GAO-24-106325

FCC has the authority to regulate, allocate, and assign spectrum for nonfederal use and does so through notice-and-comment rulemaking—a process by which FCC proposes and adopts rules with input from the public.[12] FCC starts a rulemaking proceeding by notifying the public that it is proposing to adopt or modify rules on a particular subject and is seeking comments. FCC considers the comments it receives in developing final

[12]FCC is subject to the Administrative Procedure Act, which establishes general procedures for federal agencies issuing rules, and the Communications Act of 1934, as amended, which governs how the FCC administers spectrum and accounts for different types of licensees and users. The Administrative Procedure Act generally requires that agencies notify the public about, and solicit comments on, proposed regulations and consider the record in deciding whether to adopt rules. 5 U.S.C. § 553. FCC has authority under the Communications Act to "[p]rescribe the nature of the service to be rendered by each class of licensed stations and each station within any class" and to "[a]ssign bands of frequencies to the various classes of stations, and assign frequencies for each individual station and determine the power which each station shall use and the time during which it may operate." 47 U.S.C. §303(b)–(c). In addition, FCC has authority to allocate spectrum so as to provide flexibility of use, if— (1) such use is consistent with international agreements to which the United States is a party; and (2) the commission finds, after notice and an opportunity for public comment, that— (A) such an allocation would be in the public interest; (B) such use would not deter investment in communications services and systems, or technology development; and (C) such use would not result in harmful interference among users. 47 U.S.C. § 303(y). *See also* 47 U.S.C. § 301, *et seq*.

rules. As part of the rulemaking process, FCC releases documents into a publicly available proceeding record, publishes rulemaking documents in the Federal Register, and invites the public to submit comments, studies, and any other supporting documents into the record. We previously reported that there are a variety of factors that may affect the length and complexity of FCC's rulemaking process.[13] For example, some rulemakings may remain open for many years because they involve complex, technical issues and a variety of stakeholders and perspectives.

NTIA allocates and assigns spectrum to federal users and is responsible for overall management of federal spectrum use.[14] IRAC, which NTIA chairs, comprises representatives from 19 federal entities that use spectrum and advise NTIA on spectrum issues.[15] FCC serves as a liaison to the committee, in its role of managing spectrum for nonfederal users. IRAC and its subcommittees assist NTIA in assigning frequencies and in developing policies, procedures, and technical criteria on the management and federal use of spectrum. For example, IRAC's Spectrum Planning Subcommittee maintains a continuing appraisal of the current and future needs of the various federal radio services and makes recommendations regarding changes in allocations, technical parameters, or other actions, as appropriate.

## Spectrum Efficiency Efforts

One way FCC and NTIA have sought to increase spectrum access is by establishing shared goals aimed at promoting the efficient and effective use of spectrum.[16] FCC and NTIA have formalized collaboration practices through a memorandum of understanding (MOU).[17] For example, FCC and NTIA established a framework to conduct joint spectrum planning with the intention to promote efficient spectrum use and protect existing users. Such planning includes spectrum management techniques as a means of increasing commercial and federal access. The following describes additional efforts.

[13]GAO, *Telecommunications: FCC Should Take Steps to Ensure Equal Access to Rulemaking Information,* GAO-07-1046 (Washington, D.C.: Sept. 6, 2007).

[14]Under 47 U.S.C. § 904(c)(1), NTIA has authority to issue regulations necessary to carry out its functions. NTIA publishes a Manual of Regulations and Procedures for Federal Radio Frequency Management, which is incorporated by reference into the Code of Federal Regulations by 47 C.F.R. § 300.1. NTIA has stated that its manual is exempt from the Administrative Procedure Act's notice-and-comment requirements because it concerns federal management of spectrum. *See* 58 Fed. Reg. 44134, 44136 (Aug. 19, 1993).

[15]*See* 47 U.S.C. § 904(b). The members of IRAC are: Department of Agriculture, Air Force, Army, Coast Guard, Department of Commerce, Department of Energy, FAA, Department of Homeland Security, Department of the Interior, Department of Justice, National Aeronautics and Space Administration, Navy, National Science Foundation, Department of State, Department of Transportation, Department of the Treasury, U.S. Agency for Global Media, U.S. Postal Service, and Department of Veterans Affairs.

[16]We have previously reported on various efforts related to spectrum management including actions Congress, FCC, and NTIA have taken to meet the growing demand. *See* GAO, *Spectrum Management: NTIA Should Improve Spectrum Reallocation Planning and Assess Its Workforce*, GAO-22-104537 (Washington, D.C.: Jan. 27, 2022); and *5G Deployment: FCC Needs Comprehensive Strategic Planning to Guide Its Efforts*, GAO-20-468 (Washington, D.C.: June 29, 2020).

[17]FCC and NTIA updated their MOU in response to our June 2021 recommendations that FCC and NTIA should update their MOU to address identified gaps (such as the lack of clearly defined goals and agreed-upon processes for making decisions) and develop a means to continually monitor and update this agreement. *See* GAO, *Spectrum Management: Agencies Should Strengthen Collaborative Mechanisms and Processes to Address Potential Interference*, GAO-21-474 (Washington, D.C.: June 29, 2021).

- **Spectrum repurposing and sharing.** FCC and NTIA have undertaken various efforts to repurpose spectrum—either on an exclusive or shared basis—to meet growing demand.[18] Repurposing spectrum can include changing the allocation of specific frequencies from one radio-frequency service or set of services to another. It can also change the service rules associated with an allocation, such that the frequencies can be used by different entities and in different ways. FCC and NTIA may allocate the repurposed spectrum for either federal or nonfederal use, or both. Repurposing may also allow for more than one user to operate in the same frequency band—known as "spectrum sharing." Spectrum repurposing activities may involve relocating legacy systems to other frequency bands, requiring legacy and new systems to share spectrum, or, in rare cases, discontinuing legacy systems altogether.

  Current repurposing initiatives include making more spectrum available for commercial wireless services—particularly mid-band spectrum, which is critical to deploying 5G networks.[19] Existing mid-band spectrum users—known as "incumbents"—include federal government users that have primary access rights to the spectrum. We previously reported on challenges related to deploying 5G, including transitioning incumbent users to new or less favorable frequency bands.[20]

- **FCC's spectrum management principles.** In April 2023, FCC issued a policy statement establishing a set of high-level principles on how FCC intends to manage spectrum efficiently and effectively moving forward.[21] The principles draw, in part, from a white paper published by FCC's Technological Advisory Council.[22] Spectrum management principles articulated in the policy statement include expectations and responsibilities for nonfederal spectrum users. For example, FCC expects operators, users, and equipment manufacturers to consider how to accommodate a rapidly changing and congested spectrum environment, as services are placed closer together to meet the growing demand. This can include adopting "good neighbor" practices that promote more efficient and effective coexistence among users.

[18]Some repurposing efforts have been in response to specific statutory provisions. For example, the MOBILE NOW Act directed FCC and NTIA to identify at least 255 megahertz (MHz) of federal and nonfederal spectrum to be made available for mobile and fixed wireless broadband use. Making Opportunities for Broadband Investment and Limiting Excessive and Needless Obstacles to Wireless ("MOBILE NOW") Act, Pub. L. No. 115-141, div. P, tit. VI, § 603, 132 Stat. 1097, 1098 (2018).

[19]The frequency bands—often referred to as low-band, mid-band, and high-band spectrum—have different characteristics that make them more or less suitable for specific purposes. Mid-band spectrum (generally defined as between 1 GHz and 6 GHz) tends to provide greater data capacity than low bands and has better propagation qualities than higher bands, making it highly desirable for cellular network operators.

[20]GAO-20-468.

[21]Per FCC, the policy statement is intended to help guide its decision-making and stakeholder action as the radio frequency environment evolves. The policy statement does not constitute rules. Accordingly, this policy statement is not binding on FCC or other parties, and it will not prevent the agency from making a different decision in any matter that comes to its attention for resolution. *See* Federal Communications Commission, *Principles for Promoting Efficient Use of Spectrum and Opportunities for New Services; Promoting Efficient Use of Spectrum through Improved Receiver Interference Immunity Performance,* Policy Statement, 38 FCC Rcd. 3682, 3682 (2023).

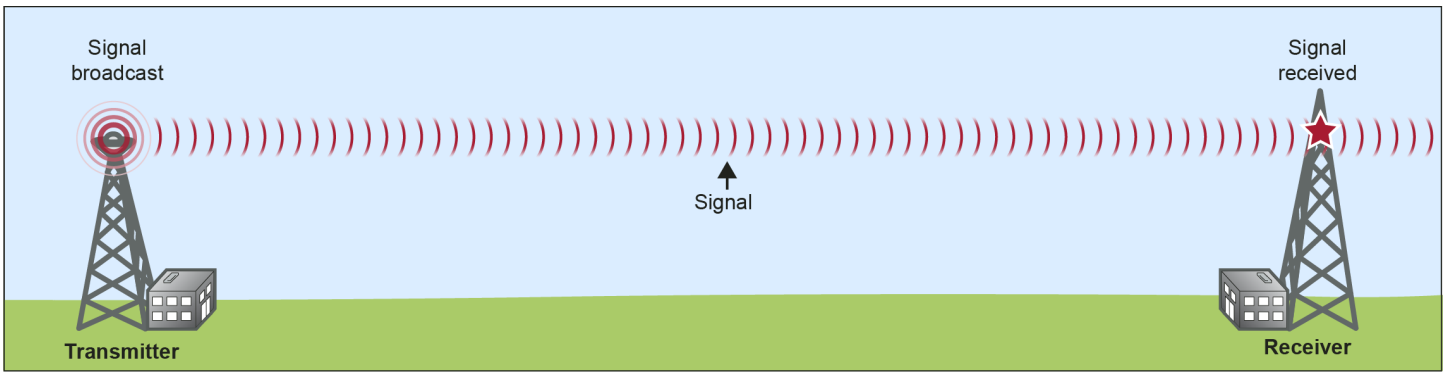
[22]Technological Advisory Council, *Basic Principles*. FCC's Technological Advisory Council consists of approximately 50 telecommunications experts that provide technical advice to FCC and make recommendations on the issues and questions presented to it by FCC.

- **National Spectrum Strategy.** In November 2023, the White House issued the *National Spectrum Strategy*, which articulates national objectives for spectrum policy.[23] These objectives include establishing a spectrum pipeline to ensure U.S. leadership in advanced and emerging technologies.[24] For example, the strategy identifies five frequency bands for in-depth, near-term study to determine potential repurposing.[25] These frequency bands consist of federal and shared federal and nonfederal bands—with an emphasis on mid-band frequencies—that will be studied for a variety of uses, including innovative space services and remotely piloted aviation systems and aircraft. The strategy also explores opportunities for spectrum sharing—bands with shared federal and nonfederal use—as a means to increase access to spectrum. In March 2024, NTIA released its implementation plan for the strategy.[26]

## Spectrum Interference

Wireless technologies that use spectrum include communications systems such as mobile communications, television and radio broadcasting, and two-way radio. They also include noncommunications systems, such as radionavigation systems (e.g., GPS), radar systems, and satellites that passively sense natural phenomena. These devices rely on a range of frequencies of electromagnetic radiation to transmit and receive signals and data. For example, radio communication involves the transmission and reception of signals by a radio system (see fig. 2).

**Figure 2: Example of a Signal Transmitted and Received by a Radio Communications System**




Source: GAO. | GAO-24-106325

[23]As required by a presidential memorandum, the Secretary of Commerce, through NTIA, submitted the National Spectrum Strategy to the President through the Assistant to the President for National Security Affairs, the Assistant to the President for Economic Policy, and the Director of the Office of Science and Technology Policy. *See* White House, *National Spectrum Strategy* (Washington, D.C.: Nov. 13, 2023); *see also* Modernizing United States Spectrum Policy and Establishing a National Spectrum Strategy, § 3, 88 Fed. Reg. 80079, 80080 (Nov. 13, 2023).

[24]Additional objectives within the National Spectrum Strategy include collaborative long-term planning to support the nation's evolving spectrum needs; unprecedented spectrum innovation, access and management through technology development; and expanded spectrum expertise and elevated national awareness. *See* White House, *National Spectrum Strategy* (Washington, D.C.: Nov. 13, 2023).

[25]Per the National Spectrum Strategy, the strategy's "efforts to create new sharing opportunities pertains to bands with federal allocations that are being newly considered for more intensive federal or nonfederal use. It will not examine bands that were previously made available for nonfederal use by the FCC, nor will it affect the rights of existing nonfederal users or otherwise constitute a modification of an existing license under 47 U.S.C. § 316."

[26]The White House designated NTIA as the steward for executing the implementation plan for the National Spectrum Strategy.

A variety of factors influence a receiver's ability to properly capture the transmitted signal and decode the information for use, including the terrain, distance, and atmospheric conditions between the transmitter and the receiver. For instance, buildings, mountains, and foliage can prevent some types of communications systems from properly receiving a transmitted signal. Communications systems must also operate in environments where a variety of natural and human-made signals are present. Such undesired radiation could impede a communications system's transmissions from reaching its intended recipients, and such an occurrence is called interference.[27]

It is impossible to eliminate interference, and not all interference will prevent the proper functioning of a system. However, in some cases, the interference can rise to the level of harmful interference, meaning that it "endangers the functioning of a radionavigation service or of other safety services or seriously degrades, obstructs, or repeatedly interrupts a radiocommunication service."[28]

Harmful interference can occur when two systems use the same frequencies or use adjacent and nearby frequencies in the same geographic area.[29] Adjacent band interference has two main causes (see fig. 3).

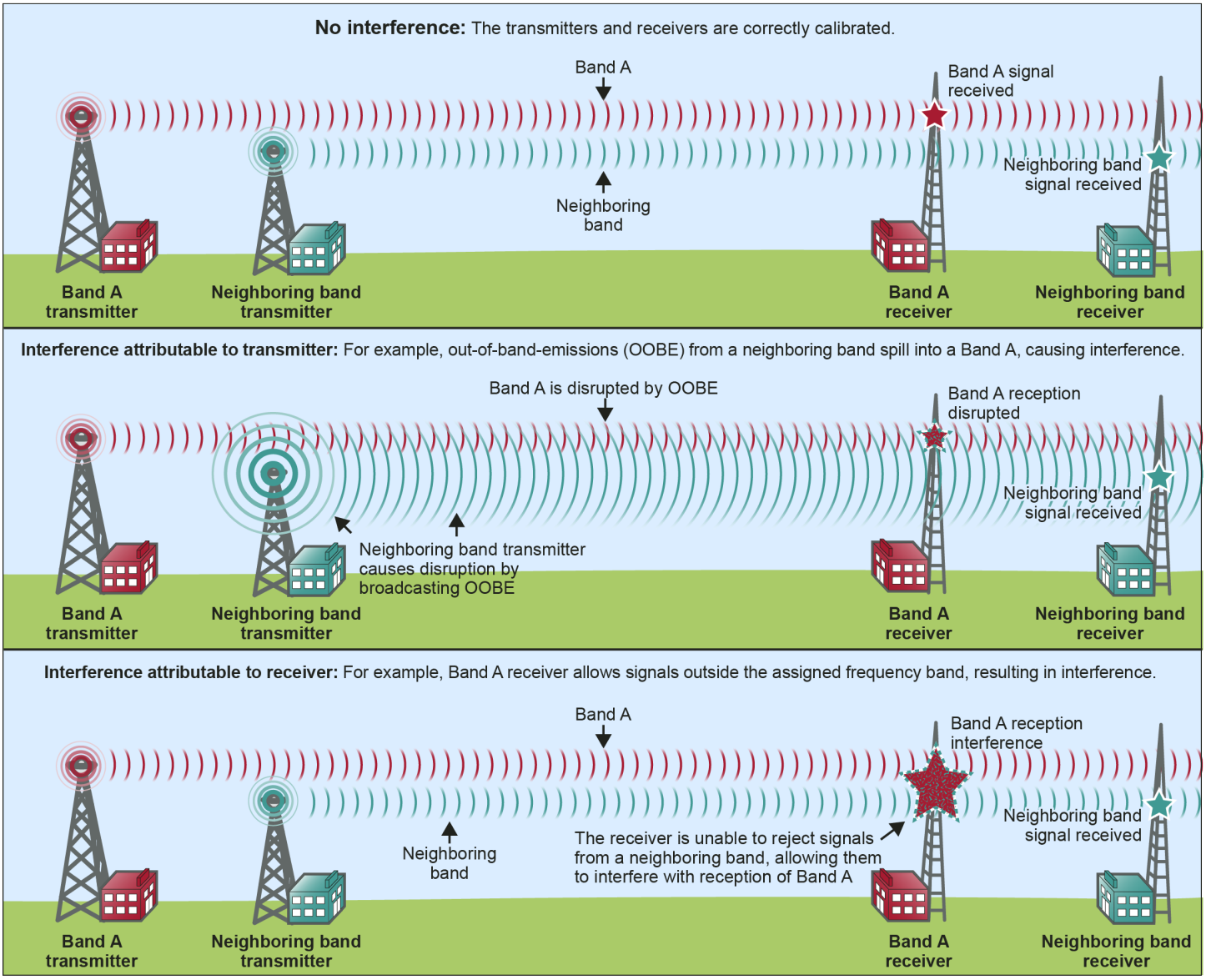
- **Out-of-band emissions.** Transmitters emit undesired emissions into adjacent frequencies that can cause interference to receivers operating on those assigned frequencies.
- **Out-of-band reception.** Receivers admit undesired emissions from transmitters operating in adjacent frequencies. In other words, the receiver may not be able to reject all undesired signals, impairing its performance.

[27]Interference is the effect of unwanted energy due to one or a combination of emissions, radiations, or inductions upon reception in a radiocommunication system, manifested by any performance degradation, misinterpretation, or loss of information which could be extracted in the absence of such unwanted energy. 47 C.F.R. § 2.1(c). Interference can be unintentional, for example when devices operating on nearby frequencies, or naturally occurring due to weather. However, bad actors can also deliberately block or interfere with signals through "jamming" and "spoofing." For example, a jammer emits signals that block or degrade a signal, while a spoofer replaces that signal with a manipulated signal.

[28]To be considered harmful interference, the interference must affect a system operating in accordance with the International Telecommunication Union Radio Regulations. 47 C.F.R. § 2.1(c).

[29]In the first case, co-channel interference occurs when two communications systems operate on the same frequency assignment in the same geographic area. In the second case, adjacent band interference occurs between two communication systems operating on different, but adjacent, frequency assignments in the same geographic area. For the purposes of this report, we are referring to adjacent band interference when discussing interference.

**Figure 3: Types of Adjacent Band Interference**




Source: GAO. | GAO-24-106325
Note: Energy from a transmitter outside its assignment (out-of-band emissions) cannot be eliminated but are managed by setting emission limits on the transmitter. In the case depicted, the intensity is at a level that can result in interference.

## Receiver Performance

Historically, FCC and NTIA have managed instances of harmful interference between users in adjacent bands mostly by setting emission limits on transmitters and establishing guard bands—a gap in the allocated spectrum between the two systems to serve as a buffer. However, the receiver also plays a critical role in preventing and reducing harmful interference. According to FCC's Technological Advisory Council, the characteristics of both the transmitting service and nearby receiving service in frequency, space, or time can

affect the degree of interference.[30] For example, although transmitters emit energy that can cause interference, interference can also result from a receiver's inability to reduce reception of noise, unwanted emissions, and undesired signals. However, energy that may otherwise result in harmful interference may not have an adverse effect if a receiver is designed to be resilient to interference.[31] Therefore, improving receiver performance, in addition to transmitter performance, can help prevent and reduce instances of harmful interference.

In addition to addressing harmful interference, improved receiver performance can also enable more efficient and effective use of the spectrum. For example, receivers designed to be resilient to interference can reduce the need for guard bands, freeing up valuable spectrum that could be repurposed for other uses. Further, improved receiver performance can help promote coexistence among different services and users by enabling services to operate closer together. Such closer operations can allow more uses and users within the finite spectrum, which can bring benefits, including increased access, new services, and device innovation.[32] In addition, designing more resilient receivers could reduce restrictions on nearby transmitters to prevent harmful interference. Increased signal strength from transmitters can allow for better service. Lastly, improved receiver performance could also result in more opportunities for sharing spectrum, including frequencies shared between federal and nonfederal users.[33]

Although the specific performance parameters for each receiver will vary, as it is case dependent, FCC's Technological Advisory Council identified practices that may result in improved receiver performance and spectrum efficiency.[34] According to the advisory council, operators and users should assume that the spectrum environment is constantly changing and unpredictable and, as a result, expect to encounter interference. Improving receiver performance could include applying various techniques, as appropriate, to improve a receiver's resilience to interference.[35] For instance, a receiver could be deployed with additional filtering and dynamic range to accommodate future expansion of the spectrum. Improving receiver performance could also entail designing more robust receivers including designing receivers to filter or reject interference from outside their service's assigned frequencies or channels, not just their service's current needs. Specifically, it is important to design systems to operate effectively as if other systems occupied the adjacent frequency band, even if there are no services currently assigned.

FCC has not generally imposed performance requirements on nonfederal receivers, but rather relies on the marketplace to design appropriate equipment. FCC reported, however, that it has implicitly provided incentives for receiver performance. Specifically, FCC expects the technical characteristics of a receiver to be sufficient

[30]*See* Technological Advisory Council, *Basic Principles*.

[31]*See* Policy Statement, 38 FCC Rcd. at 3686–87.

[32]Federal Communications Commission, Technological Advisory Council, Receivers and Spectrum Working Group, *Interference Limits Policy: The Use of Harm Claim Thresholds to Improve the Interference Tolerance of Wireless Systems*, White Paper (Feb. 6, 2013).

[33]Spectrum can be shared through a variety of technical and procedural techniques, such a geographic separation of equipment and use of directional antennas, or by employing dynamic spectrum access technologies which allow equipment to sense and select among available frequencies in an area.

[34]*See* Technological Advisory Council, *Basic Principles*.

[35]FCC's Technological Advisory Council identifies a variety of techniques that could help mitigate degradation from interference. According to the advisory council, some of the techniques could also be considered as optimization techniques to legacy systems. For example, directional antennas, power optimization, modulation, and scheduling may be practical features available to legacy systems to support the mitigation of interference as the spectrum usage grows. *See* Technological Advisory Council, *Basic Principles*.

for the receiver to operate within the environment—established by FCC services rule for transmissions—to successfully establish communications.[36] There have been limited circumstances where FCC has more directly addressed regulated receiver performance, both through performance standards and performance incentives.[37]

NTIA has mandatory standards for certain federal operations that include requirements for receiver performance. Specifically, NTIA has receiver standards for a large percentage of the federal authorized frequency including mobile systems, fixed systems below 15 GHz, and radar systems. Standards have requirements for receiver parameters such as selectivity—the ability of a receiver to separate the wanted from unwanted signals in the adjacent frequency, among other things.[38] NTIA's receiver standards for specific federal operations are published in NTIA's *Manual of Regulations and Procedures for Federal Radio Frequency Management* (commonly referred to as the Redbook).[39] In addition to NTIA's mandatory standards, many federal entities develop their own receiver performance requirements to ensure that receivers relevant to their missions are resilient to harmful interference. For example, DOD and FAA have receiver standards unique to their services and operations.[40]

In 2013, we reported that stakeholders—including federal and nonfederal spectrum users, commercial licensees, and manufacturers—had taken steps to improve receiver performance but identified several challenges that impeded further improvements.[41] These challenges included a lack of coordination across industries when developing receiver standards, a lack of incentives to improve receivers, and difficulty accommodating a changing spectrum environment.[42] Since then, we have found that stakeholders face an even more challenging and complex spectrum environment.[43] For instance, the spectrum environment is more congested than 10 years ago, as services are placed closer together to meet the growing demand. This can include placing dissimilar services, with different power levels, next to each other in adjacent and nearby

[36]See *Promoting Efficient Use of Spectrum through Improved Receiver Interference Immunity Performance*, Notice of Inquiry, 37 FCC Rcd. 5337, 5339–40 (2022).

[37]For example, FCC defined the minimum levels of performance that a receiver must meet to claim protection against unacceptable interference in the 800 MHz band. Specifically, FCC set minimum levels for receiver performance for non-cellular systems to mitigate interference between non-cellular and cellular systems. Therefore, spectrum users that choose to use receivers that do not meet the minimum levels are not entitled to full protection from interference. For additional examples of FCC rules on receiver performance requirements, see Notice of Inquiry, 37 FCC Rcd. at 5340–42.

[38]Additional receiver parameters can include spurious response rejection, undesired receiver response resulting from mixing the local oscillator and undesired signals—this includes the response to undesired signals at the image frequency; and intermodulation rejection, the ability of a receiver to reject intermodulation products produced by mixing two or more signals at the input to the receiver.

[39]U.S. Department of Commerce, National Telecommunications and Information Administration, *Manual of Regulations and Procedures for Federal Radio Frequency Management*, Chapter 5 (Jan. 2023 rev).

[40]According to FAA officials, FAA has used and continues to use standards development bodies such as RTCA to develop standards. RTCA is a private, not-for-profit corporation that develops consensus-based recommendations on communications, navigation, surveillance, and air traffic management system issues. RTCA standards serve as a partial basis for subsequent FAA regulatory and certification processes.

[41]GAO-13-265.

[42]Standards can help guide receiver designs that prevent interference from adjacent spectrum users and can be either voluntary or mandatory.

[43]GAO-21-474.

bands. The congested spectrum environment, among other factors, can contribute to an increased risk of interference to existing services and operations.

In addition, FCC identified instances from its recent rulemakings in which the ability of existing receivers to filter or reject signals outside of their intended bands has been directly relevant to the timing and scope of new services introduced to the spectrum environment.[44] Such instances are as follows.

- **L-Band.** In 2020, the FCC conditionally approved Ligado Networks LLC's license to establish a new service in the L-Band—a spectrum band allocated for federal and nonfederal mobile satellite services.[45] GPS industry groups and NTIA submitted petitions for FCC to reconsider its decision, citing concerns of harmful interference to GPS receivers operating in adjacent bands.[46] As of June 2024, FCC has not published a decision regarding the petitions for reconsideration. FCC's order directs Ligado to work with federal agencies on interference issues, but Ligado says federal agencies have not engaged with Ligado while the petition for reconsideration remains pending. According to Ligado, it therefore cannot currently comply with the order and deploy service in the band.[47]
- **C-Band**. In 2020, FCC repurposed a band of spectrum—previously used for fixed-satellite service—for commercial wireless services to deploy 5G networks in the C-Band.[48] Aviation industry groups and the FAA raised questions about 5G signals from planned telecommunications systems potentially causing harmful interference to aviation radar altimeters operating in a nearby band. Specifically, according to FAA officials, potential harmful interference could occur from 5G emissions that are in-band or out-of-band, as some 5G out-of-band transmissions are in the radar altimeter band (see fig. 4 below). FAA reported that harmful interference could have significant safety implications by interrupting or degrading radar altimeter functions during critical phases of flight.[49]

[44]*See* Notice of Inquiry, 37 FCC Rcd. at 5342. We selected these proceedings to serve as case studies where stakeholders claimed adjacent-band interference and wherein receiver performance played or could have played a role.

[45]1526-1536 MHz, 1627.5-1637.5 MHz, and 1646.5-1656.5 MHz bands. *See LightSquared Technical Working Group Report et al.,* Order and Authorization, 35 FCC Rcd. 3772 (2020).

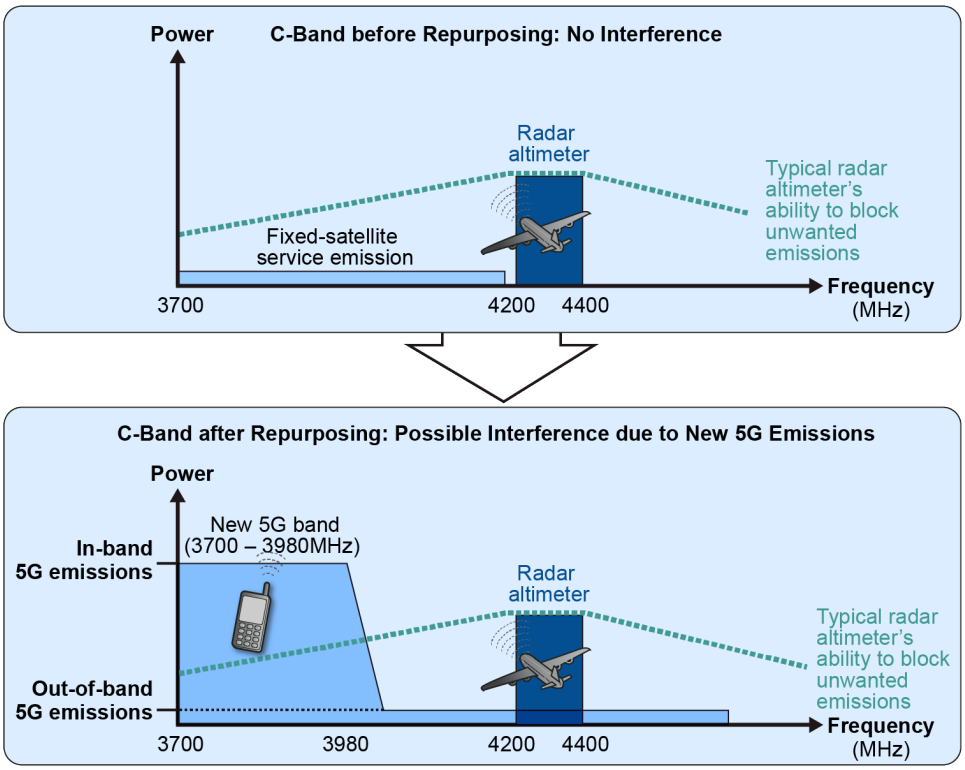
[46]NTIA filed a petition to reconsider the decision in May 2020. Petition for Reconsideration or Clarification of the National Telecommunications and Information Administration, IB Docket Nos. 11-109 and 12-340 (filed May 22, 2020). NTIA also filed a petition for stay of the decision pending resolution of the petition for reconsideration. Petition for Stay of the National Telecommunications and Information Administration, IB Docket No. 11-109 (filed May 22, 2020). In January 2021, the FCC denied NTIA's petition for stay of the Ligado decision. *LightSquared Technical Working Group et al.*, Order Denying Motion for Stay, 36 FCC Rcd. 1262 (2021).

[47]In October 2023, Ligado filed a complaint in the United States Court of Federal Claims asserting, among other claims, that DOD and NTIA effectively prevented Ligado from operating under its license by actions such as declining to cooperate with Ligado's efforts to coordinate with federal agencies to comply with FCC's order. Complaint, *Ligado Networks v. United States*, No. 23-1797 (Fed. Cl. filed Oct. 12, 2023). As of June 2024, the court has not issued a decision regarding this lawsuit.

[48]*Expanding Flexible Use of the 3.7 to 4.2 GHz Band*, Report and Order and Order of Proposed Modification, 35 FCC Rcd. 2343 (2020).

[49]Department of Transportation letter to NTIA on *Expanding Flexible Use of the 3.7 to 4.2 GHz Band,* FCC Docket Nos. GN 18-122, IB 20-205, GN 20-305 (Dec 1, 2020).

**Figure 4: Model of New 5G Emissions Potentially Interfering with Aviation Radar Altimeters Operating in a Nearby Band**




Source: GAO presentation of RTCA analysis; GAO (illustrations). | GAO-24-106325

Note: The dotted line represents a typical radar altimeter's interference tolerance mask. RTCA determined this by combining the measured interference tolerance thresholds—the maximum allowable level of a specified interference signal—among all altimeter models included in that usage category. Energy from a transmitter outside its assignment (out-of-band emissions) cannot be eliminated but are managed by setting emission limits on the transmitter. The model above depicts altimeters that have not been replaced or retrofitted to be more resistant to interference from signals outside of the altimeter's band.

In 2022, stakeholders, including commercial wireless providers and FAA, reached an agreement to manage deployment of 5G services (e.g., reduce power levels) until aircraft could: (1) replace or retrofit impacted altimeters to increase resistance to interference or (2) install an acceptable radio frequency filter to block unwanted signals. This includes developing new radar altimeter performance standards, which were previously established in 1980.[50] FAA reported that, as of the end of September 2023, U.S. airlines had upgraded the affected radar altimeters and the near-term risk of 5G interference has been mitigated.[51]

[50]FAA uses Technical Standard Orders to set minimum performance standards for specified articles used on civil aircraft. The order for airborne low-range radio altimeters requires that, subject to modification in the order's appendix I, such altimeters meet the applicable minimum performance standards in EUROCAE document ED-30, *Minimum Performance Standards for Airborne Low-Range Radar Altimeter Equipment*, Edition 2, dated March 1980. Federal Aviation Administration, *Airborne Low-Range Radio Altimeter*, TSO-C87a (May 31, 2012).

[51]According to FAA officials, among domestic commercial airlines, approximately 5,300 aircraft and 11,500 radio altimeters needed to be retrofit. FAA officials told us that, as of March 2024, approximately 130 out-of-production aircraft remain to be retrofitted and expect them to either be completed or removed from airline service over the next 18 months.

# Stakeholders and Experts Identified Several Key Challenges to Improving Receiver Performance, including the Rapidly Evolving Spectrum Environment

Selected stakeholders and experts we spoke with identified five key challenges to improving receiver performance: (1) the rapidly evolving spectrum environment; (2) information and data sharing limitations; (3) technical tradeoffs and physical limitations; (4) cost; and (5) disagreements and varied perceptions among stakeholders.

## Rapidly Evolving Spectrum Environment

Selected stakeholders and experts told us that it can be difficult to design and modify receivers to operate in accordance with numerous and ongoing changes in the spectrum environment due to spectrum repurposing.

Stakeholders and experts told us that receiver performance requirements, which are used to help guide the design and procurement of receivers, are generally based on the current spectrum environment. According to DOD officials, DOD does not typically design receivers but specifies performance requirements through its acquisition process based on its assessment of the current spectrum environment.[52] Receiver performance requirements can determine the quality of data received by the receiver, among other things.[53] In addition, receivers are designed and built to meet the specificities of mission requirements. For example, officials from the National Aeronautics and Space Administration (NASA) told us that some of their missions, especially those associated with space and science, require unique receiver specifications to enable mission success.

According to FCC, issues related to receiver performance, including instances of potential or realized harmful interference, are sometimes the result of a receiver that was designed for a spectrum environment different than its current operating environment.[54] For instance, an incumbent system may have been designed based on different assumptions about the spectrum environment in adjacent or nearby frequency bands. Yet, receiver manufacturers we interviewed told us that it can be difficult, if not impossible, to anticipate changes in all bands adjacent to the devices at the time of design. For example, in some cases, spectrum bands adjacent to the device may be used for a different purpose at the time of design.

In addition, a new service may have been placed in a band not previously allocated for a higher intensity use. As a result, the receiver may not be resilient to signals transmitted from new devices introduced into the

[52]DOD Instruction 3222.03, “DOD Electromagnetic Environmental Effects (E3) Program” (Aug. 25, 2014); DOD Instruction 4650.01, “Policy and Procedures for Management and Use of the Electromagnetic Spectrum” (Jan. 9, 2009). This program, as defined in DOD Instruction 3222.03, is concerned with ensuring mutual electromagnetic compatibility of military platforms, systems, subsystems, and equipment, including transmitters and receivers, through electromagnetic compatibility design, test, analysis, and/or modeling and simulation, as appropriate. Performance requirements are stipulated for both transmitters and receivers in the DOD acquisition process through the Joint Capabilities Integration and Development Systems process, spectrum management and spectrum supportability risk assessments, military standards, engineering analyses and impact assessments, and test and evaluation.

[53]Features of receiver standards can include: selectively, the ability of a receiver to separate the wanted from unwanted signals in the adjacent frequency; sensitivity, the detection limit of the receiver to admit the weakest desired signal level; and dynamic range, the range of desired signal levels from the weakest to the strongest that a receiver can admit and function properly.

[54]Notice of Inquiry, 37 FCC Rcd. at 5342.

spectrum environment. FAA officials told us that this can include signals within the receivers' band emanating from transmitters outside of that band while still operating within the FCC license limits. DOD officials told us that they frequently model the spectrum environment in which DOD's receivers operate and make adjustments, as needed, to prevent and reduce harmful interference. However, such modeling cannot account for deploying new devices if nearby bands are repurposed for uses not anticipated at the time of the modeling. Further, FAA officials told us that models cannot account for what they do not know, including which other systems may be placed next to an existing system, and that unanticipated interactions can occur.

Stakeholders and experts told us that these challenges can be exacerbated by devices with long lifecycles. For example, experts and FAA officials told us that aviation equipment is often designed to last for decades, with aviation radar altimeters built to last at least 30 years, on average. NASA officials told us they expect many space-based receivers, such as satellites, to operate for decades and are often designed years before launch. Further, experts we interviewed noted that it is easier and more cost effective to incorporate changes or updates to a receiver during the design phase, rather than upgrading or retrofitting existing equipment. As a result, these types of legacy receivers are difficult, and at times impossible to adapt to a dynamic and changing spectrum environment.

Additionally, stakeholders and experts told us that the time needed to assess and address the impact of proposed changes may not align with how fast the spectrum environment is evolving. For example, FAA officials told us they need a significant amount of time and resources to determine the impact of proposed repurposing decisions on existing services and operations, especially if a proposed action involves integrated safety-of-life equipment, like altimeters. According to FAA officials, in some cases, this cannot be completed within the time allocated for FCC's rulemaking process. If technical changes are needed to accommodate the new use, it can take even more time. FAA and DOD stated in comments filed with FCC's rulemakings that they lacked sufficient time to modify legacy receivers to address potential interference when FCC repurposed spectrum in the C-Band and L-Band that could affect aircraft and military operations, respectively. FCC notes that it follows the requirements established by the Administrative Procedure Act, the Commission's rules, and applicable precedent in conducting rulemaking proceedings.[55]

## Information and Data Sharing Limitations

Selected stakeholders and experts told us that information and data sharing limitations can also cause challenges to improving receiver performance. During FCC's notice-and-comment rulemaking process, stakeholders can submit information into the public record to support proposed rules including information regarding any new technologies that may use spectrum. Other stakeholders can then use this information to perform modeling and simulations to determine the impact on their devices and services and if any technical changes or mitigations are required. FCC also relies on information submitted by stakeholders to support its final rules. Knowing the characteristics of devices operating in adjacent bands is critical to effectively prevent or reduce harmful interference and enable coexistence. However, stakeholders and experts told us that data sharing limitations, especially between federal and nonfederal users, can impact the ability to design and procure, or modify existing receivers. NASA and FAA officials told us that in many instances, commercial stakeholders may not provide the empirical data or characteristics of proposed new technologies because they consider the information to be proprietary. Further, companies may not want competitors to acquire information

[55]*See, e.g.,* 5 U.S.C. § 553(c) (requiring that the FCC "shall give interested persons an opportunity to participate" after issuing a notice of proposed rulemaking); 47 C.F.R. §1.415(a)–(c) (providing a "reasonable time" for comments and reply comments).

about signal strength or the energy level of devices, among other information. Therefore, federal stakeholders may lack the desired level of certainty regarding inputs when modeling and simulating the potential for interference.

Further, in performing modeling and simulation, at times the assumptions developed by the federal stakeholders diverge from the assumptions of the commercial stakeholders which can lead to competing conclusions. For example, a commercial wireless industry stakeholder reported that harmful interference to altimeters would not occur under reasonable scenarios. Specifically, T-Mobile critiqued an FAA interference study, concluding that the study did not demonstrate that harmful interference would likely result under reasonable scenarios.[56] Aviation industry stakeholders and FAA officials said that studies involving safety-of-life equipment, such as radar altimeters, need to take into account the full range of operations, including routine and allowable worst-case scenarios during which the equipment is expected to function given the risk and consequence of failure. DOD officials said that its program for testing whether equipment can operate effectively in its intended spectrum bands also includes some worst-case scenario assumptions.

In addition, FAA officials told us that there can be a lack of detailed technical information provided during FCC's notice-and-comment rulemaking process. For example, according to FAA officials, FCC's rulemaking process may not include compatibility studies that take into account federal users. In addition, FAA officials told us that joint studies with both federal and commercial users are rarely conducted early in the rulemaking process. As a result, FAA and other federal agencies may provide input on the rulemaking without knowledge of the full characteristics of a proposed change. Nonfederal stakeholders we spoke with told us that they also encountered information and data sharing limitations during the rulemaking process stating that they lacked the necessary data and technical information from federal users to effectively assess the impact of proposed changes. Stakeholders and experts told us that this may be due to national security concerns such as those pertaining to military services and operations. The FCC notes that it attempts to encourage the maximum amount of information sharing but can be constrained by statutory requirements on confidentiality and by other concerns outside its control.

## Technical Tradeoffs and Physical Limitations

Experts told us that there are technical tradeoffs and physical limitations to improving receiver performance. They noted that it is not as simple as designing more robust receivers; rather there are tradeoffs associated with improving a receiver's design. Specifically, if one aspect of a receiver's design changes—such as accessibility, weight, size, power, and sensitivity—it may impact another aspect.

In some cases, existing equipment can be modified to prevent or mitigate receiving harmful interference. Specifically, an electronic filter component can be added to transmitters or receivers in some cases. For example, in response to interference concerns involving 5G signals affecting safety, an FAA airworthiness directive prohibited transport and commuter category aircraft from performing certain landing operations after

[56]In October 2019, FAA partially funded the Aerospace Vehicle Systems Institute to conduct preliminary bench tests to determine the interference impact from proposed 3.7-3.98 GHz 5G signals on a range of radio altimeter models.

June 30, 2023, unless they (1) have 5G C-Band-tolerant radar altimeters or (2) install an acceptable radio frequency filter.[57]

However, experts told us that a receiver's design entails limits that technology cannot physically overcome. One expert told us that current aviation radar altimeters provide such an example. Unlike other communication channels where some amount of incoming data are usually lost during transmission, altimeters can afford very minimal data loss due to the potential catastrophic impacts to aircraft operations, including loss of situational awareness. This presents tradeoffs between the strength of a filter and the faintness of the signal the receiver can detect, as well as the speed at which the receiver can detect signals. For example, a filter can introduce greater latency—delaying signals being received and affecting the performance of the altimeter, according to the expert.

In other cases, receivers cannot be physically accessed to make updates and improvements. For example, NASA and National Oceanic and Atmospheric Administration officials said that once a satellite is in space, it is not accessible to update or modify. According to NASA officials, while much can be done to manage Earth-based receivers used for space exploration and operation, it is far more difficult to mitigate interference to space-based receivers due to their distance from Earth, launch and orbit considerations, and operational constraints required to enable communications.

## Cost

Selected stakeholders and experts identified various cost factors associated with improved receiver performance. For example, in addition to updating the actual receiver, there are costs associated with integrating the updated device into existing equipment and operations. For instance, in addition to the cost of adding filters to radar altimeters to prevent interference from 5G signals, airlines must also take an aircraft out of service to retrofit the altimeter with the filter. Experts told us that the cost of making updates to the actual receiver is nominal but that the steps to integrate the updated receiver into existing equipment can be costly. In addition, one expert told us that there are costs associated with researching how to best improve receiver performance.

Stakeholders and experts told us that a misalignment of incentives between new and existing users can also present challenges to improving receiver performance. Specifically, experts told us that there can be a lack of incentives for existing users to improve receivers. For example, one expert told us that unless there is a performance or safety issue, it is not feasible for incumbents to regularly update their receivers just in case there is a change in the spectrum environment. NTIA officials agreed that many federal users do not see a need to upgrade a receiver if it is not currently experiencing interference. This can run counter to some nonfederal stakeholders, such as commercial licensees, which aim to optimize performance to get the most use out of the spectrum they have purchased. Further, experts told us that, in some cases, federal users may oppose changes to the spectrum environment because it would be more cost effective to resist change than to update their receivers.

[57]FAA officials told us that as of the end of September 2023, U.S. airlines had upgraded the majority of all affected radar altimeters on the domestic commercial airline fleet. They stated further that, in combination with specific transmission limitations contained in voluntary agreements signed by all 21 C-Band licensees, the near-term risk of 5G interference has been mitigated.

NASA officials told us that federal agencies are not typically appropriated funds specifically to retroactively change operational hardware. As a result, making substantial changes to operational systems could require reallocating funding from other systems and could limit agencies' abilities to accomplish their mission objectives. In contrast, DOD officials said that they have accessed resources available to agencies to help recover the costs of migrating operations from one spectrum band to another. Specifically, the Spectrum Relocation Fund, a statutory fund established in 2004, can help agencies cover the costs associated with repurposing certain spectrum. However, while the fund enables federal agencies to repurpose or share bands, DOD officials told us that making spectrum available for nonfederal use can take time. According to DOD officials, it is critical to ensure that national security operations are protected, and that performance is not compromised when repurposing spectrum. In the interim, a new licensee may want faster access to a spectrum band, creating challenges for both the new and existing user. Officials told us that it can also be challenging to implement solutions that match the pace of rapidly evolving operational requirements and technology advances among commercial use.

In addition, stakeholders and experts told us that the roles and responsibilities for new and incumbent users are not always clear, including who ultimately bears the responsibility for the activities and costs associated with responding to changes in the spectrum environment. For example, a new user may benefit from improved receiver efficiency that could allow previously unused spectrum to be reallocated for use. However, that efficiency could be the result of costly changes to legacy receivers belonging to existing users. One federal spectrum user told us that roles and responsibilities between new and incumbent users are becoming increasingly blurred, especially in shared bands in which federal users may not have the funding and resources to make improvements. Conversely, FCC officials told us that costs to an incumbent user should not be the only consideration. In addition, new users may have to pay higher bids in auctions if less spectrum is available or incur greater costs for transmitters to reduce power and emissions on spectrum they have already purchased.

## Disagreements and Varying Perceptions among Stakeholders

Selected stakeholders and experts told us that disagreements and varying perceptions regarding spectrum use among stakeholders can present challenges to improving receiver performance. For example, stakeholders may disagree on issues related to potential interference due to proposed changes in the spectrum environment. Disagreements may involve the cause and severity of interference, and whether it is considered harmful. For example, FAA officials told us that while a 1 percent chance of a short-term coverage outage may be acceptable to commercial wireless services, a 1 percent chance of a catastrophic accident in low visibility operations is exponentially more frequent and unacceptable for aviation operations.

Varying perceptions among users regarding spectrum use can also cause challenges. For example, in many recent repurposing cases, incumbent users are federal agencies whose main priority is to prevent harmful interference to their services and operations. As a result, incumbent users may resist changes in the spectrum environment and new services in nearby spectrum bands. For instance, the National Academies reported in its analysis of potential interference issues related to the L-Band that federal spectrum users may be motivated to

resist change and, if a change were to occur, there is a view that it should not impact existing operations.[58] Similarly, DOD officials told us that when incumbents within a frequency band require protection from harmful interference, a new entrant must coordinate with the incumbent to show it will not cause harmful interference.

However, resistance to change can conflict with the interests of new entrants, which tend to be commercial users. Commercial wireless stakeholders that we interviewed have stated that, while their intention is to avoid harmful interference to existing services, the spectrum environment is not static. They suggested that existing users should improve their ability to adapt to the changing spectrum environment rather than resist it. For example, in its comments to FCC's Notice of Inquiry regarding efficient spectrum use and improved receiver performance, AT&T stated that using poorly performing receivers and failing to implement reasonable improvements, such as installing filters, may effectively infringe on the rights of other spectrum users just as much as using transmitters with excessive out-of-band emissions.[59]

## FCC Sets Expectations Regarding the Performance of Nonfederal Receivers but Has Not Identified Goals, Strategies, and Related Barriers

As a part of its broader efforts to improve spectrum efficiency, FCC established nine high-level spectrum management principles for transmitters and receivers that include expectations for users of nonfederal receivers. However, FCC has not applied key practices that we previously found could help agencies better manage and assess the results of federal efforts—including identifying goals, strategies, and barriers—to implement its spectrum management principles. Applying these key practices could also help FCC address or mitigate the challenges to improving receiver performance discussed above.

In April 2023, FCC issued a policy statement that included policy and technical considerations for both transmitters and receivers. Specifically, the policy statement established nine spectrum management principles grouped under three categories (see table 1).

[58]The William M. (Mac) Thornberry National Defense Authorization Act for Fiscal Year 2021 directed DOD to seek to enter into an agreement with the National Academies of Sciences, Engineering, and Medicine to carry out "an independent technical review of the Order and Authorization adopted by the Federal Communications Commission on April 19, 2020 (FCC 20-48), to the extent that such Order and Authorization affects the devices, operations, or activities of the Department of Defense." Pub. L. No. 116-283, § 1663, 134 Stat. 3388, 4074 (2021). The Office of the Secretary of Defense, Chief Information Officer, with the assistance of the Air Force Research Laboratory, entered into a contract with the National Academies, and the National Academies appointed the Committee to Review FCC Order 20-48 Authorizing Operation of a Terrestrial Radio Network Near the GPS Frequency Bands to carry out the study per the statement of task.

[59]AT&T Services, Inc. Comments to FCC Docket 22-137, *Promoting Efficient Use of Spectrum through Improved Receiver Interference Immunity Performance* (Apr. 21, 2022).

**Table 1: FCC's Spectrum Management Principles for Transmitters and Receivers**

| Category | Category information |
|---|---|
| Interference realities | 1. Interference and harmful interference are affected by the characteristics of both the transmitting service(s) and nearby receiving service(s) in frequency, space, and/or time.<br>2. The spectrum environment is highly variable, and elimination of occasional service degradation or interruption cannot be guaranteed.<br>3. Services should plan for the spectrum environment in which they intend to operate, the service they intend to provide, and the characteristics of spectrally and spatially proximate operations. Planning should be ongoing and account for changes in spectrum operating environments. |
| Shared responsibilities | 4. Transmitters should be designed to minimize the amount of their transmitted energy outside of the service's assigned frequencies and authorizations.<br>5. Receivers should be designed to mitigate interference from emissions from outside of their service's assigned frequencies or channels.<br>6. Radio transmitter and receiver system operators and equipment manufacturers should plan for and design error tolerant systems, using good engineering practices, to mitigate degradation from interference. |
| Data-driven regulatory approaches to promote co-existence | 7. Relevant information about services' transmitter and receiver standards, guidelines, and operating characteristics is needed to promote effective spectrum management and efficient coexistence.<br>8. Quantitative analyses of interactions between services that are fact- and evidence-based, sufficiently robust, transparent, and reproducible are needed to better inform spectrum management decision-making.<br>9. FCC will explore, in future rulemakings, interference limits policies in particular spectrum bands to promote effective coexistence. |

Source: *Principles for Promoting Efficient Use of Spectrum and Opportunities for New Services; Promoting Efficient Use of Spectrum through Improved Receiver Interference Immunity Performance, Policy Statement*, 38 FCC Rcd. 3682 (2023). | GAO-24-106325

According to FCC, the purpose of the spectrum management principles is to help inform FCC's future actions and stakeholders' expectations regarding: (1) harmful interference issues; (2) the responsibilities of both transmitters and receivers to mitigate interference; and (3) further regulatory steps that ensure coexistence among services in increasingly congested spectrum bands. The policy statement is helpful for providing insight into what FCC hopes to achieve, including defining its ideal spectrum environment. However, we found that FCC has not applied key practices that we previously found could help agencies better manage and assess the results of federal efforts, such as efforts to improve spectrum efficiency.

Through our prior work, we have identified key practices for effectively implementing federal evidence-building and performance-management activities.[60] Specifically, we identified three key practices that can help a federal organization plan for results by providing a clear picture of what it is trying to achieve, how it will achieve it, and any obstacles that may affect its ability to do so.

1. **Defining goals.** Goals communicate the results that an organization seeks to achieve. They guide the organization's activities and allow decision-makers, staff, and stakeholders to assess performance by comparing planned and actual results. Key actions for defining goals include: (1) defining goals for all activities; (2) identifying both long-term outcomes and near-term measurable results; and (3) aligning goals across organization levels.

[60]GAO-23-105460.

2. **Identifying strategies and resources.** After an agency has identified its goals, it identifies how it plans to achieve them. Key actions include: (1) identifying strategies for each goal; (2) coordinating with other organizations, programs, and activities contributing to the goal, when applicable; and (3) identifying the resources needed to achieve each goal.

3. **Assessing the environment for potential barriers.** Factors within and outside an organization can affect its ability to achieve its goals. An organization's internal factors include its culture, its management practices, and its business processes. External factors can include economic, social, and technological trends as well as statutory, regulatory, and other legal requirements. Key actions for assessing the environment include: (1) identifying both internal and external factors that could affect goal achievement; and (2) defining strategies to address or mitigate the factors.

FCC officials told us the policy statement draws on the key practices described above but does not explicitly invoke them because FCC plans to operationalize the spectrum management principles through future rulemakings. FCC officials noted that, at the time of our review, there had not yet been an opportunity to apply the spectrum management principles to a specific rulemaking. They further noted that applying the principles will be case-dependent, and the FCC commissioners will ultimately have discretion on how to apply them.

However, because individual FCC rulemakings focus on specific bands, FCC may need to apply the key practices at a broader level to address all stakeholders operating in the spectrum environment. While we recognize FCC's regulatory function, we previously found that even regulatory agencies can benefit from adopting a framework that explicitly applies key practices to plan for results, as described above.[61] In addition, broadly applying key practices to plan for results could help FCC address or mitigate the challenges that stakeholders and experts identified to improving receiver performance.

Although the details of specific rulemakings may differ, we have found that several of the challenges stakeholders and experts identified to improving receiver performance are crosscutting and long-standing. For example, in 2013, we reported that stakeholders faced challenges regarding a lack of coordination and incentives and difficulty accommodating a changing spectrum environment.[62] Not only do these challenges continue to persist, but also grow in their complexity as the spectrum environment becomes increasingly crowded. Further, experts told us that issues pertaining to receiver performance, including instances of potential or realized harmful interference, will only increase as 5G networks—and eventually 6G networks—deploy, along with other services.[63]

Defining goals related to implementing the spectrum management principles could help FCC address or mitigate challenges to improving receiver performance by articulating the results it expects to achieve in the near term. One of FCC's spectrum management principles states that planning should be ongoing and account for changes in spectrum operating environments. In addition, receivers should be designed to reflect the characteristics of spectrally and spatially proximate operations. However, as described above, stakeholders may have difficulty anticipating changes to the spectrum environment. Defining goals related to this principle, such as specifying bands or time frames, may provide greater direction and certainty to users. For example,

[61]GAO, *Managing for Results: Strengthening Regulatory Agencies' Performance Management Practices,* GAO/GGD-00-10 (Washington, D.C.: Oct. 28, 1999).

[62]GAO-13-265.

[63]Approximately every 10 years since the early 1980s, wireless carriers have deployed a new generation of wireless communication technology. *See* GAO-20-468.

experts told us that FCC could provide more certainty to stakeholders with regards to planning by identifying potential bands that could be repurposed in the next 5 to 10 years.

In 2022, FCC's Technological Advisory Council made a similar recommendation that FCC should consider the extent to which it can provide regulatory certainty for the future status of potentially shared spectrum bands.[64] For example, the advisory council suggested that FCC coordinate with NTIA to develop a long-term spectrum plan.[65] Defining goals related to the spectrum management principles could also enable FCC to assess progress toward achieving broader spectrum efficiency initiatives. Specifically, having goals could help FCC determine whether and how its efforts related to spectrum management are contributing to achieving national objectives outlined in the National Spectrum Strategy.

Identifying the strategies and resources needed to facilitate and achieve the spectrum management principles could help FCC address or mitigate challenges to improving receiver performance by ensuring that its efforts related to spectrum management are complementary and mutually reinforcing. For example, another spectrum management principle acknowledges the importance of information sharing for achieving spectrum efficiency and promoting coexistence among users. However, as we described previously, there are data sharing limitations regarding device characteristics and operating parameters, especially between federal and nonfederal users. Although NTIA requires federal users to provide device characteristics for certain receivers, FCC relies on stakeholders to provide this information during the rulemaking process. FCC reported, however, that in some situations this level of detail has not been made available.[66] As previously discussed, this could be due to nonfederal users being hesitant to provide information that they consider to be proprietary.

In addition, users and a majority of experts told us that there are few formal mechanisms in place for coordination between federal and nonfederal users regarding issues related to receiver performance. For example, coordination between federal and nonfederal users may be required in instances after a repurposing decision has been issued but there are unresolved disputes or interference concerns that still need to be addressed.[67] FCC has previously encouraged federal and nonfederal users, for example in the C-Band rulemaking, to set up and participate in multi-stakeholder groups that evaluate possible interference reporting mechanisms, among other matters. However, coordination across various industries and sectors can be challenging due to competing interests and the lack of shared data and information, as previously described. By identifying the strategies and resources needed to facilitate and achieve the spectrum management principles, FCC can better ensure activities in place are appropriate and effective.

Assessing the environment to identify both external and internal factors could also help FCC identify and address barriers stakeholders and experts identified to improving receiver performance. For example, one

[64]Federal Communications Commission, Technological Advisory Council, *Recommendations to the Federal Communications Commission Based on Lessons Learned from CBRS* (Dec. 2022).

[65]In 2021, we recommended that FCC should, in consultation with NTIA, clarify and further identify shared goals or outcomes for spectrum-management activities that involve collaboration and ways to track progress. As of June 2024, this recommendation remains open. *See* GAO-21-474.

[66]*Principles for Promoting Efficient Use of Spectrum and Opportunities for New Services; Promoting Efficient Use of Spectrum through Improved Receiver Interference Immunity Performance,* Policy Statement, 38 FCC Rcd. 3682, 3692 (2023).

[67]In 2021, we recommended that FCC should, in consultation with NTIA, establish clearly defined and agreed-upon processes for making decisions on spectrum-management activities that involve other agencies, particularly when consensus cannot be reached. As of June 2024, this recommendation remains open. *See* GAO-21-474.

spectrum management principle states that receivers should be designed to mitigate interference from emissions from outside of their service's assigned frequencies or channels. However, as described above, stakeholders identified various factors that may limit their ability to do so. Although some factors, such as technological limitations, cannot be addressed, other factors, such as cost, may have feasible solutions. For example, the National Academies reported that establishing a well-defined mechanism to identify and address the economic and other externalities associated with the highest and best use of spectrum (e.g., improved receiver performance) may reduce much of the contention experienced in rulemakings in the future. It further noted that this could be accomplished through an overarching policy rather than on a case-by-case basis.[68]

In addition, internal factors such as FCC's operational processes and management activities may also affect its ability to implement the principles. For example, stakeholders and a majority of experts told us that FCC's current notice-and-comment proceedings may not facilitate or support the quantitative analysis required to assess and determine the potential impact of repurposing decisions on existing receivers. One of FCC's spectrum principles states that quantitative analyses of interactions between services that are fact- and evidence-based, sufficiently robust, transparent, and reproducible are needed to better inform spectrum management decision-making. However, stakeholders told us that they may not have the necessary time, resources, or information to conduct such analyses within the current spectrum management processes. Additionally, as previously discussed, different assumptions among stakeholders, particularly when from different industries and sectors, may inform modeling and analyses that result in conflicting conclusions. Assessing the environment to identify both external and internal factors could help FCC anticipate both future opportunities and challenges, and to plan accordingly.

By incorporating key practices for effectively managing and assessing the results of federal efforts into its implementation of the spectrum management principles, FCC will be better positioned to achieve results. On a broader level, the key practices could help FCC use the principles as part of its larger spectrum management framework. At a more specific level, FCC would be better positioned to address and mitigate challenges encountered by stakeholders to improve receiver performance.

## NTIA Mandates Certain Performance Standards and Collects Information on Federal Receivers but Has Not Fully Aligned Activities to Broader Spectrum Efficiency Efforts

NTIA considers the performance of federal receivers by mandating performance standards for certain receivers and collecting information through its process to authorize spectrum use. However, NTIA has not fully aligned its activities to broader spectrum efficiency efforts, including spectrum management goals shared with FCC.

NTIA primarily manages federal receiver performance by ensuring certain receivers meet performance standards through its system certification process. Specifically, agencies seeking authorization for a new use of spectrum provide NTIA information related to receiver performance, depending on the service and system. NTIA then certifies federal equipment after ensuring it meets mandatory receiver standards. According to NTIA, mandatory standards for receivers apply to about 60 percent of federal spectrum assignments, including land mobile radio, fixed, radar, and aeronautical mobile telemetry systems. Additional standards set by federal

[68]National Academies of Sciences, Engineering, and Medicine, *Analysis of Potential Interference Issues Related to FCC Order 20-48* (2023).

spectrum users like FAA cover another 10 percent of federal spectrum assignments. NTIA and federal spectrum users also adopt industry-developed standards when they are available for a given service. For federal spectrum users that have specific applications or lack a commercial equivalent, NTIA can establish its own standards, as it did for radar systems, or choose to not establish standards. When procuring equipment, federal spectrum users must set specifications that comply with the NTIA mandatory standards.

In addition to certifying systems, NTIA uses the information it collects regarding federal receiver performance in a variety of ways. For example, NTIA uses the data collected for certain systems as part of an automated process that optimizes frequency assignments. NTIA also uses this information to analyze spectrum sharing opportunities. For instance, NTIA reported that as it considers commercial wireless systems operating near federal systems, it uses the available receiver performance information that agencies have provided in their system certification requests.[69] Further, FCC and NTIA's MOU states that receiver performance data—in addition to other relevant technical data, analysis, and available tests—will be used to facilitate evidence-based spectrum policymaking efforts, in particular when participating in each other's public proceedings. For example, receiver performance data could be used to identify any technical issues that may result in a dispute or disagreement during rulemakings.

According to NTIA, the information it currently collects from agencies through its system certification process includes relevant characteristics of receiver performance. NTIA officials told us that receiver performance is defined as a receiver's immunity to interference (i.e., the ability to filter out or reject unwanted signals). Specifically, NTIA requires agencies to submit the technical characteristic needed, depending on the service and system, to evaluate compliance with appliable standards within the current operating environment. These standards establish a baseline of performance with respect to receiver interference immunity. However, this is only one aspect of receiver performance, according to experts that we interviewed. Other aspects of receiver performance could include factors related to the robustness of a receiver. Both FCC and FCC's Technological Advisory Council have identified additional factors associated with receiver performance, including practices and techniques that could promote spectrum efficiency and coexistence. For example, designing receivers to adapt to a changing spectrum environment and using the latest technological developments and designs could enhance spectrum use. In addition, according to FCC's Technological Advisory Council, deploying a receiver without proper filtering or dynamic range because no systems are located nearby at the time of installation would be considered poor engineering practice, and future interference can be expected.[70] Further, there could be receiver performance parameters that are more critical for allowing the introduction of new services in nearby or adjacent bands without causing unacceptable interference.

As mentioned above, both NTIA and FCC have undertaken various efforts related to spectrum efficiency. For example, NTIA and FCC have established shared goals within their MOU to promote the efficient and effective use of spectrum, including identifying practices, metrics, and technologies that may enhance spectrum use. The National Spectrum Strategy also acknowledges that spectrum efficiency and the ability for services to coexist requires a holistic approach dependent on receiver characteristics, in addition to transmitter operations.

Such an approach can include efforts to improve the performance of both the transmitter and the receiver. For example, the strategy states that federal spectrum users must incorporate spectrum efficiency requirements

[69]NTIA Comments to FCC Docket 22-137, *Promoting Efficient Use of Spectrum through Improved Receiver Interference Immunity Performance* (June 27, 2022).

[70]*See* Technological Advisory Council, *Basic Principles*.

early in acquiring spectrum-using systems, including using state-of-the art technologies and advanced operational techniques to maximize coexistence with other spectrum users. In addition, the strategy states that the federal government will encourage private entities to improve receivers' resistance to harmful interference and develop and offer technologies and services that are responsive to both commercial and unique federal requirements. Further, the federal government will explore ways to encourage agencies to procure systems that can operate outside of traditional frequency allocations and across frequency bands, if authorized.

Our prior work has demonstrated that federal decision-makers need evidence about whether federal programs and activities are achieving intended results. We previously found that applying certain key practices can help agencies in planning and implementing evidence-building activities.[71] Key practices to assess and build evidence include:

1. **Assessing the extent to which existing evidence addresses key questions.** Key actions include identifying key questions to address; identifying relevant internal and external sources of evidence; and assessing the coverage and quality of the evidence. Coverage involves having evidence that covers all aspects of the key questions, relevant goals, and contributing strategies. Quality affects the conclusions that can be drawn from the evidence, and ultimately how useful it is to decision-makers.
2. **Identifying and prioritizing new evidence needs.** Key actions include identifying new evidence needs and prioritizing how and when to fulfill those needs.
3. **Generating new evidence.** Key actions include developing an evidence-building implementation plan and ensuring that new evidence will meet quality standards.

That is, agencies first should assess the extent to which existing evidence addresses key questions expressed by decision-makers and stakeholders. Then, agencies should determine if existing evidence meets organizational needs for learning and decision-making. If existing evidence is not sufficient or if there are gaps, then agencies should consider new evidence sources.

In March 2024, NTIA released its implementation plan for the National Spectrum Strategy, which included developing a roadmap, in consultation with FCC, for improving receiver resistance to harmful interference as a means to improve spectrum efficiency and bolster coexistence.[72] However, at the time of our review, NTIA officials told us that they had not seen the need to conduct further assessments on the performance of federal receivers on a government-wide scale. Specifically, NTIA officials told us that they believe the information they currently collect regarding receiver performance demonstrates that most federal receivers are resilient.

NTIA officials also told us that receiver performance is generally not an issue when conducting system certifications and that most receivers comply with NTIA's standards. According to NTIA officials, in some cases, radars may not comply with NTIA's standards because manufacturers claim that radar receivers need wider bandwidth to detect signals from much longer distances and are likely sensitive. The officials explained that NTIA therefore occasionally approves waivers for radars with slightly larger bandwidth, and in cases where the radar operates in a contiguous spectrum allocated for radiolocation service.

[71]GAO-23-105460.

[72]NTIA officials told us that NTIA has contracted with MITRE, regarding this initiative, to prepare a report on the relevant interference mechanisms; existing industry, government, and international standards; approaches to testing; technical mitigations; policy incentives; and best practices. According to NTIA officials, the MITRE report is scheduled for completion by the end of 2024.

Further, NTIA officials told us that when they conduct compatibility assessments between existing and potential new users to determine spectrum repurposing or sharing opportunities, they have found that it is often the transmitter contributing to interference, not the receiver. For example, according to NTIA officials, it is often a commercial deployment's out-of-band emissions that would potentially harm an existing federal device.

Although the information NTIA currently collects is helpful to prevent harmful interference to federal operations, it may not provide insight into other aspects of receiver performance that could promote spectrum efficiency and coexistence such as (1) the robustness of a receiver's design or (2) its ability to adapt to changes in the spectrum environment. For instance, monitoring the spectrum environment for interference versus systems inherently being robust and able to perform in a degraded environment may mean different things.[73] In addition, just because a receiver is resilient to interference today does not mean it will be resilient to interference from new or different systems in the future, especially as the spectrum environment continues to evolve.

Nor does the information currently collected provide any insight into the efficiency of federal receivers or the extent to which receiver performance is being optimized, such as if agencies are using the latest technological developments and designs. Specifically, NTIA's mandated standards provide a baseline for performance but do not indicate if agencies are using more efficient or better receivers. We previously reported that federal users often use proven, older technologies that were designed to meet a specific mission and may be less efficient than more modern systems.[74] In addition, one federal spectrum user told us that many receivers that are critical to federal operations, such as GPS, are not owned by the federal government.

NTIA officials told us that they are aware of additional factors related to receiver performance and spectrum efficiency—such as the spectrum management principles outlined in FCC's policy statement—but have no plans to adopt similar principles for federal spectrum users. Officials noted that they do not believe federal receiver performance is an issue across all bands.

By assessing the information it currently collects on federal receiver performance, NTIA can ensure that it has the evidence needed to address broader spectrum efficiency efforts, including objectives outlined in the *National Spectrum Strategy* and goals shared with FCC to promote spectrum efficiency and coexistence. Identifying and collecting information regarding other aspects of federal receiver performance could help NTIA better understand and address challenges related to receiver performance. For example, identifying new evidence sources related to the robustness of receivers may help provide clarity to stakeholders, both federal and nonfederal, on how well receivers may perform in a changing spectrum environment. In addition, having more comprehensive information could help facilitate communication and collaboration practices outlined in FCC and NTIA's MOU, including practices aimed at identifying and resolving technical, procedural, and policy differences.

[73]We previously reported that NTIA's system certification process for federal spectrum use tends to focus on compliance with existing standards to avoid interference, not on spectrum efficiency. For example, we found that while NTIA's certification process helps avoid interference, it does not directly consider whether systems would use too much spectrum or could incorporate other technologies to improve spectrum efficiency. *See* GAO, *Spectrum Management: Better Knowledge Needed to Take Advantage of Technologies That May Improve Spectrum Efficiency*, GAO-04-666 (Washington, D.C.: May 28, 2004).

[74]GAO-13-265.

# Conclusions

Meeting the growing demand for spectrum in an increasingly crowded environment will require a holistic approach that considers all aspects of a system. Improving receiver performance is one of several ways to encourage more efficient spectrum use. However, stakeholders continue to face long-standing challenges to design and procure more robust receivers. Some challenges, such as those imposed by technical limitations, may be difficult to overcome. But other challenges, such as uncertainties due to the changing spectrum environment, could be addressed through improved spectrum management and planning.

While FCC has set expectations for users of nonfederal receivers, it could provide more clarity and direction to stakeholders by applying key practices that we have previously found can help agencies better manage for results. For example, identifying goals, strategies, and potential barriers related to implementing its spectrum management principles could help FCC provide a clearer picture of what it is trying to achieve, how it will achieve it, and any obstacles that may affect its ability to do so.

The information NTIA currently collects regarding federal receiver performance is helpful for assessing and preventing instances of harmful interference. However, it may not provide the evidence needed to answer broader policy questions, including how the federal government can more efficiently and effectively manage spectrum moving forward. Applying key practices to assess and build evidence could help ensure that NTIA has the information necessary to address broader spectrum efficiency efforts. This includes objectives outlined in the National Spectrum Strategy and goals shared with FCC to promote spectrum efficiency and coexistence. Further, new evidence sources regarding other aspects of receiver performance may also help FCC and NTIA execute practices aimed at improving communication and collaboration regarding future spectrum management decisions.

## Recommendations for Executive Action

We are making a total of four recommendations, including three to FCC and one to NTIA.

The Chair of FCC should define measurable goals related to implementing the spectrum management principles outlined in FCC's April 2023 policy statement. (Recommendation 1)

The Chair of FCC should identify strategies and resources necessary to achieve goals related to implementing the spectrum management principles outlined in FCC's April 2023 policy statement. (Recommendation 2)

The Chair of FCC should identify internal and external factors that could affect FCC achieving goals related to implementing the spectrum management principles outlined in its April 2023 policy statement. These factors should inform FCC's efforts to develop strategies for achieving its goals. (Recommendation 3)

The NTIA Administrator should assess current information and evidence sources related to federal receiver performance and identify and collect additional information as appropriate. Such information and evidence should align with and address broader spectrum efficiency efforts including objectives outlined in the National Spectrum Strategy and FCC and NTIA's MOU. (Recommendation 4)

## Agency Comments and Our Evaluation

We provided a draft of this report to FCC, Commerce, DOD, and the Department of Transportation for review and comment. We received written comments from FCC and Commerce (including NTIA) that are reprinted in appendixes II and III, respectively, and summarized below. DOD told us that they had no comments on the draft report. FCC, NTIA, and Transportation also provided technical comments, which we incorporated as appropriate.

In its written comments, FCC agreed with our recommendations. As FCC noted, issues related to spectrum use continue to evolve and additional research in this area is ongoing, which could be reflected in future FCC proceedings related to its spectrum management. Currently, FCC believes that its emphasis on individual proceedings represents an effective means to address our recommendations. FCC acknowledged that as it gains more experience in implementing its policy statement, it can more broadly apply key practices, as identified in our report, to more or all situations.

In its written comments, Commerce agreed with our recommendation to NTIA and enclosed statements from NTIA. In its written statement, NTIA identified activities it is taking which, if implemented effectively, would address our recommendation.

We are sending copies of this report to the appropriate congressional committees, the FCC Chair, the Secretaries of Commerce, Defense, and Transportation, and other interested parties. The report is also available at no charge on the GAO website at http://www.gao.gov.

In you or your staff have any questions about this report, please contact me at (202) 512-2834 or vonaha@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made key contributions to this report are listed in appendix IV.

Andrew Von Ah
Director, Physical Infrastructure

# Appendix I: Objectives, Scope, and Methodology

This report examines: (1) key challenges that selected stakeholders and experts identified to improving receiver performance; (2) how the Federal Communications Commission (FCC) considers the performance of receivers as part of its spectrum management; and (3) how the National Telecommunications and Information Administration (NTIA) considers the performance of receivers as part of its spectrum management.

To address our objectives, we reviewed relevant statutes, regulations, and FCC and NTIA guidance and documentation. We also reviewed literature on receiver technology, standards, and interference including white papers and reports issued by FCC's Technological Advisory Council and the National Academies of Sciences, Engineering and Medicine to learn about receiver performance and spectrum efficiency.[1]

Additionally, we studied a judgmental sample of instances where stakeholders claimed adjacent-band interference, and wherein receiver performance played or could have played a role, to serve as case studies in our review. To compile a list of possible cases, we reviewed FCC's Notice of Inquiry regarding efficient spectrum use and improved receiver interference immunity, reviewed FCC proceedings, and discussed potential cases with officials from FCC and NTIA.[2] We reviewed the sample and selected case studies to ensure variation in application and use (e.g., communications, navigation), federal and nonfederal users, among other characteristics. We selected two cases: (1) potential interference between commercial wireless communication and aviation services in the C-Band, and (2) potential interference between mobile satellite and GPS services in the L-Band. For each case, we analyzed relevant rulemaking proceedings, reports, and other documentation and interviewed relevant stakeholders, as identified below.

To describe challenges stakeholders and experts identified to improving receiver performance, we reviewed documentation and interviewed selected stakeholders including federal spectrum users, nonfederal spectrum users (i.e., commercial licensees), industry associations, and manufacturers. We selected stakeholders based on their involvement in our selected case studies and through comments submitted in response to FCC's Notice of Inquiry.[3]

Due to their roles in our selected case studies, we focused on FCC, NTIA, the Department of Defense, and the Federal Aviation Administration as the cognizant agencies and agency components in our review. We selected four additional federal spectrum users through their membership in NTIA's Interdepartment Radio Advisory Committee (IRAC), which consists of representatives from federal entities. We interviewed officials from the National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration, U.S. Agency for Global Media, and the U.S. Department of Agriculture's Forest Service to learn about federal

[1]Federal Communications Commission, Technological Advisory Council, Spectrum and Receiver Performance Working Group, *Basic Principles for Assessing Compatibility of New Spectrum Allocations* (Dec. 11, 2015) and National Academies of Sciences, Engineering, and Medicine, *Analysis of Potential Interference Issues Related to FCC Order 20-48* (2023).

[2]*See Promoting Efficient Use of Spectrum through Improved Receiver Interference Immunity Performance*, Notice of Inquiry, 37 FCC Rcd. 5337 (2022).

[3]Notice of Inquiry, 37 FCC Rcd. 5337.

spectrum users' perspectives and experiences with adjacent-band interference and actions to improve the performance of federal receivers and increase spectrum efficiency.

Additionally, we interviewed nonfederal stakeholders including various industry associations, commercial licensees, and manufacturers on challenges related to the performance and optimization of nonfederal receivers. We selected nonfederal stakeholders based on their involvement in our two case studies or because they otherwise had relevant interests in 5G networks, GPS, and aviation equipment. Table 1 lists these stakeholders. Because stakeholders varied in their expertise with various topics, not every stakeholder provided an opinion on every topic. Although the views of the stakeholders are not generalizable, they provided us with a variety of perspectives and insights.

**Table 2: List of Nonfederal Stakeholders Interviewed**

| Category | Category members |
|---|---|
| na | MIT-Lincoln Labs[a] |
| **Industry associations** | Aerospace Industries Association |
| **Industry associations** | CTIA- The Wireless Association |
| **Industry associations** | RTCA, Inc. |
| **Commercial Licensees and manufacturers** | AT&T |
| **Commercial Licensees and manufacturers** | Garmin International, Inc. |
| **Commercial Licensees and manufacturers** | Honeywell International, Inc. |
| **Commercial Licensees and manufacturers** | John Deere |
| **Commercial Licensees and manufacturers** | Ligado Networks |
| **Commercial Licensees and manufacturers** | Motorola |
| **Commercial Licensees and manufacturers** | T-Mobile International AG |
| **Commercial Licensees and manufacturers** | Qualcomm, Inc. |
| **Commercial Licensees and manufacturers** | Verizon |

Source: GAO. | GAO-24-106325

[a]MIT-Lincoln Labs is a federally funded research and development center. We included it under our list of nonfederal stakeholders due to it being a public-private partnership.

To examine how FCC and NTIA consider receiver performance as part of their spectrum management, we compared agencies efforts related to receivers against key practices we have identified through our prior work to help manage and assess the results of federal efforts.[4] Specifically, we focused on key practices to plan for results and assess and build evidence. We assessed the extent to which FCC and NTIA have applied these key practices by analyzing FCC and NTIA documents. This included NTIA's *Manual of Regulations and Procedures for Federal Radio Frequency Management* (commonly referred to as the Redbook), and agency-specific policies, procedures, and spectrum-management directives and manuals. We also interviewed FCC and NTIA officials on efforts related to receiver performance and spectrum efficiency.

Finally, to obtain additional perspectives on all our objectives, we interviewed experts on spectrum management-related topics including receiver performance and interference. We identified experts with assistance of the National Academies of Sciences, Engineering, and Medicine. The National Academies

[4]GAO, *Evidence-Based Policymaking: Practices to Help Manage and Assess the Results of Federal Efforts,* GAO-23-105460 (Washington, D.C.: July 12, 2023).

selected a preliminary list of 20 individuals from a pool of over 75 candidates, of whom we then selected 12 individuals. We developed the candidate list from extensive canvassing, starting with recommendations from individuals in the National Academies networks and suggestions from GAO staff. We selected experts with expertise in aviation radio altimeter C-band interference, GPS satellite L-band interference, and spectrum technology policy, including regulating and improving receiver performance from both academia and industry. To identify conflicts of interest and other circumstances that could be reasonably viewed by others as affecting the independence or objectivity of an expert's contribution, selected experts provided a conflict of interest and independence assessment prior to each interview. We conducted semi-structured interviews with the 12 selected experts (see table 2).

**Table 3: List of Experts Interviewed**

| Experts |
|---|
| JP (Pierre) de Vries, Silicon Flatirons Center, University of Colorado Boulder |
| Joseph Evans, University of Kansas |
| Dale Hatfield, Silicon Flatirons Center, University of Colorado Boulder |
| Keith Gremban, Silicon Flatirons Center, University of Colorado Boulder |
| Christopher Hegarty, MITRE |
| Sai Kalyanaraman, Collins Aerospace |
| Julius Knapp, Federal Communications Commission (retired) |
| Preston Marshall, Google |
| Richard Reaser, Independent Consultant |
| Jean-Luc Robin, Airbus |
| Gregory Rosston, Stanford University |
| Andrew Roy, ASRI |

Source: GAO. | GAO-24-106325

# Appendix II: Comments from the Federal Communications Commission

Federal Communications Commission
Washington, D.C. 20554

June 10, 2024

Andrew Von Ah
Director, Physical Infrastructure
Government Accountability Office
441 G Street NW
Washington, DC 20548

Dear Mr. Von Ah:

Thank you for the opportunity to review the Government Accountability Office's draft report, "Spectrum Management: Key Practices Could Help Address Challenges to Improving Receiver Performance." Last year, as part of its continuing effort to ensure the efficient, effective, and equitable use of airwaves to support the spectrum needs of next-generation technologies and applications, the Commission issued a Policy Statement providing guidance on how the FCC intends to manage spectrum efficiently and effectively going forward. In the Policy Statement, the FCC set forth nine core principles in three general categories to help inform both its own future actions as well as stakeholder expectations about interference from spectrally and spatially proximate sources. Specifically, and relevant to GAO's inquiry, the Policy Statement addressed the role of receivers in interference scenarios and discussed the policy and technical considerations that the FCC expects for those who design and operate receivers in the increasingly congested spectrum environment.

As GAO recognizes, the FCC is in the earliest stages of implementing the Policy Statement, and we continue to anticipate the application of its principles to future spectrum-related rulemaking proceedings. In the meantime, we are committed to taking meaningful steps to elevate awareness and consideration of transmitter- and receiver-related issues in wireless systems both within the FCC's processes and by relevant stakeholders. For example, by working with our spectrum management colleagues at NTIA on long-range spectrum planning, including furtherance of the National Spectrum Strategy, we will help stakeholders better understand where in the rapidly evolving spectrum environment changes are most likely to occur – well before any rulemaking proceeding begins. By encouraging continuing research in the communications field and closely following the development of new standards and technologies, we can promote more meaningful and appropriate considerations of the technical tradeoffs, physical limitations, and cost considerations that stakeholders have identified as challenges to improving receiver performance. And, in operating under the recently revised FCC-NTIA Memorandum of Understanding, which emphasizes the role of evidence-based spectrum policy-making and timely and effective communication, we are better positioned to identify and address disagreements and varying perceptions about receivers and their expected performance that can delay or obstruct efforts to achieve more efficient spectrum use. Collectively, such actions will place both the FCC and relevant stakeholders in a better position to address many of the key challenges to improving receiver performance that GAO has identified.

The Policy Statement is designed to further the FCC's objective of reorienting its spectrum management framework to a holistic inquiry that considers both the transmitter and receiver components of wireless systems. At the highest level, our goal is to engage stakeholders in spectrum-related discussions that acknowledge the interference realities and shared responsibilities identified in the Policy Statement, and to establish a shared baseline from which we can employ data-driven regulatory approaches to realize more effective co-existence between spectrum users. In applying each of the nine spectrum management

principles, we agree with the approach recommended by GAO – that we define measurable goals, identify strategies and resources necessary to achieve those goals, and identify internal and external factors that could potentially affect the FCC's ability to achieve those goals. Because the FCC makes spectrum management decisions within the rulemaking context and such decisions are highly dependent on the nature and characteristics of the spectrum under consideration, there is considerable variance in what measurable goals can be identified, the appropriate strategies and resources needed to achieve those goals, and the potential barriers to implementing those goals in any given situation. Thus, we anticipate that applying these principles will be most effective in such distinctive, fact-specific scenarios. For example, our expectations for using good engineering practices in transmitter and receiver design will have to take into account the state of technology at the time equipment was designed and deployed, and what opportunities there have been to update or replace legacy equipment, as well as the market for such equipment. Similarly, the potential barriers associated with spectrum decisions likely will be different when multiple services or affected bands host both federal and non-federal users than when there are fewer users of a similar nature. While we believe that the Commission's emphasis on individual spectrum management proceedings represents an effective means to give effect to GAO's recommendations, we also acknowledge its observation that the "FCC may need to apply the key practices at a broader level." As the FCC gains more experience in implementing the Policy Statement, we will be better positioned to identify commonalities in applying the nine spectrum management principles that we can draw on to state goals, identify strategies and resources, and recognize potential barriers that can be applied in most or all situations.

Finally, we recognize that the forward-looking Policy Statement that is the focus of GAO's recommendations was adopted last year, whereas the rules governing the C-Band transition were adopted in 2020. Nevertheless, there are aspects of the C-Band proceeding and subsequent developments that were not included in the report's narrative that are closely aligned with the objectives identified in the Policy Statement. For example, although the report describes a "typical" radio altimeter potentially vulnerable to interference from adjacent-channel operations, this description does not reflect the fact that at the time of the FCC rulemaking there already were altimeter models with significant market penetration that in fact had been designed to tolerate 5G out-of-band emissions. Thus, even in spectrum configurations as complex as C-Band, there were manufacturers whose existing products were broadly aligned with the later Policy Statement's "shared responsibility" objective. In addition, the draft of the report that we reviewed did not recognize the work of the JI-FRAI (Joint Interagency – 5G Radar Altimeter Interference) program, which confirmed through over-the-air testing that radar altimeter performance was unaffected by 5G out-of-band, nor the comprehensive studies conducted by NTIA's Institute for Telecommunication Sciences that are visually documented at https://www.youtube.com/watch?v=QCK26X-U678. Transparent, quantitative and reproducible analyses such as these are the types of data-driven analysis that the Policy Statement seeks to promote. We highlight these examples because, going forward, we believe that they can serve as useful models for how the Policy Statement objectives can be applied to real-world situations.

Sincerely,

Ronald T. Repasi
Chief
Office of Engineering and Technology

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# Accessible Text for Appendix II: Comments from the Federal Communications Commission

June 10, 2024

Andrew Von Ah
Director, Physical Infrastructure
Government Accountability Office
441 G Street NW
Washington, DC 20548

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As GAO recognizes, the FCC is in the earliest stages of implementing the Policy Statement, and we continue to anticipate the application of its principles to future spectrum-related rulemaking proceedings. In the meantime, we are committed to taking meaningful steps to elevate awareness and consideration of transmitter- and receiver-related issues in wireless systems both within the FCC's processes and by relevant stakeholders. For example, by working with our spectrum management colleagues at NTIA on long-range spectrum planning, including furtherance of the National Spectrum Strategy, we will help stakeholders better understand where in the rapidly evolving spectrum environment changes are most likely to occur – well before any rulemaking proceeding begins. By encouraging continuing research in the communications field and closely following the development of new standards and technologies, we can promote more meaningful and appropriate considerations of the technical tradeoffs, physical limitations, and cost considerations that stakeholders have identified as challenges to improving receiver performance. And, in operating under the recently revised FCC-NTIA Memorandum of Understanding, which emphasizes the role of evidence-based spectrum policy-making and timely and effective communication, we are better positioned to identify and address disagreements and varying perceptions about receivers and their expected performance that can delay or obstruct efforts to achieve more efficient spectrum use. Collectively, such actions will place both the FCC and relevant stakeholders in a better position to address many of the key challenges to improving receiver performance that GAO has identified.

The Policy Statement is designed to further the FCC's objective of reorienting its spectrum management framework to a holistic inquiry that considers both the transmitter and receiver components of wireless

systems. At the highest level, our goal is to engage stakeholders in spectrum-related discussions that acknowledge the interference realities and shared responsibilities identified in the Policy Statement, and to establish a shared baseline from which we can employ data-driven regulatory approaches to realize more effective co-existence between spectrum users. In applying each of the nine spectrum management principles, we agree with the approach recommended by GAO – that we define measurable goals, identify strategies and resources necessary to achieve those goals, and identify internal and external factors that could potentially affect the FCC's ability to achieve those goals. Because the FCC makes spectrum management decisions within the rulemaking context and such decisions are highly dependent on the nature and characteristics of the spectrum under consideration, there is considerable variance in what measurable goals can be identified, the appropriate strategies and resources needed to achieve those goals, and the potential barriers to implementing those goals in any given situation. Thus, we anticipate that applying these principles will be most effective in such distinctive, fact-specific scenarios. For example, our expectations for using good engineering practices in transmitter and receiver design will have to take into account the state of technology at the time equipment was designed and deployed, and what opportunities there have been to update or replace legacy equipment, as well as the market for such equipment. Similarly, the potential barriers associated with spectrum decisions likely will be different when multiple services or affected bands host both federal and non-federal users than when there are fewer users of a similar nature. While we believe that the Commission's emphasis on individual spectrum management proceedings represents an effective means to give effect to GAO's recommendations, we also acknowledge its observation that the "FCC may need to apply the key practices at a broader level." As the FCC gains more experience in implementing the Policy Statement, we will be better positioned to identify commonalities in applying the nine spectrum management principles that we can draw on to state goals, identify strategies and resources, and recognize potential barriers that can be applied in most or all situations.

Finally, we recognize that the forward-looking Policy Statement that is the focus of GAO's recommendations was adopted last year, whereas the rules governing the C-Band transition were adopted in 2020. Nevertheless, there are aspects of the C-Band proceeding and subsequent developments that were not included in the report's narrative that are closely aligned with the objectives identified in the Policy Statement. For example, although the report describes a "typical" radio altimeter potentially vulnerable to interference from adjacent-channel operations, this description does not reflect the fact that at the time of the FCC rulemaking there already were altimeter models with significant market penetration that in fact had been designed to tolerate 5G out-of-band emissions. Thus, even in spectrum configurations as complex as C-Band, there were manufacturers whose existing products were broadly aligned with the later Policy Statement's "shared responsibility" objective. In addition, the draft of the report that we reviewed did not recognize the work of the JI-FRAI (Joint Interagency – 5G Radar Altimeter Interference) program, which confirmed through over-the-air testing that radar altimeter performance was unaffected by 5G out-of-band, nor the comprehensive studies conducted by NTIA's Institute for Telecommunication Sciences that are visually documented at https://www.youtube.com/watch?v=QCK26X-U678. Transparent, quantitative and reproducible analyses such as these are the types of data-driven analysis that the Policy Statement seeks to promote. We highlight these examples because, going forward, we believe that they can serve as useful models for how the Policy Statement objectives can be applied to real-world situations.

Sincerely,

Ronald T. Repasi
Chief
Office of Engineering and Technology

# Appendix III: Comments from the Department of Commerce


June 24, 2024

Mr. Andrew Von Ah
Director, Office of Physical Infrastructure
U.S. Government Accountability Office
441 G Street, NW
Washington, DC 20548

Dear Mr. Von Ah:

Thank you for the opportunity to review the Draft Report entitled *GAO 24-106325: Spectrum Management: Key Practices Could Help Address Challenges to Improving Receiver Performance.* The Department of Commerce appreciates the U.S. Government Accountability Office's work on this matter.

The Draft Report proposes one recommendation to NTIA. On behalf of the Department, I have enclosed a response to the Draft Report from NTIA that addresses this recommendation. The Department agrees with the recommendation proposed and will prepare a formal action plan upon release of GAO's Final Report.

If you have any questions, please contact MaryAnn Mausser, Department GAO Audit Liaison, at (202) 482-8120 or via email at mmausser@doc.gov.

Sincerely,

JEREMY PELTER Digitally signed by JEREMY PELTER Date: 2024.06.24 16:04:08 -04'00'

Jeremy Pelter
Deputy Assistant Secretary for Administration,
Performing the Non-Exclusive Functions and Duties
of the Chief Financial Officer and Assistant
Secretary for Administration

Enclosure

**The National Telecommunications and Information Administration's Response to Recommendation Included in the Draft Report Entitled GAO 24-106325: Spectrum Management: Key Practices Could Help Address Challenges to Improving Receiver Performance.**

The National Telecommunications and Information Administration's (NTIA) respectfully provides a response to the U. S. Government Accountability Office (GAO) Draft Report entitled *GAO 24-106325: Spectrum Management: Key Practices Could Help Address Challenges to Improving Receiver Performance.*

NTIA appreciates GAO's examination of issues related to receiver performance and identified challenges to improving receiver performance.

NTIA is committed to efficient use of federal spectrum. As noted in your report, this includes the recent National Spectrum Strategy and the related Implementation Plan.

**Recommendation 4:** The Administrator of NTIA should assess current information and evidence sources related to the performance of federal receivers, and identify and collect additional information as appropriate. Such information and evidence should align with and address broader spectrum efficiency efforts including objectives outlined in the National Spectrum Strategy and FCC and NTIA's memorandum of understanding (MOU).

**NTIA Response:** NTIA agrees with this recommendation. The Implementation Plan for the National Spectrum Strategy includes development of a roadmap for improving receiver resistance to harmful interference. In addition, as noted in your report, NTIA has contracted with MITRE to provide a detailed report on this subject.

# Accessible Text for Appendix III: Comments from the Department of Commerce

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Director, Office of Physical Infrastructure
U.S. Government Accountability Office
441 G Street, NW
Washington, DC 20548

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JEREMY PELTER

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Jeremy Pelter
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Enclosure

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**Response to Recommendation Included in the Draft Report Entitled**

**GAO 24-106325: Spectrum Management:**

**Key Practices Could Help Address Challenges to Improving Receiver Performance.**

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# Appendix IV: GAO Contact and Staff Acknowledgments

## GAO Contact

Andrew Von Ah, (202) 512-2834 or vonaha@gao.gov

## Staff Acknowledgments

In addition to the contact named above, Andrew Huddleston (Assistant Director); Colleen Taylor (Analyst in Charge); Zachary Conti; Saar Dagani; Richard Hung; Alicia Loucks; Thanh Lu; Malika Rice; Kelly Rubin; Michael Soressi; and Alicia Wilson made key contributions to this report.

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