Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

In the Matter of Petition to Revise Sections 2.106 and 25.142 of the Commission's Rules to Expand Spectrum Availability for Small Satellites by Adding a Mobile-Satellite Service Allocation in the Frequency Band 2020-2025 MHz	)))))))	RM- _______

To: FCC Secretary

PETITION FOR RULEMAKING

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EXECUTIVE SUMMARY

Spire Global, Inc. ("Spire") and Kepler Communications Inc. ("Kepler") petition the Commission to initiate a rulemaking to add a Mobile-Satellite Service ("MSS") allocation to the 2020-2025 MHz band and make the spectrum available for use by small satellites ("smallsats").[1] Smallsats are technologically sophisticated satellites—sometimes as small as a bread loaf—that have lowered the cost of access to space and opened new platforms for scientific and commercial innovation.

Only a few short years after their introduction, smallsats are already conducting advanced earth exploration, assisting with weather monitoring and disaster response, supporting state-of-the-art machine-to-machine communications, and advancing the frontiers of science. Analysts predict the smallsat market, which is comprised of companies with extensive operations in the United States, will increase from an estimated $2.8 billion industry in 2020 to a $7.1 billion industry by 2025.[2]

At present, however, the United States has not allocated any spectrum for exclusive commercial smallsat use. Operators have instead selected a random assortment of spectrum assignments that are not only time-consuming and costly to secure, but also challenging to coordinate in support of interference-free operations. Allocating five megahertz of spectrum for smallsat operations in the otherwise unoccupied 2020-2025 MHz band would lower the time and cost of securing frequency resources and provide the industry with the certainty necessary to sustain continued investment in the U.S. smallsat sector.

The reallocation would occur by revising section 2.106 to restore an MSS allocation to the 2020-2025 MHz band and by integrating new licensing rules for the band in Part 25 of the

[1] *See* 47 C.F.R. § 1.401.

[2] *See* Press Release, MarketsandMarkets, Small Satellite Market worth $7.1 billion by 2025, https://bit.ly/2GRYAHv.

Commission's rules.[3] The 2020-2025 MHz band has been unused by licensed operators for more than 20 years and would provide vital access to spectrum needed by the smallsat industry.

[3] *See* 47 C.F.R. §§ 2.106; 25.142. MSS would deploy subject to coordination under International Telecommunication Union ("ITU") Radio Regulations No. 9.11A and Resolution 716 (Rev.WRC-12). *See id*. § 2.106 n.5.389A.

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PETITION FOR RULEMAKING

Two leading smallsat operators, Spire Global, Inc. ("Spire") and Kepler Communications Inc. ("Kepler"), petition the Commission to (i) revise section 2.106 by replacing the Fixed and Mobile services allocations in the frequency band 2020-2025 MHz with an MSS space-to-Earth allocation in 2020-2021 MHz and MSS Earth-to-space allocation in 2021-2025 MHz and (ii) adopt new licensing rules in Part 25 to protect the investment-backed expectations of other services and promote future entry in the band.[4]

I. INTRODUCTION.

Spire and Kepler will play a critical role in growing the U.S. smallsat industry. Both companies either offer or plan to offer asset tracking and narrowband connectivity, among other services, with space-based technologies deployed within months of system design and for fractions of the cost associated with launching large satellites.[5] Spire manufactures smallsat platforms; operates a CubeSat constellation providing maritime, aviation, meteorological, and land surface monitoring services; and offers convenient, affordable, and on-demand access for hosted

[4] *See* 47 C.F.R. §§ 1.401; 2.106; 25.142. MSS would deploy subject to coordination under ITU Radio Regulations No. 9.11A and Resolution 716 (Rev.WRC-12). *See id*. § 2.106 n.5.389A.

[5] Both parties hold various FCC space and earth station authorizations.

payloads.[6] Kepler develops and manufactures next-generation satellite communication technologies and provides global satellite data backhaul services for wideband, narrowband, and Internet-of-Things applications. Kepler's long-term ambition is to build a network of satellites to provide in-space connectivity.[7] As part of the smallsat industry, Spire and Kepler have both experienced the limitations of current spectrum availability.[8] For that reason, Spire and Kepler propose that the Commission revise its rules to allow for the use of the 2020-2025 MHz band for MSS space-to-Earth and Earth-to-space operations.

II. SMALLSAT OPERATORS NEED UNENCUMBERED ACCESS TO SPECTRUM IF THE UNITED STATES HOPES TO MAINTAIN LEADERSHIP IN THE THRIVING SMALLSAT INDUSTRY.

Modernizing and streamlining commercial space regulation has helped fuel the United States' current leadership in the smallsat industry. Between 2012 and 2019, more than 1,700 smallsats launched into space–nearly doubling the number of smallsat launches from 24% of all launches in 2012 to 45% of all launches in 2019.[9] *Eighty-one percent* of the commercial smallsats

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[6] *See Streamlining Licensing Procedures for Small Satellites*, Notice of Proposed Rulemaking, 33 FCC Rcd 4152, ¶ 5 (2018) ("*Smallsat NPRM*") ("The CubeSat is a standardized interface consisting of an approximately 10 cm x 10 cm x 10 cm unit or "U" that can be scaled up to create CubeSats that 33 FCC Rcd 4152are 3U (three units) or 12U (12 units) in size, for example."). Spire offices are distributed across the United States (Boulder, Colorado; San Francisco, California; and Washington, DC), Scotland, Luxembourg, and Singapore.

[7] Narrowband-MSS typically uses a channel bandwidth of 200 to 500 kilohertz. *See* Technical Annex at Table 3.

[8] The companies helped create a trade association, Commercial Smallsat Spectrum Management Association ("CSSMA"), focused on addressing smallsat licensing and coordination issues and educating new entrants on how to navigate international and domestic commercial space regulations. *See* Commercial Smallsat Spectrum Management Association, https://cssma.space/ (last visited Oct. 29, 2020).

[9] *See* Bryce Space and Technology, *Smallsats by the Numbers 2020*, https://bit.ly/35jKkzx (last visited Oct. 29, 2020).

are manufactured by U.S. companies, and *seventy percent* are operated by U.S.-based SpaceX, Planet, and Spire.[10]

U.S. satellite companies are providing a range of services to the public such as television, telephone, and broadband, to name a few. Smaller satellites are of increasing interest and have been more widely used in recent years by Spire, Kepler, other startups, and established U.S. government contractors.[11] Northrop Grumman is manufacturing "extensive and flight-proven" small-spacecraft platforms that can conduct "astrophysics, Earth science/remote sensing, heliophysics, planetary exploration and technology demonstration missions."[12] Lockheed Martin will build a smallsat mesh network, by the end of 2022, to "link[] terrestrial warfighting domains to space sensors."[13] The company's funding for a California-based startup, Terran Orbital, will also advance smallsat design and manufacturing.[14] Raytheon invested in a Virginia-based startup, HawkEye 360, to support space-based geolocation.[15] Boeing financed a Colorado-based startup, BridgeSat, which seeks to relay information among smallsats using lasers, and bought a California-based startup, Millennium Space Systems, to bolster its smallsat manufacturing capabilities.[16] The

[10] *See id.*

[11] *See id*.

[12] Science and Environment Satellites, Northrop Grumman, https://bit.ly/3lSfhRJ (last visited Oct. 29, 2020).

[13] *Lockheed Martin to build 10 small satellite mesh network in two years*, INTELLIGENT AEROSPACE (Sept. 3, 2020), https://bit.ly/3o0HMyO.

[14] *See* Aaron Gregg, *Defense giants bet big on small satellites*, WASH. POST (Sept. 16, 2018), https://wapo.st/3nZuouL.

[15] *See id.*

[16] *See id.*

defense giants have signaled that joining the smallsat revolution gives them "a better mousetrap" for future success.[17]

To maintain its leadership, the United States must assess ways to support the increased spectrum requirements arising from the growth of the smallsat industry and allow the industry to continue to offer important services such as broadband and narrowband connectivity, as well as weather forecasting to name a few. The 2020-2025 MHz band is a frequency that is currently mostly fallow and should be put to good use.

A. Deploying Bread-Loaf-Size Satellites—Instead of School-Bus-Size Satellites—Has Unleashed Next-Generation Low-Data-Rate Connectivity Options, Accurate Weather Forecasting, Timely Asset Tracking, and High-Resolution Earth Imaging at Low Costs.

The years-long dream of a vibrant space economy has started to become a reality with smallsat systems. Groundbreaking technologies, plummeting launch costs, and a wealth of new commercial opportunities to cost-effectively provide an array of new services has attracted billions of dollars of private-sector commercial investment.[18] The next generation space economy has coalesced around a strong business case in offering broadband services, protecting international borders, identifying minerals and fuel deposits, tracking goods and services, monitoring and predicting weather events, and offering an assortment of other services never before thought possible.[19] The emergence of consumer-off-the-shelf technological capabilities, hardware miniaturization, and algorithmically expanding computing power combined with explosive demands for connectivity, data, and intelligence have reduced costs and expanded potential

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[17] *Id.* (internal quotations omitted).

[18] *See* Michael Sheetz, *An investor's guide to space, Wall Street's next trillion-dollar industry*, CNBC (Nov. 9, 2019), https://cnb.cx/2X7hWxz.

[19] *See generally* Bhavya Lal et al., *Global Trends in Small Satellites*, Institute for Defense Analyses Science & Technology Policy Institute (July 2017), https://bit.ly/2ZDv7YK.

revenue opportunities to the point where some analysts predict the space and satellite industry will transform into the next "multitrillion-dollar economy in the next 10 to 20 years."[20]

B. The United States Currently Leads the Smallsat Industry Revolution.

Recent commercial space policy directives, rulemakings, and reports illustrate early U.S. leadership in the smallsat industry. Space Policy Directive-2 ("SPD-2") instructed regulatory agencies to eliminate duplicative and unnecessary regulation of commercial space.[21] SPD-2 concluded that updating the regulatory regimes for satellite services promised to "promote economic growth;" "protect national security, public-safety, and foreign policy interests; and encourage American leadership in space commerce."[22] In 2010, the Commission released a National Broadband Plan that called for accelerating deployment in 90 megahertz of MSS spectrum, among other objectives, leading to a national spectrum policy race for even more spectrum bands to be considered to meet this goal.[23] In 2019 and 2020, the Commission adopted a streamlined licensing process for smallsats and updated rules on orbital debris mitigation.[24] The National Oceanic and Atmospheric Administration has revamped its remote sensing licensing

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[20] Michael Sheetz, *An investor's guide to space, Wall Street's next trillion-dollar industry*, CNBC (Nov. 9, 2019), https://cnb.cx/2X7hWxz. *See generally* Bhavya Lal et al., *Global Trends in Small Satellites*, Institute for Defense Analyses Science & Technology Policy Institute (July 2017), https://bit.ly/2ZDv7YK.

[21] *See* Space Policy Directive-2, Streamlining Regulations on Commercial Use of Space, The White House (May 24, 2018), https://bit.ly/3dxmaVQ.

[22] *Id.*

[23] *See Connecting America: The National Broadband Plan*, FCC, at 76 (rel. Mar. 17, 2010), https://bit.ly/31g2XTz.

[24] *See Streamlining Licensing Procedures for Small Satellites,* Report and Order, 34 FCC Rcd 13077 (2019); *Mitigation of Orbital Debris in the New Space Age*, Report and Order and Further Notice of Proposed Rulemaking, 35 FCC Rcd 4156 (2020).

framework,[25] and the Federal Aviation Administration modernized its commercial space launch and reentry requirements.[26] The National Aeronautics and Space Administration ("NASA") has also acknowledged that the growing commercial space sector requires access to spectrum resources to support the increased spectrum requirements.[27] Through these and other actions, the U.S. government has recognized the imminent proliferation of smallsats on orbit and taken the lead in regulating the industry.[28]

C. Operators, However, May Relocate Operations from the United States to Wherever Better Accommodates Their Spectrum Needs and Breakneck Deployment Schedules.

i. Current and predicted smallsat spectrum needs continue to increase.

Smallsat operators have demonstrated—and the ITU and Commission have acknowledged—that expanded and flexible spectrum access remains necessary for industry to expeditiously deliver a range of cutting-edge, inexpensive services. The smallsat trade association CSSMA previously explained that smallsat MSS operators may need 5-50 kilohertz bandwidth to achieve a 1-50 Kbps data rate for tracking telemetry and command ("TT&C"), 1-30 megahertz bandwidth to achieve a 1-100 Mbps data rate for user service links, and 1-300 megahertz bandwidth to achieve a 1-1000 Mbps data rate for backhaul links.[29] The ITU expects that

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[25] *See* Licensing of Private Remote Sensing Space Systems, 85 FR 30790 (May 20, 2020) (to be codified at 15 C.F.R. pt. 960).

[26] *See Streamlined Launch and Reentry Licensing Requirements,* Final Rule, Docket No. FAA-2019-0229 (rel. Sept. 30, 2020).

[27] *See Spectrum 101, An Introduction to National Aeronautics and Space Administration Spectrum Management,* NASA, at vi (Feb. 2016), https://go.nasa.gov/31fScAG.

[28] *See generally* Space Foundation Editorial Team, *Space Briefing Book: U.S. Space Laws, Policies and Regulations, US Government*, SPACE FOUNDATION, https://bit.ly/31feH8V (last visited Oct. 15, 2020).

[29] *See* Comments of The Commercial Smallsat Spectrum Management Association, IB Docket No. 18-86, at 27-28, Table 1 (filed July 9, 2018) (summarizing also the data needs for Earth

bandwidth and data rate requirements for smallsats will increase over time with "the continuing miniaturization of technologies and the expansion of innovative applications for nanosatellite and picosatellite systems."[30] The Commission has also observed a "growth in th[e] [smallsat] sector across the full range of activities" and sought to promote "efficient use of spectrum for the dynamic sector."[31]

ii. Obtaining authorizations for currently available frequency bands has proven untimely, costly, unworkable, and sometimes impossible.

Four blocks of spectrum primarily support smallsat operations today, but they suffer from limitations that severely constrain their utility for the developing smallsat sector in the United States. The four available bands include: UHF (~399.9-450.25 MHz), S-band (~2025-2290 MHz), X-band (~8025-8400 MHz), Ku-band (~10.7-14.5 GHz), and Ka-band (~17.8-30.0 GHz).[32] In theory, some MSS bands, namely 1525-1559/1626.5-1660.5 MHz, 1610-1626.5/2483.5-2500 MHz, and 2000-2020/2180-2200 MHz, can also support smallsats. In practice, however, these bands either form part of an exclusive agreement among geostationary orbit ("GSO") operators, are exclusively licensed, or have incumbent operators. These bands offer little alternative spectrum for smallsat operations.

UHF – Challenging Federal Encumbrances. Available UHF bands are subject to unfavorable sharing conditions or must be vacated by non-Federal operators. Operations in the

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Exploration-Satellite Service ("EESS") imaging and non-imaging, commercial science, tomography, and synthetic aperture radar).

[30] Characteristics, definitions and spectrum requirements of nanosatellites and picosatellites, as well as systems composed of such satellites, Rep. ITU-R SA.2312, at 12 (Sept. 2014).

[31] *Smallsat NPRM* ¶¶ 1, 4.

[32] Service allocations available for smallsat systems do not exist throughout the listed frequency ranges. They appear solely as reference points.

399.9-400.05 MHz and 400.15-401 MHz processing round requires coordination among all the processing round participants and will likely only allow for low-power, low-data-rate, and/or TT&C operations after lengthy coordination discussions.[33] The 401-403 MHz band was closed by World Radiocommunication Conference-2019 ("WRC-19").[34] The 449.75-450.25 MHz is noisy, particularly with federal occupation, and subject to mandatory ITU coordination.[35] This regulatory atmosphere encourages companies to consider other licensing jurisdictions to avoid the problems.

L-band and S-band (MSS) – Encumbered by Sensitive Adjacent Band Services or Incumbent System Deployments. The MSS bands available in the United States cannot readily accommodate new smallsat users. In 1525-1559/1626.5-1660.5 MHz, Ligado obtained a Commission license only after contentious coordination discussions spanning ten years.[36] Questions still remain as to whether Ligado's service will adequately protect sensitive adjacent band radionavigation-satellite services, including the Global Positioning System.[37] In 1610-1626.5 and/or 2483.5-2500 MHz, Iridium and Globalstar have long established MSS operations in the bands, so later smallsat entrants may face lengthy coordination discussions with legacy

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[33] *See, e.g., Hiber Inc. Petition for Declaratory Ruling to Access U.S. Market Using the Hiberband Low-Earth Orbit Systeym*, Order and Declaratory Ruling, 35 FCC Rcd 4619 (2020); *Myriota Pty. Ltd. Petition for Declaratory Ruling Granting Access to the U.S. Market for Non-Voice, Non-Geostationary Satellite System*, Order and Declaratory Ruling, 35 FCC Rcd 5475 (2020).

[34] *See* World Radiocommunication Conference 2019 (WRC-19) Final Acts, ITU (2019), https://bit.ly/3j0V76o ("WRC-19 Final Acts").

[35] *See* 47 C.F.R. § 2.106 nn.5.286, US87; *see also* Stamp Grant, Spire Global, Inc., File No. SAT-PDR-20190321-00018 (granted in part Oct. 7, 2019) ("Spire must take all practical steps to keep the carrier frequency between 450.15 and 450.25 MHz.") ("Spire Market Access Grant").

[36] *See generally Ligado Amendment to License Modification Applications et al.*, Order and Authorization, 35 FCC Rcd 3772 (2020) ("*Ligado Grant*").

[37] *See* Amanda Macias, *Bipartisan lawmakers call on FCC to reverse Ligado 5G decision, citing GPS interference*, CNBC (Apr. 29, 2020), https://cnb.cx/3ooWNut.

operators.[38] In 2000-2020/2180-2200 MHz, terrestrial mobile operations may deploy, and the Commission has acknowledged that "same-band, separate operator sharing between mobile satellite and terrestrial operations [is] 'impractical'" in these bands.[39]

S-Band (Non-MSS) – Onerous Coordination Requirements. S-band frequencies function as critical data links for science agencies worldwide and broadcasters in the United States and, therefore, require time-consuming coordination that leads to burdensome sharing, where operations are allowed at all. Site-by-site coordination is especially onerous. Broadcasters already use 2025-2110 MHz, and finding open channels is very difficult. Extensive federal use of the globally harmonized 2200-2290 MHz band prevents commercial satellite operators' domestic deployment in the band, and outside of the United States, smallsat operators are required to abide by regional black-outs in the band during launch operations to accommodate the increasing launch cadence of co-frequency launch vehicles causing additional service disruptions.

X-Band – Highly Sensitive Incumbent Systems. X-band frequencies' occupancy by the science agencies worldwide and adjacency to the deep-space research band inhibit smallsat operators from deploying quickly in this range. Frequency coordination must be conducted with individual federal agencies that have limited resources to conduct the frequency coordination for all commercial and non-commercial operators. This results in substantial backlogs and time spent coordinating this use. An operator adding or modifying its concept of operations, including

[38] *See, e.g.*, *Iridium Constellation LLC et al.*, Order and Authorization, 31 FCC Rcd 8675, n.9 (2016); *Globalstar Licensee LLC et al.*, Order of Modifications, 23 FCC Rcd 15207, ¶ 1 (2008).

[39] *DISH Network Corporation et al.*, Memorandum Opinion and Order, 28 FCC Rcd 16787, ¶ 20 (2013).

deployment of new ground stations or reconfiguring the constellation on orbit, must re-coordinate its spectrum use before any system changes.

Ku-Band and Ka-Band – Already Congested Spectrum Slated to House Numerous New Mega-Constellations. The Ku-band and Ka-band frequencies are quickly accumulating a roster of occupants that operate or intend to operate constellations comprised of large numbers of space stations, and operational requirements can prevent some smallsat operators from using these bands. Not all smallsats typically possess the power capabilities necessary to operate in these bands. More importantly, tens of thousands of satellites have already requested access to use these bands through processing rounds.

iii. Competing administrations seek to lure the smallsat industry from the United States by promoting expedited access to generally unencumbered spectrum and an overall lightweight regulatory approach.

Spectrum availability, limited coordination requirements, expedited licensing timelines, and potential government-backed investment support are attracting smallsat operators away from conducting business in the United States. Often these wooed operators are then forced to analyze the most beneficial jurisdiction by comparing international jurisdictions with the U.S. regulatory approach.

III. THE FALLOW 2020-2025 MHZ BAND—UNUSED BY LICENSED OPERATORS FOR OVER TWENTY YEARS—COULD HELP SATISFY SMALLSAT OPERATORS' SPECTRUM NEEDS.

MSS and terrestrial Fixed and Mobile operators may operate on a co-equal basis in the 2020-2025 MHz band outside of the United States. All three ITU regions allow Fixed and Mobile services in the 2020-2025 MHz band. ITU Region 2, which includes North, Central, and South

America, also permits MSS (Earth-to-space).[40] Interested MSS providers must coordinate, as required by ITU Radio Regulations No. 9.11A and Resolution 716, and not constrain Fixed and Mobile service deployments in ITU Regions 1 and 3.[41]

As a result, allowing MSS in the 2020-2025 MHz band will not impair MSS deployments of neighboring countries, Mexico and Canada.[42] Bilateral negotiations can address trans-border operational issues, if any exist. A potentially interfering operator would only need to select the opposite polarization of the potential victim system, reduce its Effective Isotropic Radiated Power ("EIRP"), and/or deploy a power control mechanism.

Domestically, the 2020-2025 MHz band once supported MSS but now only permits Fixed and Mobile services. In 1997, MSS received a U.S. allocation within 2020-2025 MHz.[43] Within

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[40] *See* Final Acts of the 1995 World Radiocommunication Conference (WRC-95), Geneva (1995), https://bit.ly/31Wu2LM; 47 C.F.R. § 2.106 n.5.388 ("The bands 1885-2025 MHz and 2110-2200 MHz are intended for use, on a worldwide basis, by administrations wishing to implement International Mobile Telecommunications (IMT). *Such use does not preclude the use of these bands by other services to which they are allocated.* The bands should be made available for IMT in accordance with Resolution 212 (Rev.WRC-15). (see also Resolution 223 (Rev.WRC-15).") (emphasis added); *id.* at n.5.389c ("The use of the bands 2010-2025 MHz and 2160-2170 MHz in Region 2 by the [MSS] is subject to coordination under No. 9.11A and to the provisions of Resolution 716 (Rev.WRC-12)."); *id.* at n.5.389E ("The use of the bands 2010-2025 MHz and 2160-2170 MHz by the [MSS] in Region 2 shall not cause harmful interference to or constrain the development of the fixed and mobile services in Regions 1 and 3.").

[41] *See* 47 C.F.R. 2.106 § n.5.389C.

[42] As detailed in the Technical Annex, terrestrial services in neighboring countries will not encounter harmful interference from the proposed MSS operations. Conversations with Innovation, Science and Economic Development Canada ("ISED") indicated the 2020-2025 MHz band remains fallow in Canada. Kepler, therefore, has petitioned ISED to permit smallsat use of the band.

[43] *See Amendment of Section 2.106 of the Commission's Rules to Allocate Spectrum at 2 GHz for Use by the Mobile-Satellite Service*, First Report and Order and Further Notice of Proposed Rule Making, 12 FCC Rcd 7388, ¶ 1 (1997).

six years, however, the Commission adopted service rules, removed the MSS allocation due to non-deployments, and allocated the band for Fixed and Mobile services.[44]

The Commission initially paired the 2020-2025 MHz and 2175-2180 MHz bands and proposed service rules.[45] But, in 2008, it chose not to adopt the proposal.[46] The 2020-2025 MHz band then remained largely forgotten until 2013.[47] At that point, the Commission proposed to align the band with the 2155-2180 MHz band to support complementary uplink/mobile operations for terrestrial systems in other frequencies.[48] The Commission, however, deferred action on addressing the 2020-2025 MHz band because it was waiting for DISH to elect either uplink or downlink operations in the adjacent 2000-2020 MHz band.[49] Although DISH selected its current S-band configuration four years ago, the proposal has not been revisited, and the unpaired 2020-2025 MHz band remains fallow.

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[44] *See, e.g.*, *Establishment of Polices and Service Rules for Mobile Satellite Service in 2 GHz Band*, Report and Order, 15 FCC Rcd 16127, ¶¶ 1, 16, 164 (2000); *Amendment of Part 2 of the Commission's Rules to Allocate Spectrum Below 3 GHz for Mobile & Fixed Services et al.*, Third Report and Order et al., 18 FCC Rcd 2223, ¶ 3, Appendix A (2003).

[45] *See Amendment of Part 2 of the Commission's Rules to Allocate Spectrum Below 3 GHz for Mobile and Fixed Services to Support the Introduction of New Advanced Wireless Services, including Third Generation Wireless Systems*, Sixth Report And Order, Third Memorandum Opinion and Order, and Fifth Memorandum Opinion and Order, 19 FCC Rcd 20720, ¶ 3 (2004); *Service Rules for Advanced Wireless Services in the 1915-1920 MHz, 1995-2000 MHz, 2020-2025 MHz, and 2175-2180 MHz Bands; Service Rules for Advanced Wireless Services in the 1.7 GHz and 2.1 GHz Bands*, Notice of Proposed Rulemaking, 19 FCC Rcd 19263, ¶ 1 (2004).

[46] *See Amendment of the Commission's Rules with Regard to Commercial Operations in the 1695-1710 MHz, 1755-1780 MHz, and 2155-2180 MHz Bands*, Notice of Proposed Rulemaking and Order on Reconsideration, 28 FCC Rcd 11479, ¶ 35 (2013).

[47] *See id*.

[48] *See id.* ¶ 2.

[49] *Amendment of the Commission's Rules with Regard to Commercial Operations in the 1695-1710 MHz, 1755-1780 MHz, & 2155-2180 MHz Bands*, Report and Order, 29 FCC Rcd 4610, ¶ 59 (2014). DISH chose to use the adjacent band for downlink operations. *See* Letter from Jeffrey H. Blum, Senior Vice President & Deputy General Counsel, DISH, to Marlene H. Dortch, Secretary, FCC, WT Docket No. 13-225 (filed June 1, 2016).

Adding MSS in the band will not hinder U.S. terrestrial wireless development. Before WRC-19, the ITU had identified 1900 megahertz of new spectrum for terrestrial wireless use; after WRC-19, another 17,250 megahertz of new terrestrial spectrum became accessible.[50] Additional spectrum will likely become available after WRC-23, where the ITU will consider additional frequencies like C-band for terrestrial wireless.[51] The Commission's active auction docket will expedite access to the ITU-identified spectrum in the United States.[52] Allocating *just five megahertz of unusable terrestrial spectrum* for MSS—a service long recognized as being congested in a limited number of service allocations—will not disrupt terrestrial wireless roll-outs in the United States, especially considering some existing terrestrial licensees have yet to deploy their network and all operators will soon have the opportunity to obtain additional licenses.[53]

Free of federal encumbrances and now possessing limited usefulness for the terrestrial industry, the 2020-2025 MHz band has become a leading and perhaps only candidate to replenish the scarce spectrum arsenal of smallsat operators in the United States. Federal users and the Commission have no planned use for the long-forgotten 2020-2025 MHz band. NTIA's 2019 Spectrum Report explained that "[n]o further action related to this five megahertz, unpaired band has been taken. The FCC is currently considering the next steps to accommodate fixed and mobile

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[50] *See Key outcomes of the World Radiocommunication Conference 2019*, ITU News Magazine, at 21 (June 2019), https://bit.ly/3j4rMIm.

[51] *See* Agenda for the 2023 World Radiocommunication Conference, Resolution 811 (WRC-19) (2019).

[52] *See, e.g.*, *Auction 105: 3.5 GHz*, FCC, https://bit.ly/3jdsXFv (last visited Oct. 29, 2020); *Auction 107: 3.7 GHz Service*, FCC (last visited Oct. 29, 2020), https://bit.ly/355R6sd.

[53] *See* WRC-19 Final Acts at Recommendation 206 ("[T]here are a limited number of frequency bands allocated to the MSS, [and] these bands are already congested.").

broadband services in that band."[54] Existing as an unpaired band serves Fixed and Mobile service providers no benefit and, therefore, will remain unused.

Spectrum-deprived smallsat operators, however, could quickly employ the band in the United States. Spire has downlinked data in the 2020-2025 MHz band—with no reported interference concerns—on a non-interference, non-protected basis since 2016. Kepler has already launched three satellites capable of utilizing the 2020-2025 band for MSS and will be launching eight additional similarly-equipped satellites before 2020 concludes. Spire and other companies have also deployed downlinks in another S-band frequency, 2200-2290 MHz, outside of the United States.[55] That architecture, including antennas and software-defined radios, could be readily adapted to accommodate 2020-2025 MHz operations. As a result, the entire band can be put to immediate good use.

IV. MSS IN THE 2020-2025 MHZ BAND WILL NOT HARMFULLY INTERFERE WITH ADJACENT-BAND OR IN-BAND OPERATIONS.

The continued absence of licensed operations in the 2020-2025 MHz band should prompt removal of the Fixed and Mobile service allocations and addition of a MSS allocation. These actions align with the Commission's goal of "enabling efficient use of spectrum for th[e] dynamic [smallsat] sector."[56]

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[54] *See Annual Report on the Status of Spectrum Repurposing*, Department of Commerce, at 19 (Aug. 2019), https://bit.ly/3lW2opX.

[55] *See, e.g.*, Spire Market Access Grant; Stamp Grant, HawkEye 360, Inc., File No. SAT-LOA-20190102-00001 (granted in part Dec. 10, 2019); Stamp Grant, Loft Orbital Solutions, Inc., File No. SAT-LOA-20190807-00072 (granted Oct. 8, 2020).

[56] *Smallsat NPRM* ¶ 1. The Commission also previously believed that it may be appropriate to permit short-duration smallsat operations in some MSS bands, where the smallsat operations "would limit any potential for interference into existing MSS operations, and would ensure that the small[sat] operations would have less potential for interference to either in-band or adjacent band services than operations that would typically be considered in the MSS." *Id.* ¶ 62. The

Spire and Kepler propose to split the 2020-2025 MHz band into two distinct bands: 2020-2021 MHz and 2021-2025 MHz. The 1-megahertz block will support downlink operations from satellites to earth stations; the 4-megahertz block will support uplink operations from user terminals ("UTs") to satellites. Supported by the studies in the Technical Annex, Spire and Kepler also propose operational limitations protecting adjacent-band services in 2000-2020 MHz and 2025-2110 MHz from harmful interference and enabling coexistence among multiple MSS operators in 2020-2025 MHz.

2020-2021 MHz (Satellite Data Downlink). The ITU's power flux density ("PFD") limits for the 2025-2110 MHz band should apply.[57] Namely, for angles of arrival above the horizontal plane δ, operators should limit their peak PFD in any 4-kilohertz bandwidth from -154 to -144 dB(W/m^2), as shown in Table 1. Requiring compliance with the PFD limits into the 2025-2110 MHz band ensures services in the 2025-2110 MHz band do not encounter harmful interference from new MSS in the 2020-2021 MHz band.

Table 1: PFD Limits Excerpt from ITU Radio Regulations

δ	$0° - 5°$	$5° - 25°$	$25° - 90°$
PFD / 4 kHz $dB(W/m^2)$	-154	$-154 + 0.5(\delta - 5)$	-144

2021-2025 MHz (Narrowband-MSS UT Uplink). EIRP and out-of-band emission ("OOBE") limits should apply.[58] These constraints ensure that multiple MSS operators can co-

studies and proposed rules in this petition show that MSS operations in this band would not harmfully interfere with in-band or adjacent band services.

[57] *See* ITU Radio Regulations Table 21-4.

[58] To minimize harmful interference potential, the values in this proposal have been derived from existing rulemakings or ITU and FCC regulations.

exist in the band and that adjacent-band operators will receive protection from harmful interference.

The maximum EIRP should be 36 dBm. The value is 3 dB greater than the 33 dBm limit adopted for AWS-4 UTs in the 2000-2020 MHz band.[59] But the aggregate interference power generated by low density Narrowband-MSS UTs will be similar to or less than the aggregate interference power that would have been generated by high-density AWS-4 terminals.

The OOBE outside a MSS frequency block should be attenuated below the total transmitter power (P) in watts by at least 43 + 10log(P) dB, as measured by instrumentation employing a resolution bandwidth of one megahertz or greater.[60] However, in the 250-kilohertz channels immediately adjacent to the licensee's frequency block, a resolution bandwidth of at least one percent of the transmitter's fundamental emission bandwidth may be employed.

The analysis described in the Technical Annex demonstrates that the introduction of MSS in 2020-2025 MHz, coupled with the proposed operational rules, will not disrupt other services. Studies used three different methodologies to assess interference: (i) from Narrowband-MSS UT Uplink to terrestrial deployments, (ii) from Narrowband-MSS UT Uplink to satellite receivers on orbit, and (iii) from Satellite Data Downlink to terrestrial deployments.

Study Methodology for Evaluating Interference from Narrowband-MSS UT Uplink into Terrestrial Systems. To assess the compatibility of separate systems operating in adjacent bands, the study uses a probabilistic approach based on the methodology in section 2.2 of Rep. ITU-R

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[59] *See Service Rules for Advanced Wireless Services in the 2000-2020 MHz and 2180-2200 MHz Bands et al.*, Report and Order and Order of Proposed Modification, 27 FCC Rcd 16102, ¶ 129 (2012) ("For mobile operations we adopt a power limit of 2 watts total [EIRP].").

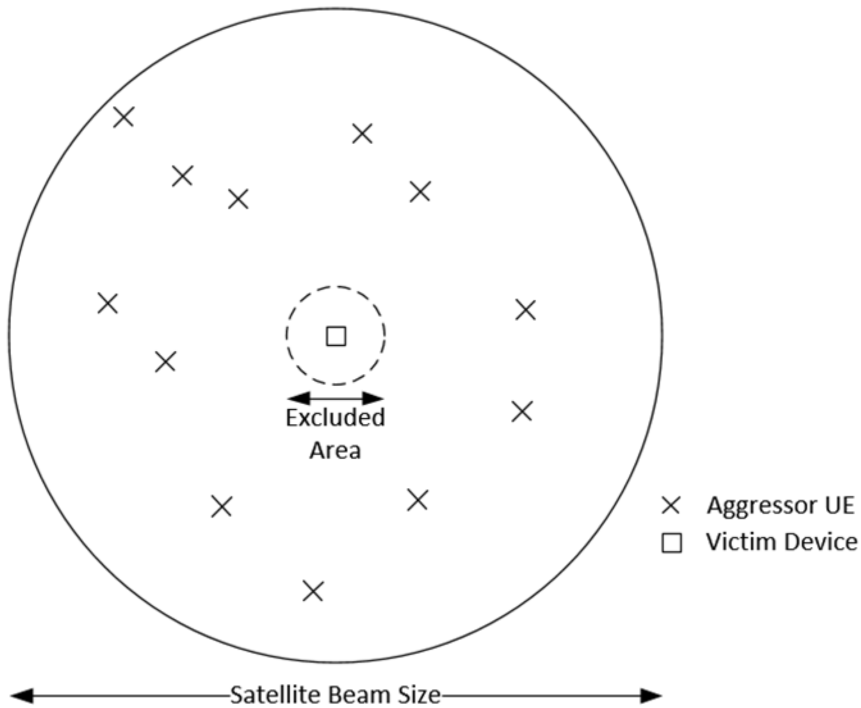
[60] This limit mirrors the Part 27 OOBE limit except for minor modifications accounting for the narrowband nature of the MSS UT emissions. *See* 47 C.F.R. § 27.53.

M.2041.[61] For each scenario, a minimum coupling loss ("MCL") is calculated based on the interference criteria, power, and unwanted emissions of the transmitter and the selectivity, sensitivity, and antenna gain of the receiver. Then, the study calculated the probability that an operator would exceed the MCL based on a propagation model and distribution of MSS user devices. MCL combined with a propagation model gives a minimum separation distance D_{min}. If an interferer is within D_{min} of the victim, the interference criteria is considered exceeded; if, however, an interferer is outside of D_{min}, no interference is expected.

The study considers the probability that D_{min} is exceeded. In general, D_{min} is on the order of hundreds of meters to kilometers for the scenarios considered. However, the relative low density of transmitting MSS UTs results in acceptable probabilities that D_{min} is exceeded.

[61] *See* Sharing and adjacent band compatibility in the 2.5 GHz band between the terrestrial and satellite components of IMT-2000, Rep. ITU-R M.2041 (2003).

Figure 1: Interference Scenario for Terrestrial Systems



To evaluate the probability of harmful interference, the victim device is placed at the center of a circular Kepler satellite receive beam. Placing the victim at the center of the beam is a worst-case scenario because user devices in adjacent beams will likely be operating on other channels. Transmitting UTs are randomly distributed throughout the satellite beam.

This methodology represents a worst-case analysis. Monte Carlo methods using tools such as SEAMCAT generally produce more favorable results. They use more realistic propagation models and loading factors, incorporate features such as adaptive power control, and account for link margin of victim systems. In particular, the probabilities calculated here are probabilities that there will be greater than 0.5-1 dB impact to the link budget of a victim system (depending on the interference-to-noise ("I/N") threshold chosen) under worst case conditions. Most links, however, typically operate with significantly more link margin or have significant capability to compensate.

Study Methodology for Evaluating Interference from Narrowband-MSS UT Uplink into an EESS or Space Research ("SR") Receiver. The simulation employed the methodology in ITU-R SA.1154 to evaluate the cumulative interference from a global population of MSS UTs[62] to the receiver of an adjacent band victim satellite system.[63] In this ITU recommendation, the victim satellite system antenna is isotropic and receives the cumulative interference from all devices within the satellite line of sight for a given orbit height. The study evaluated the summation of device power at the satellite receiver at 250 km and 36,000 km altitudes, which span the range of orbits from low low-Earth orbit to GSO.

Study Methodology for Evaluating Interference from Satellite Data Downlink into Terrestrial Systems. Although no AWS operations currently operate in 2000-2020 MHz, the study provides a methodology to evaluate and demonstrate compatibility with any current and future terrestrial systems.

First, the study considers a Satellite Data-Downlink system in 2020-2021 MHz transmitting at the proposed PFD limit into an AWS base station with a sectorial receive antenna pointed at the horizon (*i.e.*, no downtilt).[64] A satellite only transmits when in line of sight of an earth station.

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[62] The study uniformly distributed devices within the satellite line of sight. The number of devices within the satellite field of view is calculated by inferring a device density / km^2 based on the maximum number of MSS UTs transmitting per satellite beam area per channel and applying it throughout the victim satellite receiver line of sight.

[63] *See* Provisions to protect the space research (SR), space operations (SO) and Earth exploration-satellite services (EES) and to facilitate sharing with the mobile service in the 2025-2110 MHz and 2200-2290 MHz bands, Rec. ITU-R SA.1154 (1995).

[64] AWS UT receivers are susceptible to potential interference in the 2000-2020 MHz band. Analyzing, however, the interference from MSS transmissions into AWS base station receivers shows the worst-case scenario. Base stations will have higher gain than UTs in the direction of the satellite, operate above clutter and obstructions, and deploy entirely outdoors.

Second, when using the terrestrial mobile base station parameters identified in ITU-R M.2292, interference would occur only if the transmitting party exceeds -172 dBm/Hz. The study employs a power spectral density quantity because PFD limits are agnostic to specific system characteristics (*e.g.*, bandwidth) and represent the absolute worst case.

Appendices A through E in the Technical Annex analyze adjacent-band interference (Mobile (AWS-4), Broadcast Auxiliary Service ("BAS"), and EESS/SR) and in-band interference among MSS operators. The results indicate that the proposed band plan and associated rules eliminate all potential for harmful interference and permit later entrants to operate in the band.

Table 2: Summary of Interference Analysis[65]

Appendix	Aggressor	Aggressor Frequency (MHz)	Victim	Victim Frequency (MHz)	Interference Assessment
A	UT (Earth-to-space)	2021-2025	AWS UT	2000-2020	IPC exceeded < 0.1% time
B	UT (Earth-to-space)	2021-2025	MSS earth station	2020-2021	IPC exceeded < 0.6% time
C	UT (Earth-to-space)	2021-2025	BAS site	2025-2110	IPC exceeded < 0.2% time
D	UT (Earth-to-space)	2021-2025	EESS/ SR satellite	2025-2110	IPC exceeded by 1 dB in the lowest adjacent 250-kilohertz channel (2025-2025.250 MHz)

[65] Any MSS operations in 2000-2020 MHz will not encounter harmful interference because the power from co-channel AWS base stations will vastly exceed the potential interference power from adjacent-channel MSS space or earth station transmissions in 2020-2025 MHz.

Appendix	Aggressor	Aggressor Frequency (MHz)	Victim	Victim Frequency (MHz)	Interference Assessment
E	Satellite (space-to-Earth)	2020-2021	AWS base station[66]	2000-2020	IPC never exceeded, 12 dB margin

In all but one case, the expected probability of interference occurred less than 0.6% of the time. For the outlier MSS UT – EESS/SR scenario, the MSS UT exceeds the IPC by only 1 dB in the lowest adjacent 250-kilohertz channel (2025-2025.250 MHz). The Commission has held that this faint interference from a new service does not equal harmful interference.[67] As a result, reintroducing MSS in the 2020-2025 MHz band is justified.

The simulation in the Technical Annex also shows that multiple MSS systems can exist in the 2021-2025 MHz band. Recognizing the potential for more than a single MSS system operating uplinks in the band, the study evaluated the proposed emission limits against the Kepler system and assumed a user density and concept of operations identical to the Kepler system given no MSS systems currently operate in the band.

[66] AWS UT receivers are susceptible to potential interference in the 2000-2020 MHz band. Analyzing, however, the interference from MSS transmissions into AWS base station receivers shows the worst-case scenario. Base stations will have higher gain than UTs in the direction of the satellite, operate above clutter and obstructions, and deploy entirely outdoors.

[67] *See Ligado Grant* ¶ 49 ("In determining whether a new service would cause harmful interference to an incumbent service, we begin with and rely on the Commission's long-standing definition embodied in our rules: 'harmful interference' is '[i]nterference which endangers the functioning of a radionavigation service or of other safety services or seriously degrades, obstructs, or repeatedly interrupts a radiocommunication service operating in accordance with [the ITU] Radio Regulations.' We note NTIA defines 'harmful interference' in the same manner, as does the ITU. We apply this definition for evaluating potential for interference with respect to all services and allocations . . . . Radio noise occurs throughout the spectrum and a small rise in background noise, however undesirable, does not by itself constitute harm to a service.").

Under worst case assumptions, the Kepler system will receive interference under high / peak load conditions without system-to-system coordination. The level of interference would be nearly 12 dB in excess of a -6 dB I/N criteria at the edge of the band (within one channel bandwidth of the interfering system). For this reason, some coordination will remain necessary among the operators using the band. Because the band is subject to mandatory coordination under the international rules,[68] an FCC coordination requirement would not counteract the proposal. Operators could quickly coordinate by choosing the opposite polarization of the Kepler system, reducing EIRP, and/or deploying a power control mechanism. For example, Kepler channels can coexist with other Kepler channels under similar assumptions by combining stricter Adjacent Channel Leakage Ratio requirements on some UTs, power control, frequency reuse, and acceptance of interference in some scenarios (> -6 dB I/N). Appendix F summarizes the analysis of the above scenario.

V. CONCLUSION.

The United States stands to benefit by making spectrum resources available to support the burgeoning smallsat sector. Permitting MSS in the 2020-2025 MHz band will offer operators much-needed relief from their spectrum crunch and preserve American leadership in smallsat deployment without degrading, obstructing, or interrupting other services.

[68] *See* 47 C.F.R. § 2.106 n.5.389C.

Employing fallow spectrum for smallsat deployment promises to promote job creation, investment, and economic growth in the United States.

Respectfully submitted,

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PROPOSED RULE CHANGES

47 C.F.R. § 2.106 (Table of Frequency Allocations)

Remove the Fixed and Mobile services allocations and add a Mobile-Satellite Service allocation and footnote 5.389C in the 2020-2025 MHz band, as indicated by the track changes below.

International Table			United States Table	
Region 1 Table	**Region 2 Table**	**Region 3 Table**	**Federal Table**	**Non-Federal Table**
2010-2025 FIXED MOBILE 5.388A 5.388B	2010-2025 FIXED MOBILE MOBILE-SATELLITE (Earth-to-space)	2010-2025 FIXED MOBILE 5.388A 5.388B		2020-2025 ~~FIXED~~ ~~MOBILE~~ MOBILE-SATELLITE (Earth-to-space and space-to-Earth)
5.388	5.388 5.389C 5.389E	5.388		5.389C

47 C.F.R. § 25.142 (Licensing Provisions for the Non-Voice, Non-Geostationary Mobile-Satellite Service)

Add new subsection (c).

(c) *Operating in 2020-2025 MHz.*

(1) Applicants may deploy non-voice, non-geostationary Mobile-Satellite Service in the frequency band 2020-2025 MHz.

(i) In 2020-2021 MHz, only space-to-Earth operations may deploy. Applicants must adhere to the following power flux density limits.

δ	$0^\circ - 5^\circ$	$5^\circ - 25^\circ$	$25^\circ - 90^\circ$
PFD / 4 kHz $dB(W/m^2)$	-154	$-154 + 0.5(\delta - 5)$	-144

(ii) In 2021-2025 MHz, only Earth-to-space user terminal operations may deploy. The maximum EIRP should be 36 dBm. The out-of-band emission outside an applicant's frequency block should be attenuated below the total transmitter power

(P) in watts by at least 43 + 10log(P) dB, as measured by instrumentation employing a resolution bandwidth of one megahertz or greater. However, in the 250-kilohertz channels immediately adjacent to the applicant's frequency block, a resolution bandwidth of at least one percent of the transmitter's fundamental emission bandwidth may be employed.

(2) The use of the band is subject to coordination under ITU-R Radio Regulations No. 9.11A and Resolution 716 (Rev.WRC 12).

(3) Subsections (a)(1), (3)(i) and (b)(1), (3)-(4) apply.

TECHNICAL ANNEX

Executive Summary

Smallsat companies in the United States may access only a few frequency bands—none of which may be used exclusively by commercial operations. Some frequencies are technically inaccessible to smallsats. Coordinating the remaining limited shared spectrum has delayed licensing and delivery of low-cost, cutting-edge services to commercial and U.S. Federal customers; has impeded otherwise breakneck manufacturing and deployment schedules; and may start incenting the U.S. smallsat industry to seek licensing or prioritize service delivery elsewhere.[1]

Other unallocated frequencies, like the 2020-2025 MHz band, could still be repurposed for their highest and best use. Adding an MSS[2] allocation in the band would involve minimal administrative burden, would expeditiously support U.S. smallsat operators' needs, and maintain the robust industry in the United States.[3]

This technical annex examines how the newly allocated service will not interfere with other services. First, it details the proposed 2020-2025 MHz MSS band plan and sharing criteria. Second, it analyzes adjacent-band interference (Mobile (AWS-4), EESS/SR, and BAS)) and in-band interference among MSS deployments. Third, it demonstrates that no service will encounter harmful interference from new 2020-2025 MHz MSS.

Proposed Band Plan and Sharing Criteria

Spire and Kepler (collectively, the "Alliance") propose to split the 2020-2025 MHz band into two distinct bands: 2020-2021 MHz and 2021-2025 MHz. The 1-megahertz block will support downlink operations from satellites to earth stations; the 4-megahertz block will support uplink operations from UTs to satellites.

Based on the following studies, the Alliance proposes operational limitations protecting adjacent-band services in 2000-2020 MHz and 2025-2110 MHz from harmful interference and enabling coexistence among MSS operators in 2020-2025 MHz.

- **A.** ***2020-2021 MHz (Satellite Data Downlink)***: The ITU's PFD limits for the 2025-2110 MHz band should apply.[4] Namely, for angles of arrival above the horizontal plane δ the peak PFD in any 4 kilohertz bandwidth should be limited to a value between -154 and -144 dB(W/m^2), as shown in Table 1. Requiring compliance with the PFD limits into the 2025-2110 MHz band ensures services in the 2025-2110 MHz band do not encounter harmful interference from new MSS in the 2020-2021 MHz band.

[1] *See* Legal Narrative at II(0)(ii).

[2] A glossary of acronyms is appended.

[3] In this band, MSS possesses primary status across all three ITU regions. *See* 47 C.F.R. § 2.106. Adding the MSS allocation would require elimination of the existing allocations for Fixed and Mobile services, which have not deployed in the band for over 20 years.

[4] *See* ITU Radio Regulations Table 21-4.

Table 1: PFD Limits Excerpt from ITU Radio Regulations

δ	$0° - 5°$	$5° - 25°$	$25° - 90°$
PFD / 4 kHz $dB(W/m^2)$	-154	$-154 + 0.5(\delta - 5)$	-144

B. ***2021-2025 MHz (Narrowband-MSS UT Uplink)***: EIRP and OOBE limits should apply.[5] As a result, multiple MSS operators may co-exist in the band, and adjacent-band operators will receive protection from harmful interference.

i. The maximum EIRP should be 36 dBm. The value is 3 dB larger than the 33 dBm limit adopted for AWS-4 terminals in the 2000-2020 MHz band.[6] But the aggregate interference power generated by low density MSS UTs will be similar to or less than the aggregate interference power that would have been generated by high-density AWS-4 terminals.

ii. The OOBE outside a MSS frequency block should be attenuated below the total transmitter power (P) in watts by at least 43 + 10log(P) dB, as measured by instrumentation employing a resolution bandwidth of one megahertz or greater.[7] However, in the 250-kilohertz channels immediately adjacent to the licensee's frequency block, a resolution bandwidth of at least one percent of the transmitter's fundamental emission bandwidth may be employed.

Summary of Study Results

Appendices A through E analyze adjacent-band interference (Mobile (AWS-4), BAS, and EESS/SR) and in-band interference among MSS operators. The results indicate that the proposed band plan and associated rules eliminate all potential for harmful interference and permit later entrants to operate in the band.

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[5] To minimize harmful interference potential, the values in this proposal have been derived from existing rulemakings or ITU and FCC regulations.

[6] *See Service Rules for Advanced Wireless Services in the 2000-2020 MHz and 2180-2200 MHz Bands et al.*, Report and Order and Proposed Modification et al., 27 FCC Rcd 16102, ¶ 129 (2012) ("For mobile operations we adopt a power limit of 2 watts total [EIRP].") ("*AWS-4 Order*").

[7] This limit mirrors the Part 27 OOBE limit except for minor modifications accounting for the narrowband nature of the MSS UT emissions. *See* 47 C.F.R. § 27.53.

Table 2: Summary of Interference Analysis[8]

Appendix	Aggressor	Aggressor Frequency (MHz)	Victim	Victim Frequency (MHz)	Interference Assessment
A	UT	2021-2025	AWS UT	2000-2020	IPC exceeded < 0.1% time
B	UT	2021-2025	MSS earth station	2020-2021	IPC exceeded < 0.6% time
C	UT	2021-2025	BAS site	2025-2110	IPC exceeded < 0.2% time
D	UT	2021-2025	EESS/ SR satellite	2025-2110	IPC exceeded by 1 dB in the lowest adjacent 250-kilohertz channel (2025-2025.250 MHz)
E	Satellite	2020-2021	AWS base station[9]	2000-2020	IPC never exceeded, 12 dB margin

The probabilities calculated here are probabilities that there will be greater than 0.5-1 dB impact to the link budget of a victim system (depending on the I/N chosen) under worst case conditions. Most links, however, typically operate with significantly more link margin or have significant capability to compensate.

In all but one case, the expected probability of interference totaled less than 0.6% of the time. For the outlier MSS UT – EESS/SR scenario, the MSS UT exceeds the IPC by 1 dB in the lowest adjacent 250-kilohertz channel (2025-2025.250 MHz). The Commission has held that this faint interference from a new service does not equal harmful interference.[10] As a result, reintroducing MSS in the 2020-2025 MHz band is justified.

[8] Any MSS operations in 2000-2020 MHz will not encounter harmful interference because the power from co-channel AWS base stations will vastly exceed the potential interference power from adjacent-channel MSS space or earth station transmissions in 2020-2025 MHz.

[9] AWS UT receivers are susceptible to potential interference in the 2000-2020 MHz band. Analyzing, however, the interference from MSS transmissions into AWS base station receivers shows the worst-case scenario. Base stations will have higher gain than UTs in the direction of the satellite, operate above clutter and obstructions, and deploy entirely outdoors.

[10] *See Ligado Amendment to License Modification Applications et al.*, Order and Authorization, 35 FCC Rcd 3772, ¶ 49 (2020) ("In determining whether a new service would cause harmful

Intra-MSS Systems Sharing in the 2021-2025 MHz Band
The Alliance proposes that the 2021-2025 MHz band may be shared amongst operators within the band. Recognizing the potential for more than a single MSS system operating uplinks in the band, the proposed emission limits were evaluated against the Kepler system. Similar assumptions on user density and concept of operations as the Kepler system were made given that no other known or proposed systems operate in 2021-2025 MHz.

Under worst case assumptions, the Kepler system will receive interference under high / peak load conditions. The level of interference would be on the order of 12 dB in excess of a -6 dB I/N criteria at the edge of the band (within 1 channel bandwidth of the interfering system). For this reason, some degree of coordination is necessary between the operators in the band. As the band is already subject to coordination internationally,[11] the Alliance does not deem such a requirement as counterproductive to the proposal. The method of coordination could be as simple as choosing the opposite polarization of the Kepler system, a reduction in EIRP, or a power control mechanism. Kepler channels can coexist with other Kepler channels under similar assumptions through a combination of stricter ACLR requirements on some proportion of UTs, power control, frequency reuse, and acceptance of interference in some scenarios > -6 dB I/N.

A full analysis of the above scenario, including assumptions and operational parameters, are presented in Appendix F.

A. Narrowband-MSS UT Network Description

Kepler intends to operate a Narrowband-MSS uplink system in 2021-2025 or some portion thereof. In most cases this would be paired with a downlink band in another frequency. The primary application of the system would be the transmission of short messages (typically <1 second transmission time, <10 times per day) from Narrowband-MSS devices deployed in applications where terrestrial connectivity solutions are not widely deployed.

The space component consists of a constellation of approximately 140 satellites in LEO. In the uplink direction, each satellite is capable of receiving on one or multiple beams, each with a nominal area coverage corresponding to a 700-km diameter circular area or other pattern with the equivalent area. Multiple channels between 200-500 kilohertz can be assigned to each beam; for the purposes of this analysis, a nominal channel size of 350 kilohertz is used. Assuming that several

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interference to an incumbent service, we begin with and rely on the Commission's long-standing definition embodied in our rules: 'harmful interference' is '[i]nterference which endangers the functioning of a radionavigation service or of other safety services or seriously degrades, obstructs, or repeatedly interrupts a radiocommunication service operating in accordance with [the ITU] Radio Regulations.' We note NTIA defines 'harmful interference' in the same manner, as does the ITU. We apply this definition for evaluating potential for interference with respect to all services and allocations[]. Radio noise occurs throughout the spectrum and a small rise in background noise, however undesirable, does not by itself constitute harm to a service.").

[11] *See* 47 C.F.R. § 2.106 n.5.389C.

operators will participate in using the spectrum block made available, and that each has similar spectrum requirements and operational characteristics to those of Kepler, it is reasonable to assume that the 4 megahertz of spectrum will be adequate and quickly put to use.

Significant flexibility exists for iterating on the characteristics of the satellites between the first satellite launched and the last/latest. For example, to more efficiently use the allocated spectrum or address interference concerns, larger antennas or more sophisticated signal processing might be deployed in a way that does not increase the interference to other systems as calculated in this document.

The Kepler user devices are deployed in mobile applications, with many if not most devices battery operated. In either case, in a nominal configuration the maximum gain of the antenna will be pointed zenith, and therefore for the vast majority of devices, the EIRP in the direction of terrestrial systems will be lower. At any moment in time a very small proportion of devices will be transmitting in any given 700-km diameter area. This is both a consequence of the relatively small amount of data that is required to be transmitted, as well as fundamental limitations on the maximum number of devices that might utilize a given channel simultaneously.

The parameters presented in Table 3 and Table 4 portray Kepler's uplink system parameters that are relevant to this study.

Table 3: UT Uplink Parameters

Parameter	**Value**
UE power	<= 1W[12]
UE antenna pattern	Peak gain < 5 dBi, Towards horizon < -1.5 dBi[13]
Polarization	Circular polarization
Satellite beam size	700 km diameter, circular
Simultaneous transmissions[14]	200

[12] The Alliance proposes a 36 dBm EIRP limit, but for the analysis, UTs transmit with a peak EIRP of 35 dBm. For most scenarios, the EIRP in the direction of the victim is 28.5 dBm.

[13] This value represents the gain in the direction of terrestrial victims.

[14] This parameter represents the maximum number of simultaneous transmitting terminals per satellite beam, per channel.

Channel bandwidth	200-500 kilohertz[15]

Table 4: Satellite Receive Parameters

Parameter	**Value**
Distance to satellite across Kepler beam	500 km (minimum) 1000 km (average)
Average satellite G/T across beam	-11.6 dB/k
ACS	>40 dB

B. Satellite Data Downlink Description

Using 2020-2021 MHz, Spire intends to downlink data stored onboard the satellite as it passes over a *limited number* of ground stations. Today, Spire operates twelve S-band sites in the United States. Each location houses either a 1.2 m or 1.8 m diameter antenna that communicates with Spire's satellite constellation consisting of no more than 175 satellites.

Data-downlink operations in the band are limited and will not cause harmful interference. A satellite only transmits when in LoS of the few earth stations, and only one satellite may communicate with one earth station at a time. OOBE will not cause harmful interference to services in adjacent bands because Spire will use a combination of baseband digital filtering and hardware radiofrequency filtering in addition to complying with PFD limits.

The parameters presented in Table 5 and Table 6 portray Spire's downlink system parameters that are relevant to this study.

Table 5: Satellite Transmit Parameters

Parameter	**Value**
Beam type	Fixed
Polarization	RHCP
Antenna peak gain	5 dBi
Beamwidth	120° (±60°)

[15] This study uses a 350-kilohertz bandwidth.

Max. transmit EIRP	8 dBW
Max transmit EIRP density	-52 dBW/Hz

Table 6: Earth Station Receive Parameters

Parameter	**Value**
Beam type	Fixed with Az/El tracking
Polarization	RHCP
Antenna gain / beamwidth (1.2m)	<25.7 dBi / 6.1°
Antenna gain / beamwidth (1.8m)	<28.5 dBi / 6.0°
Max gain toward the horizon	9.5 dBi

Study Methodology for Evaluating Interference from MSS UTs into Terrestrial Systems

Adjacent band compatibility methodology

To assess the compatibility of separate systems operating in adjacent bands, a probabilistic approach was used based on the methodology described in section 2.2 of Rep. ITU-R M.2041. For each scenario, in Rep. ITU-R M.2041, a minimum coupling loss is calculated based on the interference criteria, power, and unwanted emissions of the transmitter and the selectivity, sensitivity, and antenna gain of the receiver. Then the probability the minimum coupling loss will be exceeded was calculated based on a propagation model and the distribution of Kepler user devices.

Per section 2.2 of Rep. ITU-R M.2041 the Adjacent channel interference ratio, or ACIR, is defined as

$$\boldsymbol{ACIR = 1/(ACLR^{-1} + ACS^{-1})} \quad \text{(A)}$$

Where

- $ACLR$ - Adjacent channel leakage ratio
- ACS - Adjacent channel selectivity

The MCL is then taken as

$$MCL = EIRP + G_{rx} - [N_{th} + I/N + ACIR - Other\_Losses] \text{ (B)}$$

Where:

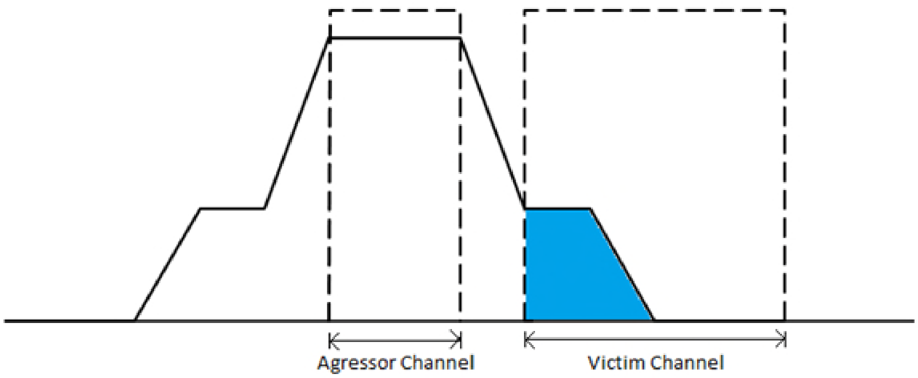
- N_{th} - is the thermal noise floor of the receiver in the bandwidth of the receiver. For most terrestrial receivers, $N_{th} = -174\ dBm/hz + NF + dB(bandwidth)$, where NF is the noise figure of the receiver
- I/N - interference protection criteria
- G_{rx}- gain of the receiving antenna
- $Other\_Losses$ - To account for other losses (including but not limited to polarization)

MCL combined with a propagation model gives a minimum separation distance D_{min}. If an interferer is within D_{min} of the victim, the interference criteria is considered exceeded; similarly, if an interferer is outside of D_{min}, no interference is expected. The probability of this happening is then calculated.

It should be noted that this methodology represents a worst-case analysis. Monte Carlo methods using tools such as SEAMCAT generally produce more favorable results because of its use of more realistic propagation models, incorporation of features such as adaptive power control, and accounting for link margin of victim systems. In particular, it should be highlighted that probabilities calculated under this methodology are the probability that there will be greater than 0.5-1 dB impact to the link budget of a victim system (depending on the I/N chosen). Most links, in most practical systems operate with significantly more link margin.

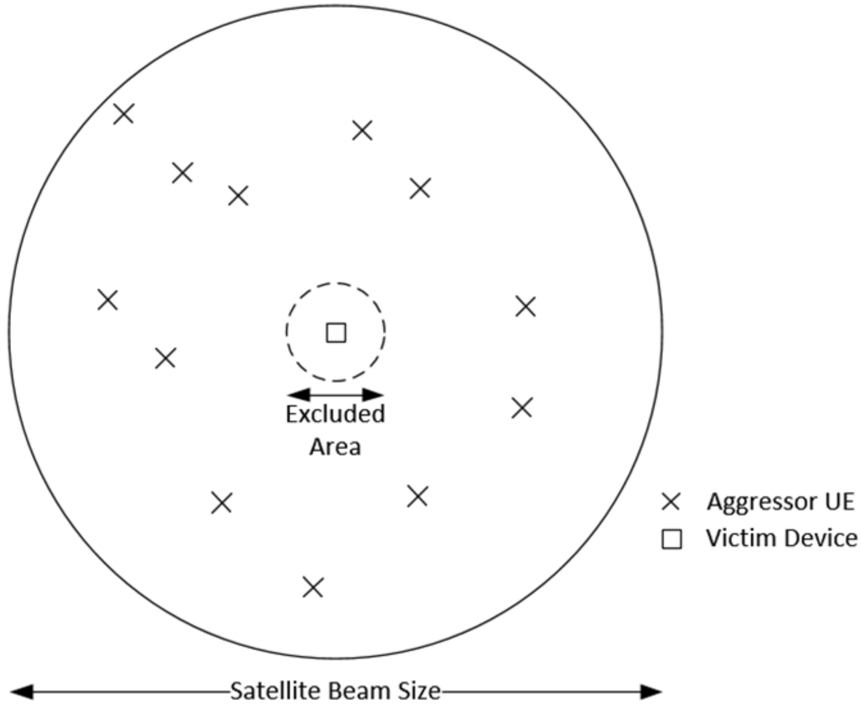
ACLR between different systems
A clarification of the ACLR parameter is required because the scenarios under consideration do not operate under the same channelization, modulations, etc. For a given victim system, the ACLR of an aggressor transmitter is taken to be the total integrated power of the emissions in the victim channel from the aggressor relative to the total integrated power of the aggressor (Figure 1).

Figure 1: ACLR in This Study is Defined as the Ratio of the Shaded Area to the Total Area of the Aggressor Signal



Terrestrial systems as the victim methodology
The probability that D_{min} is exceeded must be considered. In general, $D_{min}$is on the order of hundreds of meters to kilometers for the scenarios considered. However, the relatively low density of transmitting satellite UTs results in acceptable probabilities that D_{min} is exceeded.

Figure 2: Interference Scenario for Terrestrial Systems



To evaluate the probability of harmful interference, the victim device is placed at the center of a circular Kepler satellite receive beam. Placing the victim at the center of the beam is a worst-case scenario because it is assumed that user devices in adjacent beams will be operating on other channels, and therefore the center of the beam minimizes the distance to interfering devices. Transmitting UTs are assumed to be randomly distributed throughout the satellite beam.

Probability of Interference

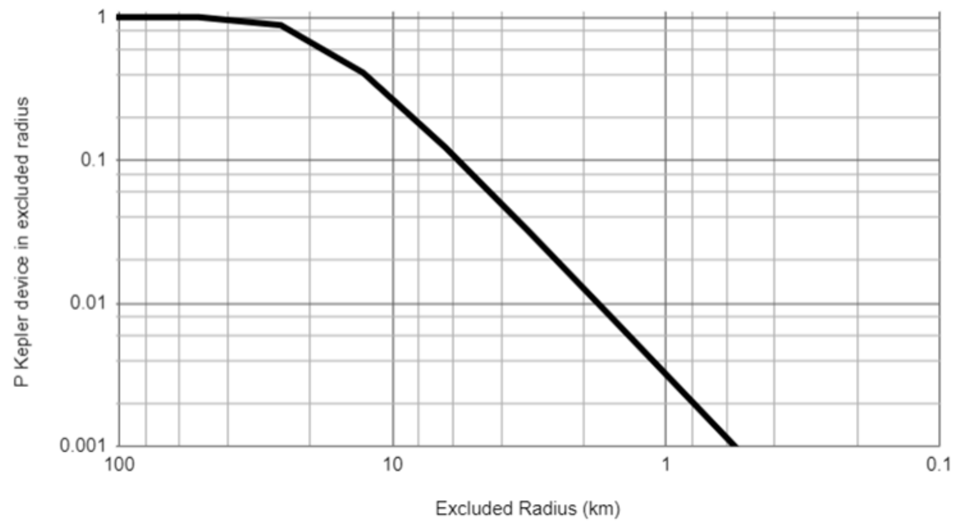
Given the portrayed scenario in Figure 2, Equation C is used to determine the probability of a UT being within the minimum distance threshold.

$$\boldsymbol{P\_exceeded} = [\mathbf{1} - [\mathbf{1} - (\boldsymbol{D_{min}/D_{beam}})^2]^{N_{devices}}]\boldsymbol{F_T} \quad \text{(C)}$$

where

- D_{min} - is the diameter of the exclusion area
- D_{beam} - is the diameter of the satellite beam
- $N_{devices}$ - is the number of simultaneously transmitting devices
- F_T - factor to account for probability satellite will be overhead

for example for D_{beam}= 700 km, $N_{devices} = 200$, and $F_T = 1$:



Derivation of Equation C

1. The probability a single device is within the excluded area is the ratio of the excluded area to the total beam area = $(D_{min}/D_{beam})^2$
2. The probability a single device is not within the excluded area is $[1 - (D_{min}/D_{beam})^2]$
3. The probability N devices are not within the excluded area is $[1 - (D_{min}/D_{beam})^2]^{N_{devices}}$
4. The probability at least one device within the N devices is inside the excluded area is $1 - [1 - (D_{min}/D_{beam})^2]^{N_{devices}}$

Number of Devices

To determine the number of simultaneous transmitting devices in a beam within one channel bandwidth of the victim, Equation B is used.

$$\boldsymbol{N_{devices} = N_{channel,peak} F_L B_{victim} / B_{channel}} \qquad \text{(D)}$$

where

- $N_{channel,peak}$ - the maximum capacity of a kepler channel
- F_L- a loading factor to account for typical usage of the kepler system
- B_{victim} - MIN(bandwidth of the victim system, 4 MHz)
- $B_{channel}$ - bandwidth of the Kepler channel

Aggregate Interference

No consideration was given to the aggregate interference of devices outside of D_{min} in the case where no interfering devices are within D_{min}. Due to the low density of devices, the probability two or more devices combine to exceed the IPC is negligible. Equivalently, the probability is extremely low that two devices will be positioned such that the power produced at the victim is comparable.

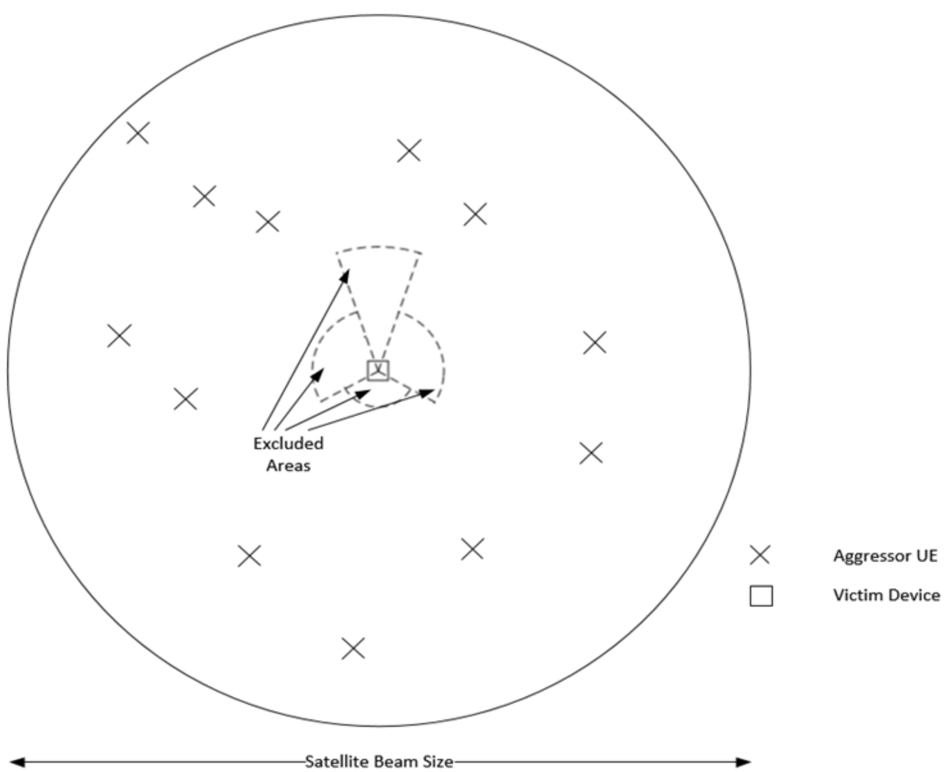
No consideration is given to devices outside one channel bandwidth of the victim system (i.e. devices not in the adjacent channel). It is assumed that impairments to the victim system due to unwanted emissions and receiver selectivity are largely dominated by devices in the adjacent channel of the victim.

Directional Victim Antennas

A modification is used for scenarios where the victim is a directional antenna (e.g. BAS receivers or satellite earth stations) as opposed to an omnidirectional antenna. In this case MCL as a function of azimuth angle is calculated based on the receiver's gain as a function of azimuth angle, and the probability integrated over all azimuth angles based on the propagation model. This scenario is illustrated in Figure 3.

Figure 3: Interference Scenario for a Directional Victim Antenna Showing a Piecewise Integration of Four Sectors.

Note the minimum separation distance in the boresight direction is larger, but only within a small range of azimuth angles.



Dual-Slope Propagation Model

The dual slope LoS model is defined in Section 3.1 of Rep. ITU-R M.2030. In particular the path loss is given by

$$L = 32.44 + 20\,log\,(f) + 20\,log\,(d) \text{ for } 1 < d < d_{break}$$

$$L = 32.44 + 20\,log\,(f) - 20\,log\,(d_{break}) + 40\,log\,(d) \text{ for } d > d_{break}$$

where

- d - distance (m)
- f - frequency (GHz)

the breakpoint is calculated as:

$$d_{break} = 4h_{tx}h_{rx} / \lambda$$

where

- h_{tx},h_{rx}- the height of the transmitter and receiver (m)
- λ - the wavelength (m)

The model is adopted here because in these studies, adjacent band interference is only likely in a LoS scenario between the victim and the receiver. The dual slope LoS model allows for LoS propagation where conservatively reasonable, without producing unreasonably conservative results at further distances.

Appendix A
Compatibility Analysis: Kepler User Terminal Interference into AWS UT Receivers in the 2000-2020 MHz Band

Summary

- The Alliance proposed to access the 2021-2025 MHz band for Narrowband-MSS user uplink communications from UTs to the MSS on a primary basis.
- This study assesses the compatibility of MSS user uplinks to LEO MSS satellites with AWS receivers which are authorized to operate in the 2000-2020 MHz band
- Worst-case operating conditions are utilized for a bounding analysis:
    - In lieu of system characteristics of other MSS systems, for the purpose of this study, it is assumed that Kepler UTs occupy all 4 megahertz.
    - A static analysis is used rather than a dynamic Monte Carlo assessment which would typically provide more favorable results.
    - Studies were also performed assuming a higher loading factor, reduced system losses, and more lax propagation models than what would realistically be observed.

The results show that the probability of I/N exceeding -6 dB is <0.1% of the time. We consider this acceptable and SEAMCAT analysis unnecessary based on the low probability of interference.

Purpose of the Study

The Alliance is proposing that the 2021-2025 MHz band be made available for MSS, specifically for Narrowband-MSS type operations, in the uplink direction. This band is presently allocated to non-Federal Fixed and Mobile services within the United States.

This study assesses the compatibility between Narrowband-MSS UTs and an existing LTE system operating user terminal downlink in the adjacent AWS band. The results demonstrate that coordination may not be necessary given the low probability of interference.

Operational Characteristics of AWS Systems

For the purposes of this study, the impact of interference caused by Narrowband-MSS UTs operating in 2021-2025 MHz on a 5-megahertz LTE channel operating at the band edge were considered.

Parameter	Value	Source
Frequency	2017.5 MHz	
Other losses	7 dB[16]	ITU-R M.2292
E-UTRA UT RX antenna gain	-3 dBi	ITU-R M.2292
Noise figure	9 dB	ITU-R M.2292

[16] This value assumes a 4 dB body loss paired with a 3 dB polarization coupling factor.

Parameter	Value	Source
Bandwidth	4.5 MHz[17]	Minimum bandwidth for Band 70 per LTE TS 136 101
ACS	33 dB[18]	LTE TS 136 101, § 7.5.1, ECC REPORT 197

Operational Characteristics of Narrowband-MSS UTs
A potential interfering system was used with the following system parameters derived from the Kepler system.

43 dB was used as the effective ACLR for a single device operating in 2021-2025 MHz based on the proposed 43 + 10log(P) emission limit. In particular, the proposed emission regulation limits any emissions in 2015-2020 MHz integrated over any 1-megahertz bandwidth to -13 dBm per megahertz at the output of the transmitter, which is 43 dB below the transmitter power in this case. Although the proposed rules allow for up to -13 dBm to be transmitted over each 1 MHz section of the 5 MHz victim channel (resulting in an ACLR of 36 dB) this is unrealistic. The unwanted emissions of interest here will be dominated by the intermodulation products. Because the emissions considered here are narrow band (350 kHz), the dominant components will also be narrow band with other components falling off quickly. Therefore, any transmitter that meets the 43 + 10log(P) criteria in the closet 1 MHz to the victim band will have negligible emissions in the other 4 MHz.

Parameter	Value
Channel frequency	2021-2025 MHz
Gain towards terrestrial station	-1.5 dBi
Transmit power	1 W
Transmit bandwidth	350 kHz
ACLR	43 dB

[17] This value assumes 5-megahertz channel spacing.

[18] This value represents a 5-megahertz bandwidth interfering signal in an adjacent channel and is assumed to also be applicable to Kepler's narrowband interference.

Study Scenario
Devices occupying all 4 megahertz between 2021-2025 MHz were considered because the size of an adjacent LTE channel is 5 megahertz. It is very unlikely all 4 megahertz will be fully loaded, and therefore an average loading factor of 50% was adopted. This is conservative. For instance, a fully loaded "two-color" frequency reuse system would have an equivalent loading factor of 50%.

A dual slope propagation model was used. Terminals were placed at a 4-meter transmitter height (the height of a short roof or the top of a truck), and LTE UTs were placed at a 1.5-meter height. A dual slope model is appropriate because only aggressor and victim devices within a few hundred meters will cause interference. For such short distances, a free space model is conservative but reasonable. Beyond a few hundred meters, the probability of a LoS scenario falls significantly due to shadowing, multipath, etc., and larger propagation losses can be expected. A dual slope model accounts for both these cases.

Parameter	Value	Source
Device distribution	B_victim = 5 MHz B_channel = 350 kHz F_L = 50% F_T = 100% N_channel,peak = 200	
Propagation model[19]	Dual-slope LOS h_tx = 4.0 m h_rx = 1.5 m	Appendix 2 Rep. ITU-R M.2030; 3GPP TR 36.942
Interference criteria	I/N = -6 dB[20]	ITU-R M.2292; 3GPP TR 36.942

Study Results
Using the methodology presented, the following results are applicable:

Results	
ACIR	32.6 dB
N_thermal	-98.5 dBm/MHz
MCL	90.4 dB

[19] This parameter corresponds to the height of a typical Kepler deployment (roof of a 1 story building, truck, railcar, etc.) and height of a mobile.

[20] This value can also be measured as a capacity loss where the criteria calls for no more than 5% capacity loss.

Results	
N_devices	1140
D_min	251 m
P_exceeded	0.06%

For a given victim terminal, there is a 0.06% probability I/N of -6 dB will be exceeded. Because Kepler devices transmit short messages (<1 second) relatively infrequently (~1-10s of times per day) this can be reasonably interpreted as a worst-case capacity loss. This is considered well within the range of acceptable loss. A 0.06% capacity loss under conservative assumptions is smaller than the 5% loss criteria typically used in a E-UTRA <> E-UTRA adjacent channel scenario and criteria used in previous Monte Carlo analysis of adjacent service compatibility with IMT.

The following parameters were additionally varied independently (i.e. keeping all other parameters the same) as a crude sensitivity analysis to capture some additional scenarios of potential interest.

Parameter	Previous Value	New Value	P_exceeded	Rationale
F	0.5	1	0.11%	Fully loaded system with no frequency re use
Other losses	7 dB	12 dB	0.03%	5 dB more favourable link budget
Other losses	7 dB	2 dB	0.10%	5 dB more severe link budget
Propagation model	Dual-slope LOS	Free space	0.16%	Absolute worst case propagation model

Conclusion

As demonstrated through the analysis detailed in this paper, Narrowband-MSS is compatible with MS adjacent to the proposed uplink band. Critically:

- Current licensees in the adjacent band are adequately protected. Given the distribution of Narrowband-MSS terminals and their relatively low duty cycle, it has been shown that the probability of interference is exceptionally low.
- Future licensees in the adjacent band are equally protected. Further deployment of terrestrial MS networks will not be hindered by the operation of a Narrowband-MSS system.

References

LTE TS 136 101 § 7.5.1
ECC REPORT 197
ITU-R M.2292
3GPP TR 36.942
ITU-R M.2030

Appendix B
Compatibility Analysis: Kepler User Terminal Interference into Satellite Earth Stations in the 2020-2021 MHz Band

Summary

- The Alliance proposed to access the 2020-2021 MHz band for satellite data downlink communications to earth station facilities on a primary basis.
- This study assesses the compatibility of MSS downlinks within the band to earth station facilities with MSS uplinks in the adjacent 2021-2025 MHz band.
- Worst-case operating conditions are utilized, based on existing deployments, for a bounding analysis.
    - Satellite earth station is pointed 10 degrees above the horizon.
    - Satellite earth station has a 9.5 dBi peak gain.
    - The UT occupies a channel directly neighboring the 2021 MHz band.
- The results show that the probability of interference from a Narrowband-MSS UT into an earth station is on the order of 0.56%, which the Alliance deems acceptable.

Purpose of the Study

The Alliance proposed that the 2020-2021 MHz band be made available for downlinking data to earth stations. This band is presently allocated to non-Federal Fixed and Mobile services within the United States.

This study assesses the compatibility of the proposed satellite data downlink with the proposed MSS uplink transmissions from ground-based UTs to a LEO satellite. The results demonstrate that coordination may not be necessary given the low duty cycle and density of the UTs and earth stations.

Operational Characteristics of Satellite Earth Stations

Table 7 depicts the gain associated with the receive earth stations at varying angles off boresight. The pattern is assumed to be symmetrical about the boresight.

Table 7: Receive Earth Station Gain Profile

Angle	0 - 15	15-20	20-25	25-180
Gain (dBi)	9.5	5.7	2.7	-0.3

In addition to the gain profile, the earth station is assumed to have parameters similar to those indicated below.

Parameter	**Value**
Frequency	2020-2021 MHz
ACS	43 dB

Parameter	Value
Other losses	0 dB

Operational Characteristics of Narrowband-MSS UTs
A potential interfering system was used with the following system parameters derived from the Kepler system.

An effective ACLR of 24.1 dB was calculated by integrating the proposed emissions mask over 1 megahertz for a 350-kilohertz channel operating at the edge of the band. Only the closest 350-kilohertz channel needs to be considered because the OOBE of the Narrowband-MSS UTs dominate over the selectivity of the receiver and the spurious emissions of transmitters in other channels.

Parameter	Value
Channel frequency	2021.175 MHz
Gain toward terrestrial station	-1.5 dBi
Transmit power	1 W
Transmit bandwidth	350 kHz
ACLR	24.4 dB

Study Scenario
The Alliance considers the propagation model, device distribution, and interference criteria appropriate for existing earth stations operating in 2020-2021 MHz.

Parameter	Value	Source
Device distribution	B_victim = 1 MHz B_channel = 350 kHz F_L = 50% F_T = 35%	
Propagation model	dual slope LoS h_tx = 4m h_rx = 10m	
$N_{th} + I/N$	-119 dBm	ITU-R M.2292, 3GPP TR 36.942

Study Results
Using the methodology presented for directional victim antennas, the following results are applicable.

Table 8: Interference Assessment between Narrowband-MSS Uplinks and Receive MSS Earth Stations

Results	
ACIR	24.3 dB
MCL - RX antenna gain	123.2 dB
N_devices	100
P_exceeded	0.56%

For directional victim antennas, D_min is a function of the azimuth angle, these are calculated below.

Azimuth angle	0 - 15	15-20	20-25	25-180
D_min (m)	2870	2360	1940	1680

In addition to the typical scenario presented in Table 8, several parameters were altered to assess the sensitivity of the results. These results are displayed in Table 9 and follow a similar trend of displaying negligible interference levels. These parameter changes are overly conservative.

Table 9: Interference Assessment between Narrowband-MSS Uplinks and Receive MSS Earth Stations Using Overly Conservative Parameters

Parameter	Previous Value	New Value	P_exceeded	Rationale
F_L	0.5	1	1.1%	Fully loaded system
ACS	43 dB	30 dB	0.66%	Possible worse selectivity close to band edge
MCL - rx antenna gain	123.2 dB	118.2 dB	0.32%	5 dB more favorable link budget

Parameter	Previous Value	New Value	P_exceeded	Rationale
MCL - rx antenna gain	123.2 dB	128.2 dB	1.0%	5 dB more severe link budget

Conclusion

As demonstrated through the analysis, Narrowband-MSS uplink is compatible with satellite data downlink into select earth stations. Critically:

- Narrowband-MSS uplink interference to earth stations is low. Given the distribution of Narrowband-MSS terminals and their relatively low duty cycle, it has been shown that the probability of interference is exceptionally low.

References

ITU-R M.2041

Appendix C
Compatibility Analysis: Kepler User Terminal Interference into Broadcast Auxiliary Service in the 2025-2110 MHz Band

Summary

- The Alliance proposed to access the 2021-2025 MHz band for user uplink communications from UTs to the MSS on a primary basis.
- This study assesses the compatibility of MSS user uplinks to LEO MSS satellites with ENG-RO stations, which are authorized to operate in the 2025-2110 MHz band.
- The results show that the probability of interference is less than 0.5% of the time.

Purpose of the Study

The Alliance proposed that the 2021-2025 MHz band be made available for MSS, specifically for Narrowband-MSS operations, in the uplink direction. This band is presently allocated to non-Federal Fixed and Mobile services within the United States.

Currently, television BAS operate ENG-RO in 2025-2110 MHz. From 2025.5-2109.5 MHz, seven 12-megahertz channels carry broadcast video from ENG trucks to ENG-RO sites. Alternatively, each 12-megahertz channel can be split into three 6-megahertz overlapping channels. For the purposes of this study, the lowest 6-megahertz channel (2025.5-2031.5 MHz) is considered because this will be the worst case.

This study assesses the compatibility between Narrowband-MSS UTs and BAS operations. This is provided for reference only, as it should be noted that in the AWS-4 rulemaking, it was concluded that under similar rules there would be no interference to BAS operations.[21]

Operational Characteristics of ENG-RO Receivers

Typical ENG-RO antennas are located 141 meters above ground with a typical antenna gain of 20 dBi.[22] Because ENG-RO antennas are directional, Table 10 depicts the gain associated with the receive earth stations at angles off boresight for an ENG-RO antenna pointed with no downtilt (worse case). The pattern is assumed to be symmetric about the boresight.

Table 10: ENG-RO Antenna Pattern

Angle off boresight angle	0 - 5	5-10	10-15	15-20	20-30	30-100	100-140	140-180
Gain (dBi)	20	15	2	0	0	-5	-8	-16

[21] *See AWS-4 Order* ¶ 104.

[22] *See* Ex Parte Comments of Engineers for the Integrity of Broadcast Auxiliary Services Spectrum, GN Docket No. 13-185 et al., ¶ 5 (filed May 12, 2014).

The peak gain was based on the typical gain of an ENG-RO site. The gain at angles off boresight are based on a category B antenna in 47 CFR § 74.641.

Parameter	**Value**
Frequency	2025.5 - 2031.5
Bandwidth	6 MHz
ACS	50 dB
Other losses	0 dB

Operational Characteristics of Narrowband-MSS UTs
A potential interfering system was used with the following system parameters derived from the Kepler system.

43 dB was used as the effective ACLR for a single device operating in 2024-2025 MHz based on the proposed 43 + 10log(P) emission limit. In particular, the proposed emission regulation limits any emissions in 2025.5-2031.5 integrated over any 1-megahertz bandwidth to -13 dBm at the output of the transmitter, which is 43 dB below the transmitter power in this case. Although the proposed rules allow for up to -13 dBm to be transmitted over each 1 MHz section of the 6 MHz victim channel (resulting in an ACLR of 35 dB) this is unrealistic. The unwanted emissions of interest here will be dominated by the intermodulation products. Because the emissions considered here are narrow band (350 kHz), the dominant components will also be narrow band with other components falling off quickly. Therefore, any transmitter that meets the 43 + 10log(P) criteria in the closest 1 MHz to the victim band will have negligible emissions in the other 5 MHz.

Parameter	**Value**
Channel frequency	2024.65 - 2025.00 MHz
Gain toward terrestrial station	-1.5 dBi
Transmit power	1 W
Transmit bandwidth	350 kHz
Effective ACLR	43 dB

Study Scenario
Two cases are worth considering when differentiating between interference scenarios driven by ACLR and ACS.

The first scenario considers only devices operating within 250% of the channel bandwidths from 2025.5 MHz or approximately the devices operating in a single 350-kilohertz channel from 2024.65-2025.00 MHz. A single fully loaded channel is considered, with an effective ACLR of 43 dB per the model described above. Practical devices operating outside this separation bandwidth are considered to have an ACLR significantly greater than 50 dB and will therefore have a negligible contribution compared to the receiver selectivity.

The second case considers the contribution of the remaining devices in the 4 megahertz between 2021-2025 MHz due to receiver selectivity only (ACLR = 1000 dB). As with scenario A, a 50% loading factor was used when considering the total number of devices.

In both scenarios, a dual slope LoS model was used with the victim antenna height set at 141 m.[23] For both scenarios, this is the same as free space due to the height of the victim antenna.

Parameter	**Case 1**	**Case 2**
Device distribution	B_channel = 350 kHz B_victim = 350 kHz F_L = 100% F_T = 35%	B_channel = 350 kHz B_victim = 3.65 MHz F_L = 0.5 F_T = 0.35
Number of simultaneous transmitting devices	200	1042
Propagation model	dual slope LoS h_tx = 4 m h_rx = 141 m	dual slope LoS h_tx = 4 m h_rx = 141 m
$N_{th} + I/N$	-108 dBm	-108 dBm

[23] *See id.*

Study Results

Results	Case 1	Case 2
ACIR	42.2 dB	50 dB
MCL - RX antenna gain[24]	94.3 dB	86.5 dB
N_devices	200	1042
	Case 1	**Case 2**
P_exceeded	0.079%	0.071%

Combining both scenarios yields a total probability of 0.15%. As a rough sensitivity analysis, increasing the minimum coupling loss by 5 dB in both scenarios produces the following results. This is excessively conservative.

	P_exceeded with 5 dB more severe link budget	**P_exceeded with 5 dB more favourable link budget**
Case 1	0.25%	0.025%
Case 2	0.21%	0.022%
Total	0.46%	0.047%

Conclusion

As demonstrated through the analysis, Narrowband-MSS is compatible with existing BAS adjacent to the proposed uplink bands. Critically:

- Current licensees in the adjacent band are adequately protected. Given the distribution of Narrowband-MSS terminals and their relatively low duty cycle, it has been shown that the probability of interference is exceptionally low.
- Future licensees in the adjacent band are equally protected. Further deployment of terrestrial BAS networks will not be hindered by the operation of a Narrowband-MSS system.

[24] The study considered the MCL - rx antenna gain because of the varying antenna gains at different azimuth angles.

Appendix D
Compatibility Analysis: Kepler User Terminal Interference into Receive Signals of the Earth Exploration-Satellite Service in the 2025-2110 MHz Band

Summary

- The Alliance proposed to access the 2021-2025 MHz band for user uplink communications from UTs to the MSS on a primary basis.
- This study assesses the compatibility of MSS user uplinks to LEO MSS satellites with the EESS which are authorized to operate Earth to space in the 2025 - 2110 MHz band.
- The results show that under the proposed rules, a heavily loaded system will cause 0.9 dB of excess interference in the 250 kilohertz immediately adjacent to 2025 MHz for LEO satellites that might use those frequencies. However simple solutions are available should interference be seen in practice.

Purpose of the Study

The Alliance proposed that the 2021-2025 MHz band be made available specifically for Narrowband-MSS operations in the uplink direction. This band is presently allocated to non-Federal Fixed and Mobile services within the United States.

This study assesses the compatibility between space-based EESS satellite receivers in the adjacent 2025-2110 MHz band with transmissions from ground-based Narrowband-MSS UTs.

Study Methodology

The methodology in section 5.1.1 of ITU-R SA.1154 was used to evaluate the cumulative interference from a global population of Narrowband-MSS UTs at the receiver of an adjacent band victim satellite system.

In ITU-R SA.1154, the victim satellite system antenna is isotropic and receives the cumulative interference from all devices within the satellite LoS for a given orbit height. Altitudes of 250 km and 36,000 km were used to span the range of orbits from LEO to GEO.

The devices are assumed to be uniformly distributed within the satellite LoS, and the summation of device power at the satellite receiver is evaluated accordingly. The number of devices within the satellite field of view is calculated by inferring a device density / km^2 based on the maximum number of Narrowband-MSS UTs transmitting per satellite beam area per channel and applying it throughout the victim satellite receiver line of sight. Multiple channels do not need to be considered as power spectral density quantities were used. The reason for this is that the protection criteria is written in terms of power spectral density, and inferring bandwidths is difficult due to the diversity of parameters that exist across spacecraft systems.

A fixed EIRP in the direction of the victim satellite was also assumed. Per ITU-R SA.1154, an additional 3 dB was added to the propagation loss to account for trees, shadowing, etc. of outdoor units.

Operational Characteristics of EESS Satellites
ITU-R SA.1154 considers omnidirectional receivers on EESS satellites typically used for TT&C applications with an average gain of 0 dBi. More directional antennas would see a smaller population of user devices which approximately compensates for the higher power received from individual devices.

In particular, the total power of interference seen by the victim spacecraft is proportional to the area covered by the receiver beam A (because the interfering devices are assumed to be uniformly distributed) and the gain of the spacecraft antenna G_0 in dBi.

$$I \propto A \times 10^{0.1G_0}$$

Under flat earth assumptions and assuming that only the devices within the 3 dB beamwidth θ_3, are considered

$$A \propto (\tan\frac{\theta_3}{2})^2$$

A common approximation for the 3 dB beamwidth in degrees for max gains less than 20 dBi and for frequencies between 1 and 3 GHz is

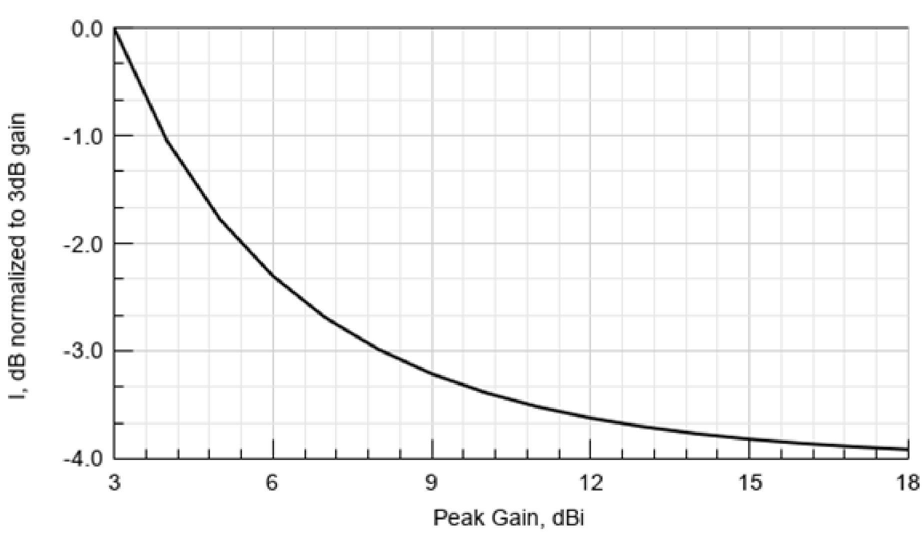
$$\theta_3 = \sqrt{27000 \times 10^{-0.1G_0}}$$

Therefore

$$I \propto \tan(0.5\sqrt{27000 \times 10^{-0.1G_0}})^2 10^{-0.1G_0}$$

Plotting normalized to $G_0 = 3$ dBi, the total received power varies by 4 dB between 3 and 18 dBi with lower gains being less favorable from an interference point of view.

Figure 4: Relative Received Power Versus Spacecraft Gain for a Satellite Receiving from a Population of Uniformly Distributed Interferes within Its 3dB Beamwidth



Satellite (Victim)	Parameter
Receive antenna gain	0 dBi
Orbits	250 km,[25] 36000 km
Protection criteria	-182 dBW/kHz[26]

Operational Characteristics of Narrowband-MSS UTs
A potential interfering system was used with the following system parameters derived from the Kepler system.

A single channel operating at the band edge was considered. Channels not operating at the boundary should pose no interference concern because the effects of unwanted emissions in this study are largely driven by third order intermodulation products which occur at transmitter center frequency offsets less than 150% of the transmitter bandwidth.

The total number of simultaneous devices was inferred by considering the peak capacity per channel, per beam and derating by 2x for frequency reuse and 4x for average system loading across the multiple beams that the victim satellite will see. A 4x peak to average capacity ratio over this area is justifiable. In particular, the field of view of a LEO satellite in a (relatively low) 250 km orbit is about 15 million square kilometers, or 50% more than the landmass of Europe.
For the system under consideration, the peak capacity per beam per channel is 200 simultaneously transmitting devices per 700 km diameter beam. Under a uniform distribution of devices over the beam area, this equates to 0.52 devices / 1000 km^2, which in this study is further de-rated by 8x (2x for frequency re use and 4x for average system loading).

[25] This parameter represents the lowest LEO orbit considered in Rec. ITU-R SA.1154.

[26] *See* Provisions to protect the space research (SR), space operations (SO) and Earth exploration-satellite services (EES) and to facilitate sharing with the mobile service in the 2025-2110 MHz and 2200-2290 MHz bands, Rec. ITU-R SA.1154 (1995).

Parameter	Value
Channel frequency	2024.825 MHz
Channel bandwidth	350 kHz
EIRP in direction of victim satellite	0 dBW
Other losses	3 dB
Propagation model	Free space
Device distribution	0.065 devices/1000 km^2

Study Results

Results	
Power density at 250 km LEO receiver	-158.1 dBW/kHz
Maximum unwanted emissions relative to transmitter	23.9 dB
Power density at GEO receiver	-177.3 dBW/kHz
Maximum unwanted emissions relative to transmitter	4.7 dB

Based on the methodology described, the 250 km LEO case is the worst case. In particular, the unwanted emissions of the transmitter into the EESS band must be no greater than 23.9 dB below the total power of the emission to not exceed the -182 dBW/kHz interference criteria.

This proposed emission criteria exceeds this requirement by 0.9 dB. In particular, for a 350-kilohertz transmitter centered at 2024.825 MHz, the maximum unwanted emissions allowed in spectral density terms are 23 dBsd. This corresponds to 43 dB below the main emission in any 3.5 kilohertz in the 250-kilohertz band between 2025.00 and 2025.25 MHz.

It should be noted that while the scenario considered here is marginal, it is an absolute worst case that only applies to the 250 kilohertz at the EESS band edge for satellites in LEO orbits below approximately 1,000 km. Should such systems experience interference, it would be reasonable to reduce power or limit the number of devices in the channel immediately adjacent to 2025 MHz.

It should further be noted that a 1 dB rise in noise floor from -182 dBW/kHz to -181 dBW/kHz corresponds to a 0.4 dB sensitivity degradation versus a 0.5 dB sensitivity degradation for a typical satellite system with a thermal noise contribution of -172 dBW/kHz.

Conclusion

As demonstrated through the analysis, Narrowband-MSS uplink is compatible with EESS satellites. Critically:

- Interference concerns are limited to within 250 kilohertz of the lower edge of the 2025 - 2110 band, and the impact is small. Victim receivers operating more than 250 kilohertz away from the band edge will not experience interference greater than -182 dBW/kHz. Victim receivers operating within 250 kilohertz of the band edge might experience interference in excess of -182 dBW/kHz but still with minimal impact to their operation.

References

ITU-R SA.1154

Appendix E
Compatibility Analysis: Satellite Data-Downlink System Interference into AWS Base Stations in the 2000-2020 MHz Band

Summary
- The Alliance proposed to access the 2020-2021 MHz band for satellite downlink communications to earth station facilities on a primary basis.
- This study assesses the compatibility of satellite downlinks with AWS base station receivers that may operate in the 2000-2020 MHz band to provide a framework for evaluating compatibility of adjacent systems under the proposed PFD limits.
- Under worst-case conditions, the proposed PFD limits are 12 dB below the interference threshold for causing interference to AWS base stations. This margin covers other permutations of potential terrestrial systems.

Purpose of the Study
The Alliance proposed that the 2020-2021 MHz band be made available for MSS, specifically for downlinking data to earth stations. This band is presently allocated to non-Federal Fixed and Mobile services within the United States.

This study assesses the compatibility of the proposed satellite downlink under the PFD limits proposed with an AWS base station receiver.[27] Although no AWS base station receivers are known to operate in 2000-2020 MHz, this study provides a methodology to evaluate and demonstrate compatibility with any current and future terrestrial systems.

Operational Characteristics of AWS System
The assessment assumes base station parameters identified in ITU-R M.2292 as follows.
- 3 dB feeder loss
- sectorial antenna defined in ITU-R F.1336
- I/N of -6 dB
- 5 dB noise figure

This translates to an interference criteria of -172 dBm/Hz. Power spectral density quantities are used because PFD limits are agnostic to specific system characteristics (e.g. bandwidth) and represent the absolute worst case.

Study Scenario
The study considers a downlink satellite system in 2020-2021 MHz transmitting at the proposed PFD limit into an AWS base station with a sectorial receive antenna pointed at the horizon (i.e. no downtilt).

[27] AWS UT receivers are susceptible to potential interference in the 2000-2020 MHz band. Analyzing, however, the interference from MSS transmissions into AWS base station receivers shows the worst-case scenario. Base stations will have higher gain than UTs in the direction of the satellite, operate above clutter and obstructions, and deploy entirely outdoors.

Study Methodology

For a given PFD, the received power spectral density is given by:

$$I_{PSD} = PFD - 10\,log\,(BW_{PFD}) + 20\,log\,(\lambda) + G_{RX}(\theta,\phi) - OtherLosses - 10\,log\,(4\pi)$$

where

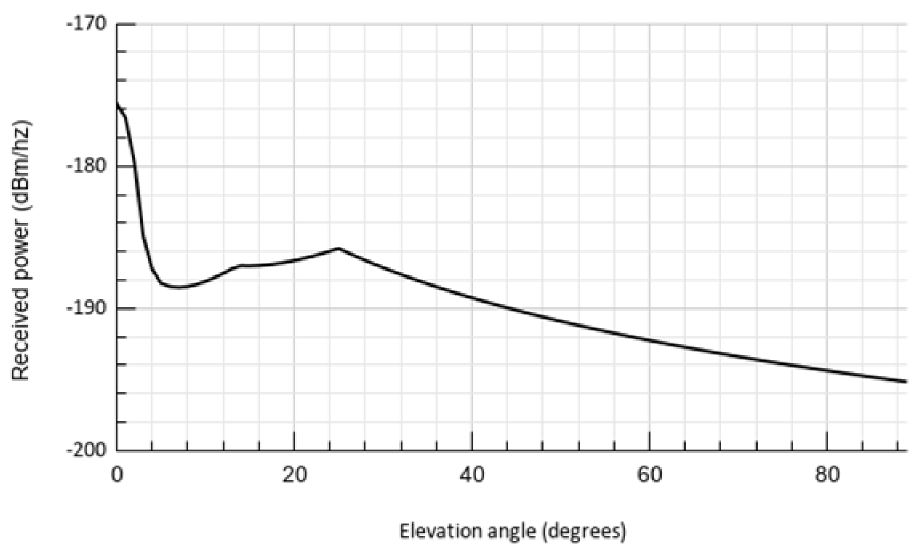
- PFD - incident power flux density in BW_{PFD}, in this study, the proposed PFD limits are given with $BW_{PFD} = 4\ kHz$
- λ - wavelength (m)
- $G_{RX}(\theta,\phi)$ - gain of the receiving antenna, boresight is at $G_{RX}(0,0)$
- $OtherLosses$ - feeder loss, polarization loss, etc.

The worst case considered here fixes the azimuth angle $\phi = 0$.

Study Results

The maximum received power occurs with the boresight of the victim antenna pointed towards the horizon at -175.6 dBm/Hz. At a minimum, unwanted emissions from satellite systems are governed by ITU-R SM.1541. For EESS systems, integrating the mask given in section 5.2 of ITU-R SM.1541 over one megahertz gives a relatively poor ACLR of 8.2 dB. Nevertheless this represents an 11.8 dB margin over the interference criteria. Most practical systems should have unwanted emissions corresponding to an ACLR of much better than 8.2 dB.

Figure 5: Received Power Spectral Density from a Satellite Following the Proposed PFD Limit into a Sectorial Antenna



Conclusion
As demonstrated through the analysis, the proposed PFD limit prevents harmful interference in current or future terrestrial deployments in adjacent bands. Critically:

- The power spectral density does not exceed -175 dBm/Hz into an AWS base station.
- With very conservative assumptions on transmitter unwanted emissions, this still represents a 12 dB margin over the interference criteria.
- This margin should cover other current and future terrestrial systems.

References
ITU-R M.2292
ITU-R F.1336 antenna pattern
ITU-R SM.1541

Appendix F
Compatibility Analysis: Intra-MSS Coexistence in the 2021-2025 MHz Band

Summary

- The Alliance proposed to access the 2021-2025 MHz band for user uplink communications from Narrowband-MSS UTs to the MSS on a primary basis.
- This study assesses the compatibility of multiple MSS systems sharing the band.
- The assessment assumes that other MSS systems use similar operating characteristics to those of Kepler's system.
- The results show that systems using adjacent channels have the ability to interfere with each other without coordination. To resolve this issue, the Alliance notes that neighboring systems should coordinate. One possible solution is to adopt orthogonal polarizations.

Purpose of the Study

The Alliance proposed that the 2021-2025 MHz band be made available for MSS, specifically for Narrowband-MSS operations, in the uplink direction. This band is presently allocated to non-Federal Fixed and Mobile services within the United States.

This study assesses the ability of multiple MSS systems to actively share the spectrum made available.

Operational Characteristics of Narrowband-MSS UTs

A potential interfering system was used with the following system parameters derived from the Kepler system.

Parameter	**Value**	**Notes**
Number of simultaneous transmitting devices	200	Same as the Kepler system
EIRP toward Kepler satellite	0 dBW	Same as the Kepler system
Transmit bandwidth	350 kHz	Same as the Kepler system
ACLR	24.4 dB	Derived from integrating the proposed emission limit over 350 kHz

Operational Characteristics of Narrowband-MSS Satellites

The model Kepler system has the following parameters. Two sets of distances and associated path losses are considered corresponding to a worst case and a nominal case based on different beams and spacecraft concept of operations.

Parameter	Worst Case Value	Average Case Value
Frequency	2023 MHz	
Average distance to terminals across Kepler beam	600 km	1000 km
Free space path loss	154.1 dB	158.6 dB
Receiver noise figure	2 dB	
Average RX antenna gain across beam	15 dBi	
N_thermal	-116.6 dBm[28]	
I/N criteria	-6 dB	
ACS	40 dB[29]	

Study Scenario

- The ACLR was derived based on operating a 350-kilohertz channel at the boundary between the interfering system and the Kepler system.
- Channels operating not at the boundary should pose no interference concern under these assumptions.
- The interference into the Kepler system is calculated as a simple summation over all devices.
- A free space path loss model was used.

Study Methodology

The power of the interference at the Kepler channel is calculated as follows:

$$I = EIRP - FSPL + G_{rx} + dB(N_{devices}) - ACIR$$

[28] This value is based off a 350-kilohertz Kepler channel and 290K antenna noise.

[29] This value is negligible compared to ACLR.

- I - The total power of interference in the Kepler channel
- G_{rx} - Gain of the Kepler spacecraft antenna
- $N_{devices}$ - Number of devices simultaneously transmitting
- $FSPL$ - Free space path loss
- $ACIR$ - As defined above

Study Results

Parameter	Average	Worst
ACIR	24.4 dB	24.4 dB
I/N	1.6 dB	6 dB
Margin on IPC	-7.6 dB	-12.0 dB

Conclusion

As demonstrated through the analysis, intra-service sharing of Narrowband-MSS is possible within the 2020-2025 MHz band. Critically:

- Coordination can be used as a mechanism to avoid harmful interference. A system similar to Kepler's will cause significant interference into Kepler's system at the band edges without coordination. However 7-12 dB can easily be accounted for by choosing orthogonal polarizations to Kepler.
- Coordination may not be necessary for all systems. Systems that operate some combination of significantly less devices, lower power, or with unwanted emissions performance exceeding the proposed rules might not require any additional coordination with the Kepler system.

GLOSSARY OF ACRONYMS

AWS-4	2000-2020 (DL) and 2180-2200 MHz (DL)
ACLR	Adjacent Channel Leakage Ratio
ACIR	Adjacent Channel Interference Ratio
ACS	Adjacent Channel Selectivity
AWS	Advanced Wireless Service
BAS	Broadcast Auxiliary Service
EESS	Earth Exploration-Satellite Service
ENG	Electronic News Gathering
ENG-RO	Electronic News Gathering – Receive Only
EIRP	Equivalent Isotropically Radiated Power
IPC	Interference Protection Criteria
I/N	Interference-to-Noise Power Ratio
IMT	International Mobile Telecommunications
ITU	International Telecommunication Union
LEO	Low Earth Orbit
LoS	Line of Sight
MCL	Minimum Coupling Loss
MSS	Mobile-Satellite Service
MS	Mobile Service
LTE	Long Term Evolution
NTIA	National Telecommunications and Information Administration
OOBE	Out-of-Band Emissions
PFD	Power Flux Density
RHCP	Right Hand Circular Polarization
RR	Radio Regulations
SR	Space Research
UT	User Terminal
3GPP	Third Generation Partnership Project