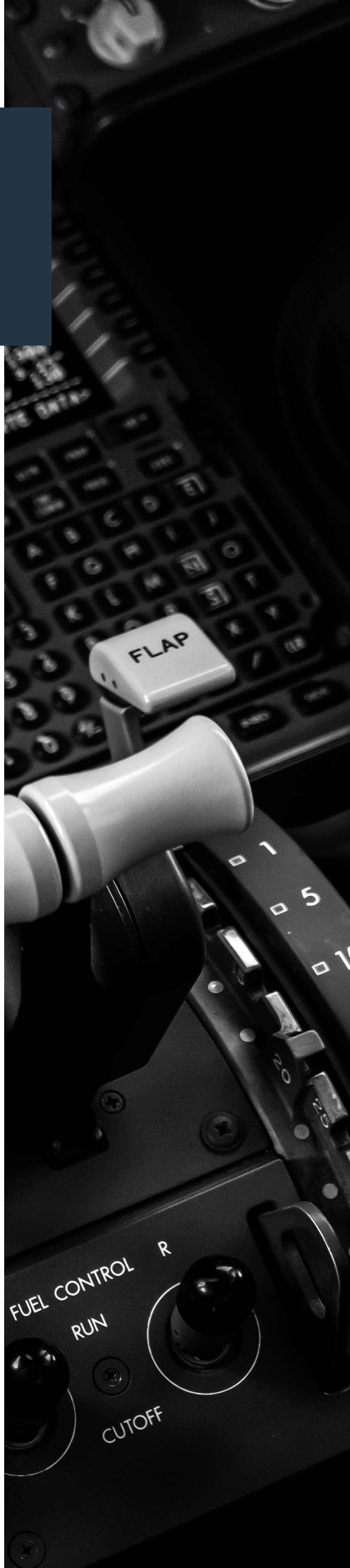
A 5G AMERICAS WHITE PAPER

MID-BAND SPECTRUM & THE COEXISTENCE WITH RADIO ALTIMETERS

JULY 2021

Contents



Executive Summary

This white paper focuses on the need for 5G spectrum to support the wireless cellular industry in low, mid, and high bands. It also discusses the global harmonization of spectrum with technology, and how spectrum supports a broad ecosystem. 3GPP specifications support new spectrum and wider bandwidths ranging from a minimum of 5 MHz – 100 MHz for sub 7 GHz spectrum, and channel sizes of 50 MHz — 400 MHz for frequency ranges above 24 GHz. For operators to deliver on the promise of 5G, regulatory bodies must ensure harmonized spectrum availability across low, mid, and high spectrum with timely allocations.

- *Low bands: Sub-1GHz supports wide area coverage and indoor coverage, and brings the 5G advantage across urban, suburban, rural regions.*
- *Mid bands: Ranges between 1 – 6 GHz and provides balanced coverage and capacity. More spectrum must be made available in this range to accommodate the wide variety of 5G use cases.*
- *High bands: mmWave ranging from 24 – 71 GHz provides high capacity and ultra-high speeds but lacks coverage and indoor penetration.*

To facilitate 5G deployments that can serve a variety of use cases, it is imperative that spectrum is made available across all three frequency ranges. Regulatory bodies throughout North America have been actively working towards the introduction of new bands to support 5G. In the United States, there has been an extensive push towards the allocation of spectrum for 5G services. Within the last couple of years, the FCC has released spectrum which has paved the way for those in the US to receive 5G wireless services.

The recent C-band (3700 MHz – 3980 MHz) spectrum auction was the biggest auction in FCC history. ISED, the Canadian regulatory body, has also been active in identifying and designating new spectrum for 5G services. ISED is planning to auction the 3450 – 3650 MHz band on June 15, 2021.[1]

Regarding Mexico, 5G services have not been launched yet while the regulator makes spectrum available for 5G. The 3500 MHz band was re-farmed, giving a contiguous spectrum block to the three operators (AT&T, Axtel, and Telmex).

The global landscape of mid-band 5G deployments, mid-band spectrum, the coordination regime, and how to maximize available spectrum are also considered. The high-level overview of the global landscape of mid-band 5G deployments includes South Korea, China, Middle East, Japan, and Europe. Approximately 105 operators are actively deploying or have launched 5G networks using band 3300 – 4200 MHz (3GPP band n77) or 3300 – 3800 MHz (3GPP band n78). There has also been some interest in deploying 4400 – 5000 MHz (3GPP band n79). In the United States, the FCC has taken steps to make spectrum available for terrestrial mobile use which allows for full-power macro-operation in the 3450 – 3550 MHz and the 3700 - 3980 MHz bands.

In addition, the coexistence of 5G in C-band with radio altimeters is discussed. 5G is being deployed globally in 3300 – 4200 MHz (3GPP band n77), 3300 – 3800 MHz (3GPP band n78), and 4400 - 5000 MHz (3GPP band n79). The nearby 4200 – 4400 MHz band is home to radio altimeters used in aircrafts and helicopters worldwide. In the United States, the FCC first sought comment on the re-purposing of the 3700 – 4200 MHz band through a Notice of Inquiry. On February 28, 2020, the FCC adopted the Report and Order approving the use of the 3700 – 3980 MHz band for commercial wireless service without any constraints on 5G deployments and parameters. The aviation industry was active in the FCC docket, and the FCC explicitly took their comments into account when making its determination that "the limits we set for the 3.7 GHz Service are sufficient to protect aeronautical services in the 4.2-4.4 GHz band. Specifically, the technical rules on power and emission limits we set for the 3.7 GHz Service and the spectral separation of 220 megahertz should offer all due protection to services in the 4.2-4.4 GHz band".

Subsequently, the aviation community developed coexistence studies. However, these studies have significant shortcomings. In particular, the study performed by the RTCA[2] was overly conservative when evaluating real-world conditions. This conclusion is supported by a review of real-world examples of non-interference in Japan, South Korea, Europe, and with the federal Systems in the United States.

1. Introduction

In 2021, 5G networks are rapidly proliferating around the globe, bringing access to 5G services to hundreds of millions of people around the world. Analysis from wireless cellular data provided by Omdia suggests global wireless 5G connections have reached 298 million by the end of Q1 2021. As of June 2021, the number of 5G commercial networks deployed worldwide hit 172. The level of 5G uptake continues to progress, as the number of 5G connections gained in 2021 is nearly triple that in 2020[3].

From the outset, 5G offers a vast range of capabilities compared to the previous generations of mobile technology. As part of IMT 2020, the International Telecommunications Union (ITU) set requirements to support such capabilities. The use cases targeted are:

- *Enhanced Mobile Broadband (eMBB): Maximum data rate of up to 20 Gbps with a user experience data rate of up to 100 Mbps*
- *Ultra-reliable low latency (URLLC): Latency as low as 1 ms with high availability and reliability*
- *Massive Machine Type Communication (mMTC): Connection density as high as 10^6 per square km with extended battery life over a wide coverage area*

5G will not only enhance the end user experience but will also have a revolutionary impact on enterprises. The 3GPP, as part of its specifications compared to LTE, added both new spectrum and wider bandwidths ranging from a minimum of 5 MHz to 100 MHz for sub 7 GHz spectrum, and channel sizes of 50 MHz to 400 MHz for frequency range above 24 GHz.

For operators to deliver on the promise of 5G, it is vital that regulatory bodies ensure timely spectrum availability across low, mid, and high spectrum. Exclusive license spectrum over wide geographical area with high power is required. 5G offers a wide array of use cases that require these larger bandwidths. Scalability must be ensured as 5G adoption grows, which will require additional spectrum to be available for these services across all low, mid, and high bands.

In addition, there are several viable bands in North America that may provide guidance to other administrations when considering spectrum allocations for 5G. Following this section, an in-depth review of important mid-band activities will be covered, followed by information on coexistence between 5G in C-band and aviation altimeters in 4200 – 4400 MHz.

2. Current Landscape of Spectrum

Spectrum can often be categorized into three ranges:

- *Low bands: Sub-1GHz supports wide area coverage and indoor coverage. It brings 5G benefits to urban, suburban, and rural areas. However, low band spectrum is crowded with existing applications and cannot meet all promised 5G characteristics.*
- *Mid bands: 1 – 6 GHz provides balanced coverage and capacity. It is critical that more spectrum be made available to accommodate the vast variety of use cases 5G can serve.*
- *High bands: mmWave such as 24/26/28/37/39/47/66-71 GHz provides high capacity and ultra-high speeds but lacks coverage and indoor penetration.*

2.1 Spectrum Usage in North America

The major licensed spectrum bands currently in use in North America are summarized in Figure 2.1.

Fig. 2.1. Spectrum in use in North America

Spectrum Type	USA	Canada	Mexico
Low-band - FDD	600 MHz, 700 MHz, 800 MHz SMR, 850 MHz	600 MHz, 700 MHz, 800 MHz SMR, 850 MHz	700 MHz, 800 MHz, 850 MHz
Mid-band - FDD	1900 PCS, AWS, 2300 WCS	1900 PCS, AWS, 2300 WCS, 2.5 GHz	1900 PCS, AWS, 2.5 GHz
Mid-band - TDD	2500 MHz, 3.5 GHz	2500 MHz, 3500 MHz	2500 MHz, 3400 – 3600 MHz (FWA)
High-band - TDD	24 GHz, 28 GHz, 37 GHz, 39 GHz, 47 GHz		

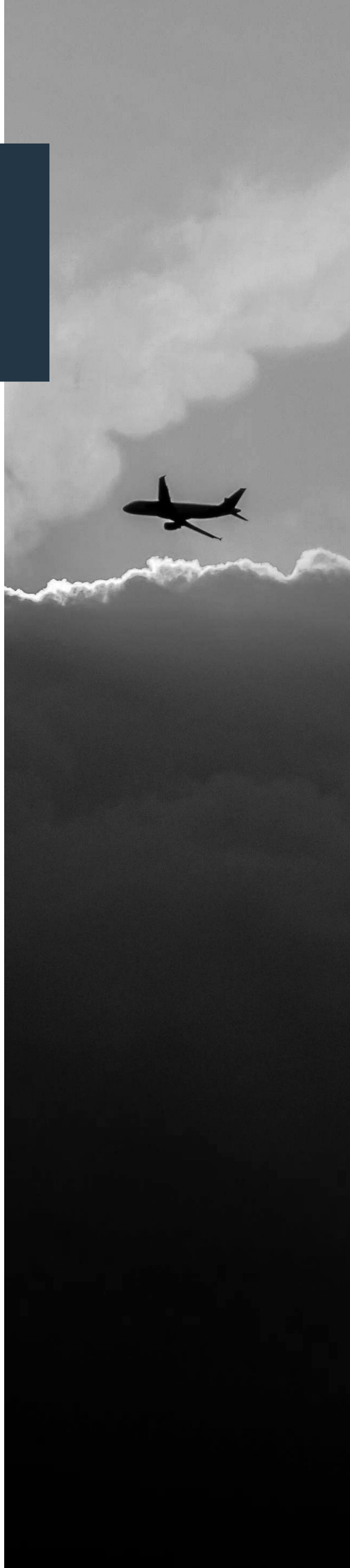


Fig. 2.2. Spectrum bandwidth (MHz) available in US for LTE/NR transmission

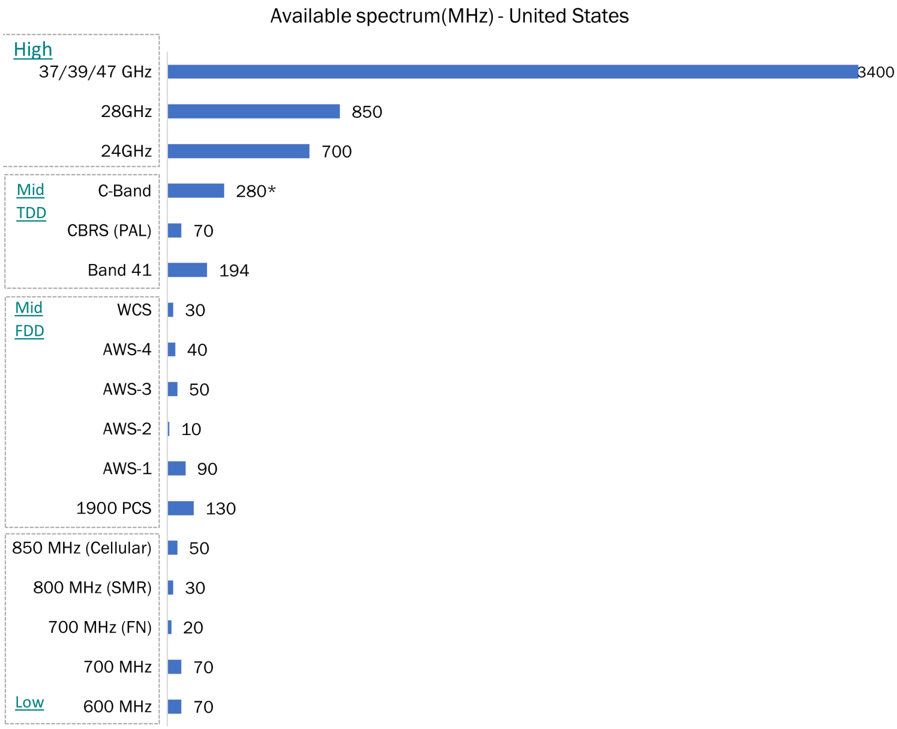


Fig. 2.3. Spectrum bandwidth (MHz) available in US for unlicensed and shared use

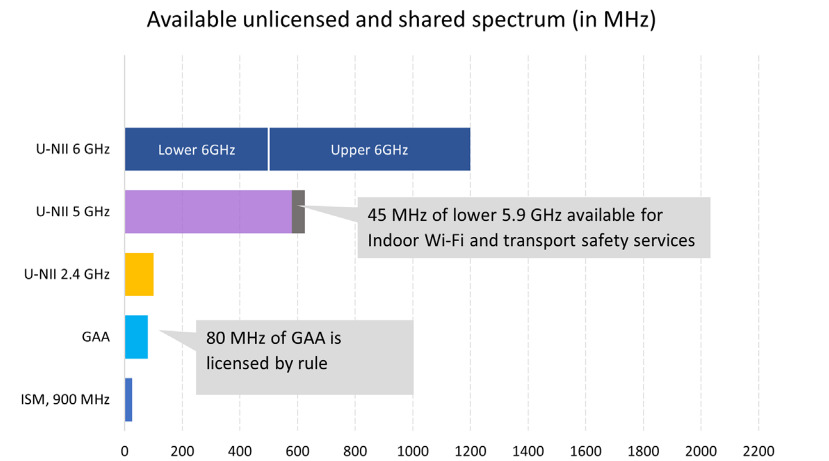
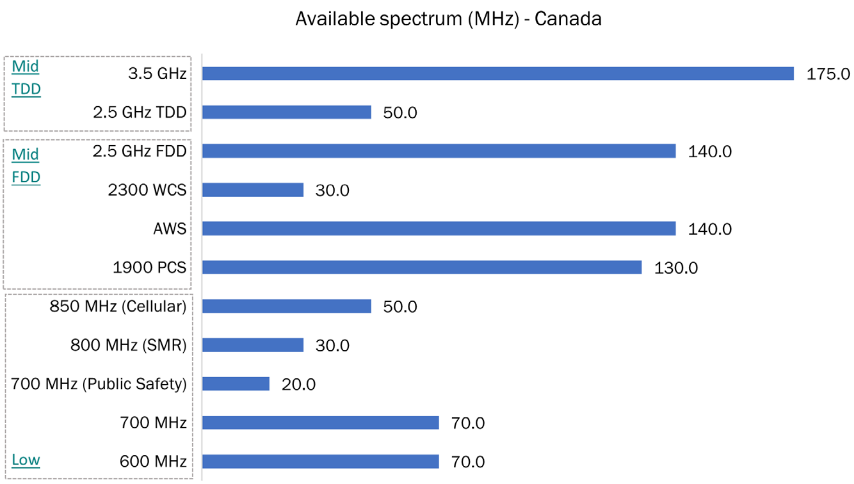


Fig. 2.4. Spectrum bandwidth (MHz) available in Canada for LTE/NR transmission



2.1.1 United States

The FCC has made all three categories of spectrum available. Figures 2.2. and 2.3. provide details on the amount of spectrum available for commercial deployments.

2.1.2 Canada

Figure 2.4. is a representation of bands available in Canada.

2.1.3 Mexico

Figure 2.5. is a representation of bands available in Mexico.

More LTE bands will be re-purposed as 5G deployments advance and mature. However, since LTE continues to be the dominant technology in North America, large swaths of LTE bands cannot be re-farmed which necessitates new spectrum to deliver on the 5G promise.

2.2 Recent Auction and Activities

Regulatory bodies throughout North America have been actively working towards introducing new bands to support 5G. However, there is more work needed to ensure that the vision of 5G can be achieved. Licensed spectrum with full power is crucial for an operator's ability to deploy with flexibility and enable a truly connected society.

2.2.1 United States

There has been an extensive push towards allocation of spectrum for 5G broadband services in the U.S. During the last couple of years, the FCC has paved the way for Americans to receive 5G wireless services by releasing both mid-band and high-band spectrum. The recent C-band (3700 – 3980 MHz) spectrum auction was the biggest auction in FCC history.

In 2020, 350 MHz of spectrum in FR1[4] (CBRS & C-Band) and 3.4 GHz in FR2[5] (37, 39 & 47 GHz) were auctioned.

Fig. 2.5. Spectrum bandwidth (MHz) available in Mexico for LTE/NR transmission

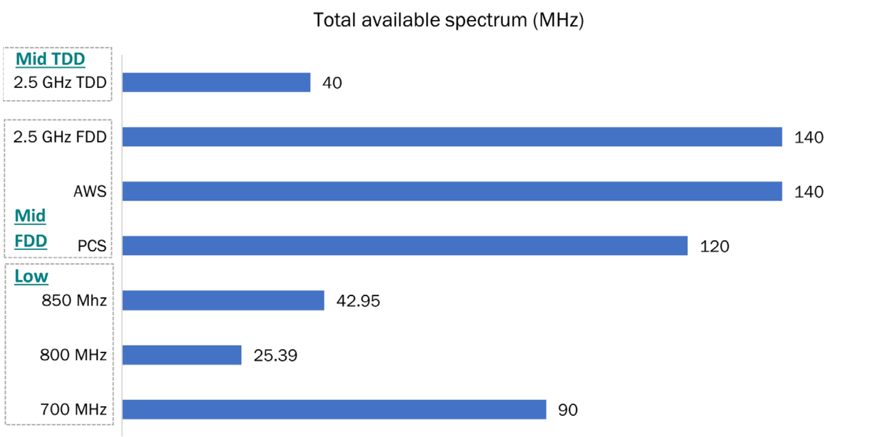
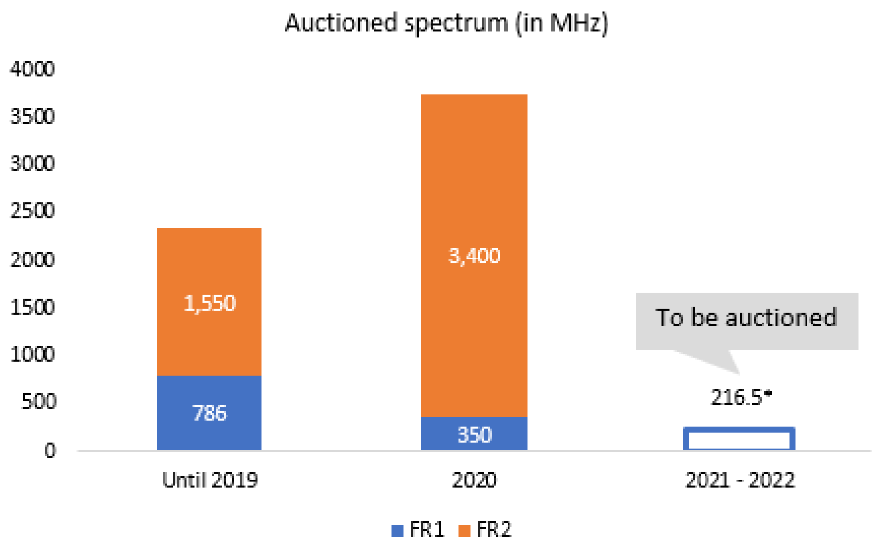


Fig. 2.6. Spectrum auctioned in US to date



Note * EBS 116.5 MHz will not have nationwide availability.

- *CBRS Priority Access Licenses (PAL) were made available in April 2021. Each license is valid for 10 years and spans a 10 MHz unpaired channel. Licenses can be aggregated to form up to 40 MHz. Access will be managed by the following factors:*
  - » *Spectrum Access System (SAS), an automatic frequency coordinator*
  - » *Environmental Sensing Capability (ESC)*
  - » *Incumbents will receive protection from harmful interference from PAL & GAA users*
- *C-Band will be available in phases according to the accelerated schedule:*
  - » *Phase 1: 100 MHz by December 2021 in top 46 PEAs*
  - » *Phase 2: 180 MHz in top 46 PEAs, 280 MHz in rest by December 2023*

Fig. 2.7. CBRS Band plan

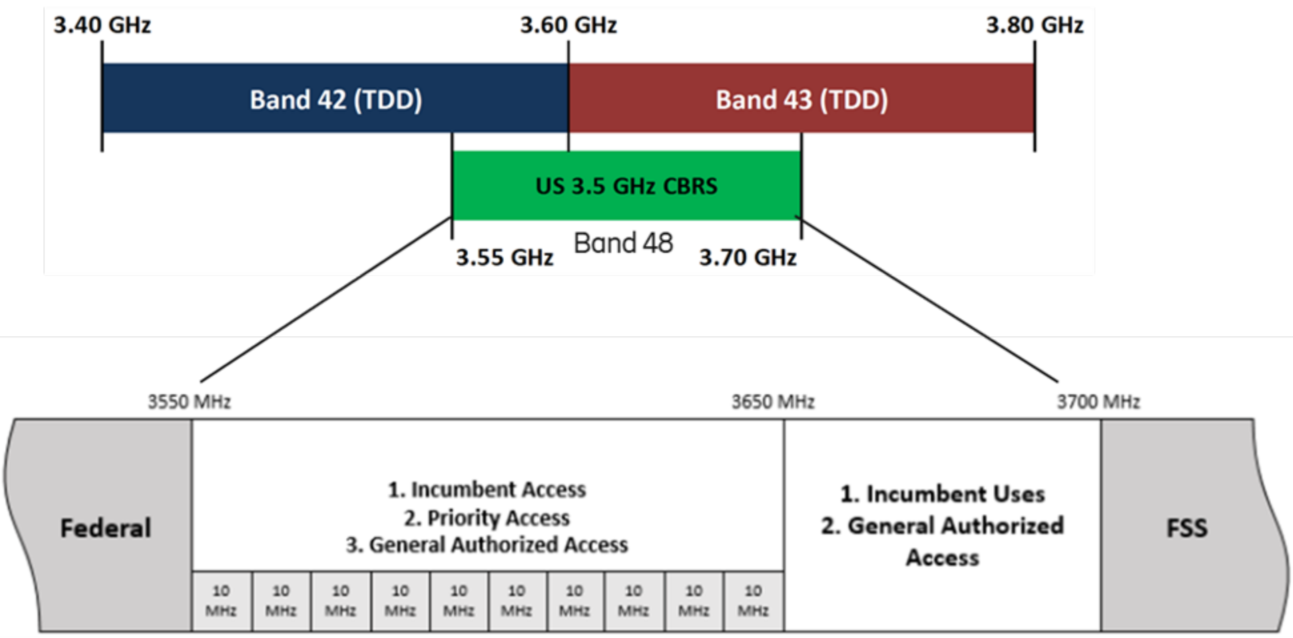


Fig. 2.8. C Band plan

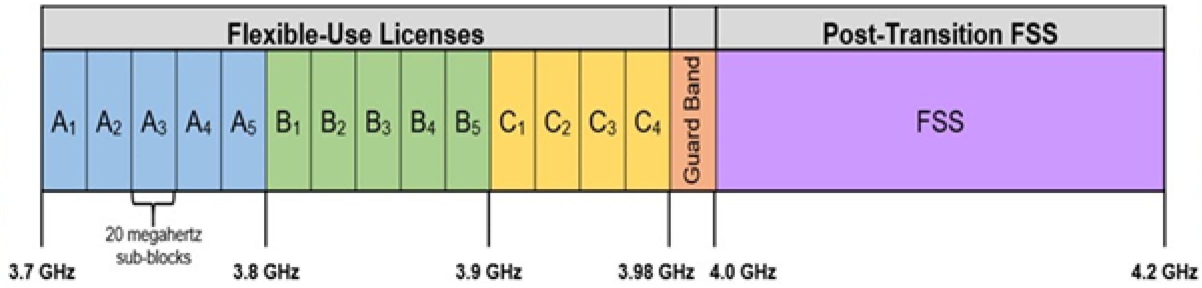
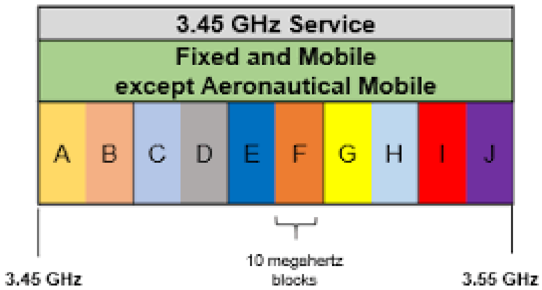


Fig. 2.9. 3.45 GHz band plan



Fourteen unpaired channels of 20 MHz each have been made available on PEA-basis; and each license is valid up to 15 years.

In 2021, 216.5 MHz of spectrum is expected to be auctioned for 5G services:

- *100 MHz in 3.45 GHz band (3450 – 3550 MHz)[6]: 4,060 flexible use licenses consisting of ten unpaired channels of 10 MHz each will be made available for commercial. Current incumbents include federal operations which will be relocated below 3450 MHz, except at certain DoD locations where some coordination is expected with DoD.*

The 3450 MHz band is expected to be available in 2022. Figure 2.10. shows the updated spectrum map post-auction:

Fig. 2.10. 2022 Spectrum availability

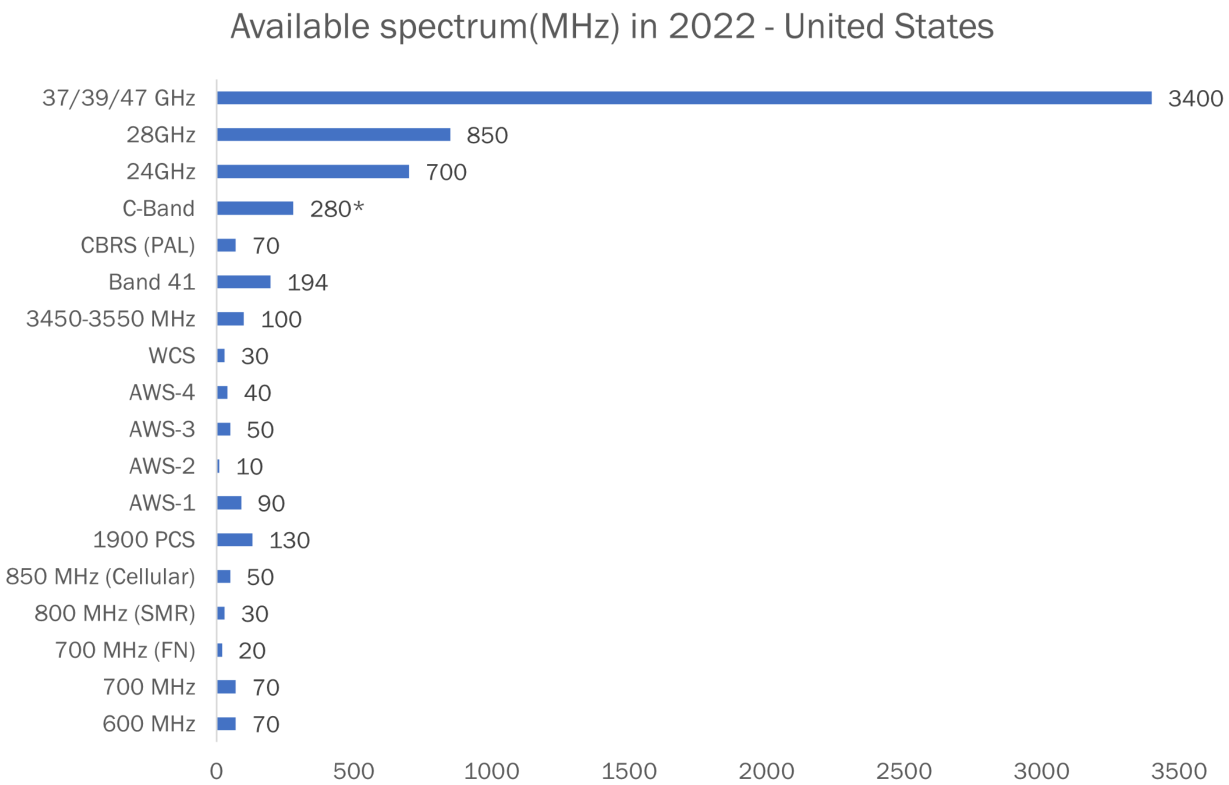
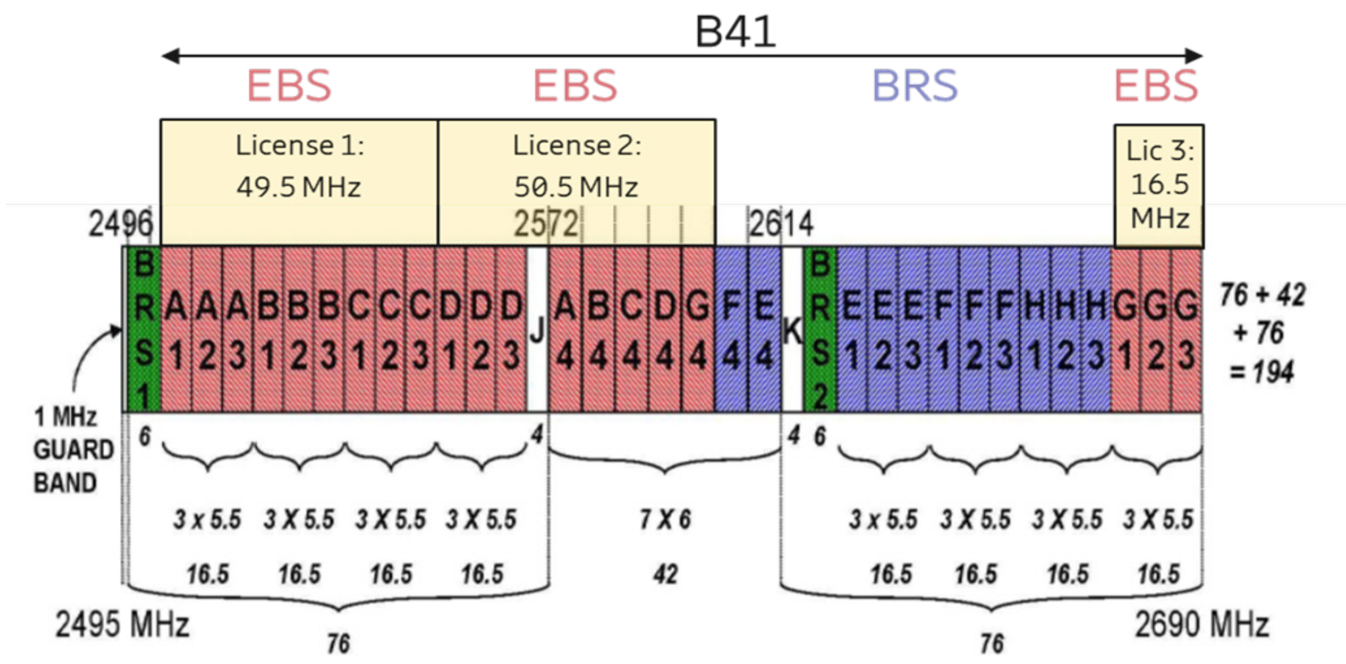


Fig. 2.11. EBS Whitespace band plan



Note * Complete C-Band availability (280 MHz) will be in December 2023.

- *116.5 MHz of Educational Broadband Service (EBS) white spaces includes three blocks of 2500 MHz spectrum:*
  - *two 50 MHz blocks (49.5 MHz + 50.5 MHz)*
  - *one block of 16.5 MHz*

These will be auctioned by counties with 8,300 licenses being made available. This spectrum will include those parts surrounding the current incumbent holdings. Ultimately, the spectrum may not cover entire counties and will have limited availability.

2.2.2 Canada

Canada's regulatory body (Innovation, Science and Economic Development Canada, or ISED) has also been active in identifying and designating new spectrum for 5G broadband services. In June 2018, ISED released Spectrum Outlook 2018 to 2022[7] which included plans to release spectrum that would support 5G services. The Outlook indicated releasing the 3450 – 3650 MHz band, which is a key band for 5G.

In May 2021, ISED made decisions on the technical and policy framework for the 3650 – 4200 MHz band, and changes to the frequency allocation of the 3500 – 3650 MHz band.[8]

- *ISED adopted a flexible use licensing model for fixed and mobile services in the 3650 – 4000 MHz band, which will provide ISED with the ability to issue flexible licenses in this frequency range.*
- *ISED added a primary mobile service, except aeronautical mobile, allocation to the 3700 – 4000 MHz band in the CFTA with a guard band of 20 MHz to protect FSS operations.*
- *3650 – 3980 MHz will be divided into 33 blocks of 10 MHz.*
- *The clearing date for Wireless Broadband Services (WBS) in 3650 – 3700 MHz & Satellite is set for March 31, 2025.*
- *The 3800 MHz auction is set for the first quarter of 2023.*

Fig. 2.12. 3800 MHz band plan

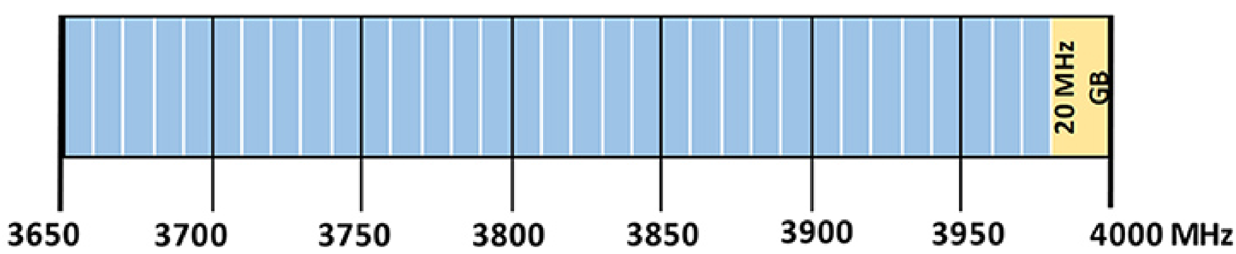
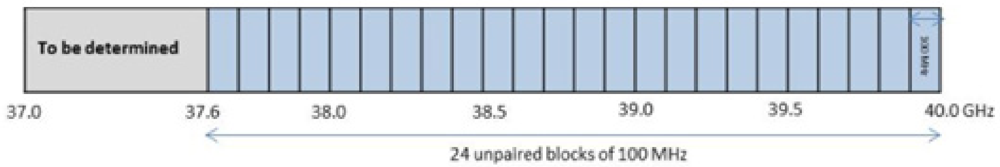


Fig. 2.13. 26.5 – 28.35 GHz band plan

Fig. 2.14. 37.0 – 40 GHz band plan



Auctions to be held in 2020 but postponed include:

- *200 MHz of spectrum in 3500 MHz band (3450 – 3650 MHz) will be reauctioned. Currently, the majority is held by Inukshuk. This auction of 3450 – 3650 MHz spectrum began in June.*
- *High band (mmWave)[9]: mmWave auctions are to be held in first quarter of 2024.*
  - » *26 GHz: coexistence between flexible use stations & fixed satellite stations (FSS)*
  - » *28 GHz: coexistence between flexible use stations & FSS*
  - » *37 – 40 GHz: band to be shared with space research service (SRS) & mobile satellite service (MSS)*
  - » *64 – 71 GHz: ISED will designate this band for license-exempt operations on a no interference, no protection basis.[10]*

2.2.3 Mexico

5G service has not been launched in Mexico yet. The 3500 MHz band was re-farmed, giving contiguous spectrum to the three operators (AT&T, Axtel and Telmex) that already own spectrum in that band. As a result, Telmex transferred spectrum in 3500 MHz to Telcel. Telcel now has access to the 3450 –3500 MHz band, and bought Axtel´s spectrum in the 3500 – 3550 MHz range. AT&T will use 3550 – 3600 MHz frequencies. These frequency bands can only be used for fixed services.

Currently, there are only 100 MHz (3350 – 3450 MHz) available for mobile services. The Federal Institute of Telecommunication (IFT) is working towards the addition of 50 MHz from 3300 – 3350 MHz. IFT identified 11.2 GHz of spectrum for 5G, but is also considering 600 MHz, 2300 MHz, and 3400 MHz. Spectrum in high bands has also been identified for potential use (26 GHz, 39 GHz, 42 GHz, 47 GHz, and 51 GHz). The 700 MHz spectrum had special treatment; the full band was given to a wholesale operator (Altan/Red Compartida) who started offering services in March 2018, while 120 MHz of the 2500 MHz band was allocated to AT&T Mexico and Telefonica for 4G services.

In August 2020, IFT initiated a public consultation of a potential spectrum auction for remaining spectrum in the 800 MHz (814 – 824/859 – 869 MHz, 20 MHz), AWS (1755 – 1760/2155 – 2160 MHz, 10 MHz), PCS (1910 – 1915/1990 – 1995 MHz, 10 MHz), and 2500 MHz (2500 – 2530/2620 – 2650 MHz, 60 MHz) that will include some national and regional blocks. This translated into the current IFT-10 Bidding that started in February 2021. Current mobile operators cannot participate in the first phase. All operators are allowed to participate if spectrum is still available after this process.

This IFT-10 process is different from the 600 MHz, L-Band, and 3500 MHz (3300 – 3450 MHz) spectrum offering that would start by end of 2021. Information about the rules of this tender is not available yet.

IFT has identified the following frequencies as 5G spectrum: 70 MHz in 600 MHz, 90 MHz in 700 MHz, 180 MHz in 2600 MHz, 300 MHz in 3500 MHz, 2850 MHz in 26 GHz, 3,000 MHz in 38 GHz, 1500 MHz in 42 GHz, 1000 MHz in 48 GHz, and 2200 MHz in 51 GHz band. The government is expected to move forward with the mmWave bands after IFT-10 bidding and the potential IFT-11 bidding that includes spectrum in 600 MHz, L-Band, and 3500 MHz.

Two key developments in Mexico:

- *Mid-bands: For IMT, the government plans to identify only 300 MHz (from 3300 to 3600 MHz). The first 150 MHz is for mobile services while the second 150 MHz are currently for fixed services. The government must change the license condition in order to offer mobile services. The rest of the band above 3600 MHz is for satellite services, and the Mexican government is very keen on maintaining that status. There is considerable discussion and pressure to identify the entire 6 GHz for unlicensed use. There would only be 300 MHz in the mid bands for 5G if this is the IFT's ultimate decision.*
- *Telefonica's decision to become an MVNO: Telefonica reached an agreement with AT&T to use their spectrum, and another agreement with the government to return its spectrum. Telefónica has already given back spectrum in 2500 MHz as well as part of 850 MHz and PCS. The plan is currently under the execution phase and expected to be completed by June 2022. This development means that perhaps only AT&T and Telcel are interested in the spectrum.*

2.3 Future Spectrum Pipeline for 5G in the United States

2.3.1 The 2.5 GHz band

The 2.5 GHz band (2496 to 2690 MHz) is comprised of 194 MHz of spectrum. Of that, 117.5 MHz of this is designated for Educational Broadband Service (EBS), and 76.5 MHz for Commercial Broadband Radio Service (CBRS). The FCC rules allowed EBS licensees to lease their excess capacity to non-educational entities, and most EBS licensees do so.

Earlier this year, the FCC announced an auction for overlay licenses in the 2500 MHz band under Auction 108. This auction will offer about 8300 geographic overlay licenses for unassigned spectrum in the 2500 MHz band. The 49.5 MHz, 50.5 MHz, and 16.5 MHz blocks will be offered and licensed on a county basis. While there are many licenses, the history of the 2500 MHz band creates a unique situation where each overlay license will be different; the amount of white space and population covered is not always obvious.

New overlay licenses in the EBS portion of the 2500 MHz band will be issued for ten-year, renewable license terms. A licensee in this band may provide any services permitted under terrestrial fixed or mobile allocations. Incumbents' licenses cover a 35-mile radius because the EBS spectrum was originally licensed as circular Geographic Service Areas with a 35-mile radius. The auction is for EBS whitespaces licenses. Auction 108 licensees may operate anywhere within its geographic area, subject to protecting the licensed areas (i.e., circular Geographic Service Areas with a 35-mile radius) of incumbent licensees.[11]

2.3.2 3.1 – 3.55 GHz Band

Currently, the entire 3100 – 3550 MHz band is allocated for both federal and non-federal radio location services. The Department of Defense (DoD) operates high-powered defense radar systems on fixed, mobile, shipborne, and airborne platforms in this band. These radar systems are used in conjunction with weapons control systems and for the detection and tracking of air and surface targets. The DoD also operates radar systems used for fleet air defense, missile and gunfire control, bomb scoring, battlefield weapon locations, air traffic control, and range safety. The shipborne radars operate at over twenty ports and along the entire Atlantic, Pacific, and Gulf coasts. Some of the airborne systems operate nationwide, while other systems are limited to four locations. The ground-based radars operate at over one hundred locations, with many located near high-population areas.

The Federal Communications Commission (FCC) is working with National Telecommunications and Information Administration (NTIA) to create additional opportunities for commercial purposes within the band.

2.3.2.1 The 3.45 GHz band (3450 – 3550 MHz)

The 3.45 GHz band comprises the upper 100 MHz of the 3100 – 3550 MHz band below the CBRS band (3550 – 3700 MHz). The FCC has scheduled an auction of additional mid-band airwaves in October of this year for 100 MHz of spectrum at 3450 – 3550 MHz.

The DoD and NTIA have identified radar locations that need protection and coordination with wireless services. There are several radar manufacturing and integration facilities that need access to the 3450 MHz spectrum for experimentation and testing for federal systems. These facilities typically operate outdoors because of the size of the systems. The NTIA has determined required coordination areas around some of the radar sites. The radius of these areas is in range of 38 to 95 km, which is significant considering that some of these radar locations are close to high population areas. It should be noted that these radii have been determined based on certain assumptions about 5G deployment configurations around these sites. More interaction between wireless interests and DoD is necessary to find ways of minimizing the extent of coordination areas during the upcoming months prior to the auction, and possibly during the time between the auction and award of licenses.

3300 – 3450 MHz presents another opportunity for adding another 150 MHz to mid-band.

2.3.3 1300 – 1350 MHz Band

Currently, 30 MHz of the 1300 – 1350 MHz band is targeted by the NTIA & FCC for clearance. The 1300 – 1350 MHz band is used by federal agencies for operating various types of long-range radar systems that perform missions critical to safe and reliable Air Traffic Control (ATC) in the national airspace, border surveillance, early warning missile detection, and drug interdiction. A multi-agency initiative is underway to explore the feasibility of altering the Federal Aviation Administration's (FAA) long-range radars operating in the 1300 – 1350 MHz sub-band, which could include relocating them to another band.

While it is too early in the process to reach conclusions, relocating these radars from the band would likely significantly improve the potential for sharing with commercial service. In fact, the federal agencies involved in the initiative propose utilizing funds from the Spectrum Relocation Fund to study the possibility of relocation consistent with the Spectrum Pipeline Act of 2015. Congress has already directed that at least 30 MHz of low band spectrum be auctioned for license use by 2024, and that the national spectrum strategy should announce at least 100 MHz of low band spectrum be auctioned by 2024. The 1300 MHz band would provide 50 MHz of spectrum for next generation wireless services, and the proceeds of that auction will help the FAA and other incumbent users to modernize radar and related systems.[12]

2.3.4 1780 – 1830 MHz

As of March 2012, more than 20 federal agencies utilized more than 3,100 individual frequency assignments in the 1755 MHz – 1850 MHz band. Primary uses of the band included fixed point-to-point microwave, military tactical radio relay, air combat training systems, precision guided munitions, tracking telemetry and commanding, aeronautical mobile telemetry, video surveillance, unmanned aerial systems, and other DoD systems including electronic warfare, software defined radio, and tactical targeting networking technology.

In 2014, the 1755 MHz – 1780 MHz band was auctioned for commercial use as part of the AWS-3 auction, providing important experience working with these agencies on reallocating and sharing such spectrum-based systems. After the auction, some systems operating over the entirety of the 1755 MHz – 1850 MHz band were being re-tuned to operate solely in the 1780 MHz – 1850 MHz portion of the band. Therefore, it is important to determine how to work with the federal systems in the 1780 – 1830 MHz segment if it is to be made available for future cellular use. The 1700 MHz band is 50 MHz directly adjacent to the AWS-3 spectrum that was auctioned in 2015 and offers great synergies with existing wireless offerings. There is good understanding by both commercial and government users of the affected government systems, which will help facilitate a smooth transition.[13]

2.3.5 4800 MHz

This band represents a significant amount of additional mid-band spectrum. The 4800 – 4990 MHz is a WRC-23 agenda item (AI1.1) that reflects the growing worldwide interest in the 4400 – 4990 MHz spectrum range for IMT. China has identified 4800 – 5000 MHz band for 5G, and it is expected that other countries will identify spectrum in this frequency range for IMT. The 4800 – 4990 MHz band is part of 4.4 – 5.0 GHz, which is a NATO Class A band. The 4400 – 4990 MHz band is also adjacent to altimeters in the 4200 – 4400 MHz band. Studies will be performed in the ITU-R as part of AI1.1 (4800 – 4990 MHz) to determine the appropriate mechanism to ensure protection of stations of the aeronautical and maritime mobile services located in international airspace and waters.

The 4400 – 4940 MHz band is primarily used by the US federal government for fixed and mobile services. The point-to-point data links can be fixed or transportable-fixed with dual capability of line-of-sight (LOS) operations at low power or trans-horizon modes for high power for long distance communications. Mobile applications in the band include air-ground operations to support Unmanned Aerial Vehicles (UAVs), target drones and flight test operations, flight telemetry and aeronautical telemetry for video/ data downlinks, and wireless bridge networks. The band 4500 – 4800 MHz (space-to-Earth) is used by non-federal fixed-satellite service providers and is limited to international inter-continental systems.

The FCC adopted its Sixth Report and Order and Seventh Further Notice of Proposed Rulemaking in the 4900 MHz (4940 – 4990 MHz) proceeding to adopt rule changes that would allow commercial use of this Public Safety band, under certain condition.[14] The FCC is currently reviewing petitions for reconsideration.[15]

2.3.6 7125 – 8500 MHz

In the U.S., this band is primarily a federally allocated band for either fixed service or satellite. However, the use of the band for fixed assignments in the 7125 – 8500 MHz has been declining. The federal agencies use this band mostly for fixed point-to-point microwave communication systems for national and military test range communications, the remote transmission of radar video and other data for functions such as weather, vessel traffic control in harbor areas, and hydroelectric grid power management. This includes the Federal Aviation Administration use of this band for fixed point-to-point microwave communications networks to connect remote long-range aeronautical radio-navigation radars to air traffic control centers.

This band is also used for Fixed Satellite and Mobile-Satellite Service. Military agencies operate the Defense Satellite Communications Systems (DSCS) series of geostationary satellites (s-e) in this frequency band. The DSCS provides federal agencies with secure jam-resistant communications for applications including command and control, crisis management, intelligence, early warning detection, and diplomatic communications. Military agencies also operate the Wideband Gapfiller Satellite (WGS) in this band. The Air Force uses this band for the space tracking and telecommand of communications satellites. Fixed satellite use in 7250 – 7750 (500 MHz, Downlink)/7900 – 8400 (500 MHz Uplink) includes DSCS and the WGS.

The feasibility of introducing flexible use in this band looks promising, but more study is needed to characterize its use. Currently, spectrum occupancy measurements taken in three cities in the U.S. indicate generally low usage of the band. In his statement outlining his 5G spectrum priorities, FCC Commissioner Carr cited that he foresees the lower 3000 MHz band, 4800 MHz, 7125 – 8400 MHz, and spectrum above 95 GHz (including terahertz bands that could be useful in 6G) as main priorities for FCC action beyond the year 2022. From an international perspective, these frequencies are also primarily allocated to fixed, mobile, fixed satellite services (FSS) and mobile satellite services (MSS).

FCC Commissioner Carr's recent keynote remarks discussing extending America's 5G leadership also mentioned this band. According to him, federal agencies have been collecting information about their operations in this band with a report due back to NTIA following a 2018 directive. With some additional legwork this year and next, this operation will be well positioned to reallocate portions of this band for commercial 5G operations. This is one of the key spectrum bands being focused after 2022.[16]

2.3.7 37.0 – 37.6 GHz

The 37.0 – 37.6 GHz is the lower band segment of the 37 GHz (37.0 – 38.6 GHz) band. The entire 37 GHz band is allocated to the fixed and mobile services on a primary basis for federal and non-federal use. Portions of the 37 GHz band are also allocated to the Space Research Service (SRS) (space-to-Earth) on a primary basis for federal use (37 – 38 GHz) and to the Fixed-Satellite Service (FSS) (space-to-Earth) on a primary basis for non-federal use (37.5 – 38.6 GHz). The use of this FSS downlink allocation is limited to individually licensed earth stations and is also subject to other limitations. The lower band segment will be fully available for use by both federal and non-federal users on a coordinated co-equal basis. Non-federal users, identified as Shared Access Licensees (SAL), will be authorized by rule. Federal and non-federal user's access to the lower portion has not been determined yet. From a coordination standpoint, there are 14 military sites and three scientific sites across the 37 GHz band, and the possibility for federal agencies to add future sites on a coordinated basis.

The third millimeter wave (mmW) Further Notice of Proposed Rulemaking (FNPRM) proposed a few coordination mechanisms, but a fully developed coordination mechanism requires further study along with government and industry collaboration.

In July 2016, the FCC issued a Report & Order adopting new service rules permitting non-federal fixed and mobile terrestrial operations in the 37.0 – 38.6 GHz band (37 GHz). The Commission coined the new service in this band and other mmWave spectrum the "Upper Microwave Flexible Use Service" (UMFUS). The Report and Order also adopted a band plan that allows for continuity of commercial operations between the 37 and 39 GHz bands, while protecting federal uses and creating a path for their future use.

2.3.8 42 GHz

The 42.0 – 42.5 GHz band (42 GHz band) consists of 500 MHz allocated to non-federal fixed and mobile services on a primary basis, and it contains no current federal allocation or service rules. The adjacent 42.5 – 43.5 GHz band is allocated to the Radio Astronomy Service (RAS) on a primary basis for federal and non-federal use and to the federal fixed, fixed-satellite (Earth-to-space), and mobile except aeronautical mobile services on a primary basis. In its Third Report and Order, Memorandum Opinion and Order, and Third Further Notice, the FCC sought comments on including the 42 GHz band in the Part 30 UMFUS Rules. This would enable the use of this band together with the existing 37 GHz and 39 GHz bands. International consideration of this band for mobile use, and the availability of 500 MHz of unassigned spectrum support the conclusion that this band is suitable for flexible use.

2.3.9 26 GHz (25.25 – 27.5)

This band is part of the spectrum frontiers proceeding and the FCC has sought comment on its use for UMFUS. However, the FCC has taken no action on the band yet. The 26 GHz band could be suitable for flexible fixed and mobile use, as the FCC has proposed. It is adjacent to the 24 GHz and 28 GHz bands, which the FCC has already allocated for fixed and mobile use. The amount of spectrum potentially available (over two GHz) could make this band a useful addition to 5G and it is a priority band for 5G in several regions around the world, including Europe. In the federal column of the U.S. Table of Allocations, the entire 25.25 – 27.5 GHz band has primary allocations for Fixed (FS), Mobile (MS), and Inter-Satellite (ISS) services, with Inter-Satellite limited to space research and Earth exploration-satellite applications in addition to transmissions of data originating from industrial and medical activities in space. The 25.5 – 27.0 GHz band has a primary allocation for both federal and non-federal Space Research service (SRS) (space-to-Earth) with non-federal Earth Exploration-Satellite Service (EESS) subject to case-by-case electromagnetic compatibility analysis. Suitable sharing or protection arrangements with incumbents in the band need to be worked.

2.3.10 Above 95 GHz

On March 19, 2019, the FCC's First Report & Order (R&O) took steps to provide new opportunities for innovators and experimenters to push the boundaries even further, and to develop new equipment and application for spectrum between 95 GHz and 3 THz. The rules adopted in the First R&O permit enhanced experimental licensing and unlicensed applications (116 – 123, 174.8 – 182, 185 – 190, 244– 246 GHz) within this spectrum band. The FCC is taking the appropriate first steps towards developing the bands above 95 GHz by providing new experimental licensing opportunities and making spectrum available for unlicensed use. The FCC expects to gain knowledge from real-world operations that will inform the Commission's future consideration of more expansive use (including nonexperimental licensed uses) in these spectrum bands.[17]

Currently in the U.S., the frequency range 95 – 275 GHz is divided into 40 frequency bands that are allocated for federal/non-federal shared use. The FCC authorized use of these frequencies is currently limited. It consists of industrial, scientific, and medical (ISM) devices, amateur radios operations in a small segment of the band, and transitional radio experiments under Part 5 experimental licensing rules. Unlicensed operations of intentional radiators under Part 15 are explicitly prohibited in these bands.

2.3.11 12.2 – 12.7 GHz (500 MHz)

The 12.2 – 12.7 GHz band is encumbered by Fixed Satellite Service (FSS), non-geostationary orbit systems (NGSO), Direct Broadcast Satellite (DBS), and Multi-Channel Video and Data Distribution Service (MVDDS) which makes flexible use difficult (500 MHz). In the United States, there are three services authorized and operating in this band: DBS providers operating under the primary Broadcasting Satellite Service (BSS) allocation, MVDDS licensees operating on a non-harmful interference basis to DBS under the co-primary fixed service allocation, and NGSO licensees operating on a non-harmful interference basis to DBS under the co-primary NGSO Fixed Satellite Service (FSS) (space-to-Earth) allocation. The Commission's rules enable sharing between co-primary NGSO FSS and MVDDS using a combination of technical limitations, information sharing, and first-in-time procedures.

In 2016 and 2017, proponents of NGSO FSS systems sought Commission authority for planned constellations of hundreds or thousands of small satellites using several frequency bands, including the 12 GHz band. In 2017, the Commission updated its rules to enable the deployment of these emerging systems. Today, two U.S.-licensed DBS providers, DISH Network L.L.C. (DISH) and DIRECTV (AT&T), use the band throughout the U.S. to provide DBS directly from geostationary-orbit (GSO) satellites to relatively small dish antennas at tens of millions of individual homes and businesses. DIRECTV and DISH Network had over 22 million combined subscribers as of the third quarter of 2020. Meanwhile, eight companies (10 legal entities) currently hold 191 of 214 MVDDS licenses.

In April 2016, the MVDDS 5G Coalition, which included eleven of the twelve MVDDS licensees at that time, filed a Petition for Rulemaking requesting reforms to the rules for the 12 GHz band to essentially add a mobile allocation to the band allowing two-way, point-to-point, or mobile broadband service at higher power.

In 2021, the FCC released a NPRM[18] seeking comment on whether regulatory changes could be implemented to increase opportunities for shared use of the band while protecting the many incumbents from harmful interference. Reply comments in the record were due May 7, 2021.

3. Review of Mid-band Spectrum for 5G

According to new research from the Boston Consulting Group (BCG) in collaboration with Cellular Telecommunications Industry Association (CTIA), 5G deployment will contribute $1.4 trillion to $1.7 trillion to U.S. GDP, and create 3.8 million to 4.6 million jobs in the next decade. This growth will occur directly through infrastructure investment, and indirectly by enabling innovation that transforms all sectors of the economy.

5G will unlock benefits across the US and will reach broadly into densely populated cities, and communities with lower population densities. Over time, the regional effects of 5G will be far-reaching as innovation enables new use cases across all industries from agriculture, to manufacturing and health care.

To bring these benefits to fruition, state, local, and federal governments must work to keep 5G rollout on track. That means policymakers, regulators, and the private sector should continue working toward additional licensed spectrum (particularly in the mid-band range), smarter and more efficient deployment policies, and a strong talent pipeline focused on encouraging upskilling of the workforce and attracting the best talent from across the globe.[19]

A framework of choice for mid-band spectrum will be one that promotes speedy, efficient, and more widespread deployments. A new engineering analysis by Rysavy Research[20] illustrates that full-power operations will speed 5G deployment, and more efficiently enable broader 5G suburban and rural coverage. Higher power levels ensure a robust 5G deployment in suburban and rural areas.

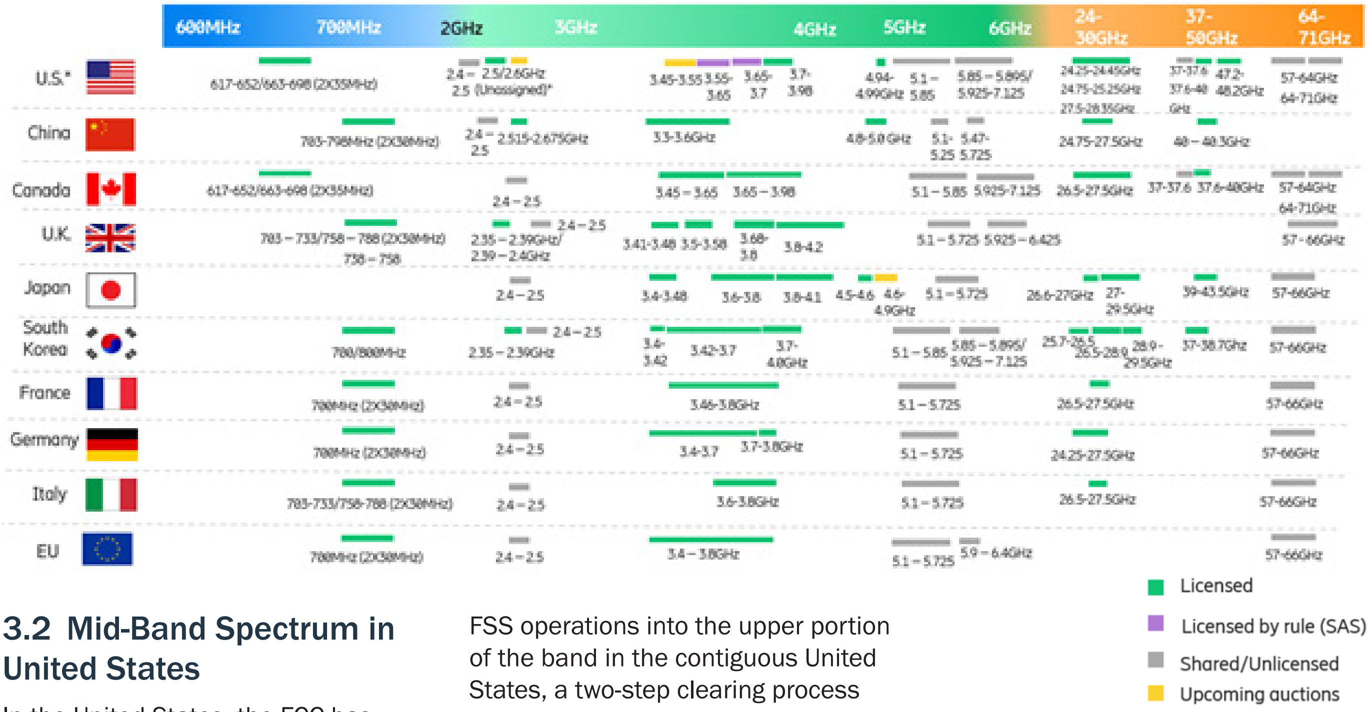
A global majority of countries are harmonizing their use of mid-band spectrum to international standards, such as using 3300 – 4200 MHz (3GPP band n77) and 3300 – 3800 MHz (3GPP band n78). By harmonizing with international standards, countries will benefit from global economies of scale for both infrastructure and subscriber equipment. The recent C-band auction with framework set by the FCC provides high-power, large licensing areas, and minimal coordination requirements. This is a testament to how such an approach is hugely attractive to the industry. At its conclusion, the reached a record of $81.16 B (excluding relocation costs) and became the largest ever spectrum auction to be held by the FCC.

3.1 Global Landscape of Mid-Band 5G Deployments

At a high level, the global landscape of mid-band 5G deployments focuses around efforts in South Korea, China, Middle East, Japan, and Europe. The latest Global Mobile Suppliers Association (GSA) paper on mid-band spectrum discusses 105 operators as actively deploying or having launched 5G networks using band n77 or n78. There is a need to maximize geographic coverage of mid-band without any limitations, which will enable the true potential of 5G use cases. Overall, the advantage of larger channel sizes and wide channels of contiguous spectrum will enable high throughputs for a better end-user experience and provide a platform for innovation.

Figure 3.1. is a representation of the global spectrum landscape:

Fig. 3.1. Global outlook on licensed & unlicensed spectrum (low, mid, high bands)



3.2 Mid-Band Spectrum in United States

In the United States, the FCC has moved to make spectrum available for terrestrial mobile use that allows full power macro-operation in the 3450 – 3550 MHz and the 3700 – 3980 MHz bands.

3.2.1 3700 – 3980 MHz

The FCC has taken steps[21] to repurpose a portion of the 3700 – 4200 MHz band, also known as the 'C-Band', to allow the introduction of mobile services for flexible-use 5G (with the exception of aeronautical services). This band was allocated in the United States exclusively for non-federal use on a primary basis for Fixed Satellite Service (FSS) and Fixed Service (FS). FSS operators use this band to deliver programming to television and radio broadcasters throughout the country, and to provide telephone and data services to consumers. However, distribution of these broadcasting signals is declining in the C-band as other transmission technologies, for instance fiber, are being used.

To allow the introduction of 5G in this band, the FCC developed a process for repurposing the use of the spectrum by repacking existing satellite operations into the upper 200 MHz of the band, and by reserving a 20 MHz guard band. To transition FSS operations into the upper portion of the band in the contiguous United States, a two-step clearing process was decided.

First, 100 MHz (plus a 20 MHz guard band) in 46 of the top 50 Partial Economic Areas (PEAs) in the 3700 – 3820 MHz band will be clear by Dec 5, 2021. This timeframe was decided on the basis that passband filters in all earth stations would be needed that could potentially be affected by flexible use operations anywhere within the PEA. This includes earth stations that are outside of, but near enough to, the PEA to experience harmful interference.

In the second step, the remaining PEAs for the first 120 MHz (3700 – 3820 MHz), as well as an additional 180 MHz (3820 – 4000 GHz), would be transitioned off FSS operation by December 5, 2023 throughout the contiguous United States, thereby clearing a total of 280 MHz for flexible use (3700 – 3980 MHz), plus a 20 MHz guard band (3980 – 4000 MHz).

Recognizing that the 3700 – 3980 MHz band will be a core band for next generation wireless networks, including 5G, the FCC established power levels consistent with other bands used for wide area wireless operations to reach its full potential. For base and mobile stations, the out-of-band emission (OOBE) requirements were based on limits similar to other AWS services. Specifically, base stations and mobile devices will be required to suppress their emissions beyond the edge of their authorization to a conducted power level of -13 dBm/MHz.

The FCC also adopted a Power Flux Density (PFD) limit to protect registered FSS earth stations from out of band emissions from 3700 MHz Service operations. For base and mobile stations operating in the 3700 – 3980 MHz band, the PFD limit is -124 dBW/m2/MHz, as measured at the antenna of registered FSS earth stations. All 3700 MHz Service licensees will be obligated to ensure that the PFD limit at FSS earth stations is not exceeded by base and mobile station emissions, which may require them to limit mobile operations when in the vicinity of an earth station receiver.

3.2.2 3450 – 3550 MHz

The FCC has taken further steps to introduce additional mid-band spectrum that is intended to enable full-power, commercial flexible-use 5G of the 3450 – 3550 MHz band. The 3450 – 3550 MHz band is part of a larger globally harmonized band for 5G and is a subset of the 3GPP band n77 extending over the range

3300 – 4200 MHz. The use of this spectrum for 5G is consistent with the broad efforts within the International Telecommunication Union (ITU) that has allocated portions of the 3 GHz band for primary fixed and secondary mobile use in all three ITU regions. The 3450 – 3550 MHz spectrum is also part of the decision made by the European Conference of Postal and Telecommunications Administrations (CEPT) that the 3400 – 3800 MHz band be the first primary band for 5G.

In the United States the band is currently used by federal radiolocation services that operate on a primary basis with non-federal radiolocation users operating on a secondary basis. The 3500 – 3550 MHz portion of that band also is allocated for federal aeronautical radionavigation services on a primary basis. The DoD operates high and low-powered defense radar systems on a variety of platforms in the 3000 MHz band, including fixed, mobile, shipborne, and airborne operations. Between 3300 and 3550 MHz, there are seven active non-federal radiolocation licenses, which are used for several different commercial and industrial radiolocation services. For example, some licensees employ Doppler radar to provide weather information to broadcast viewers. In addition, non-federal amateur services operate in the 3300 – 3500 MHz portion of the band under a secondary allocation.

To ensure a robust deployment of 5G in this band, the FCC has adopted similar technical rules to those supported in the C-band. For instance, the transmitter output power is 1-Watt (30 dBm) Effective Isotropic Radiated Power (EIRP) for mobile devices and base stations in non-rural areas, and 1640 w/MHz EIRP and 3280 w/MHz EIRP in rural areas.

3.2.2.1 Coordination Regime (3450 – 3550 MHz)

The FCC has also recently adopted service and technical rules that are similar to the C-band, and are intended to support deployment of full power 5G systems across much of the contiguous United States. First, the FCC has allocated the 3450 – 3550 MHz band for co-primary, non-federal, fixed and mobile (except aeronautical mobile) operations nationwide. The flexible use operation in this band will have unencumbered access to the entire band with limited exceptions. Meanwhile, some federal services will be relocated from this band. In limited circumstances and in locations where current incumbent federal systems will remain in the band, non-federal systems will not be entitled to protection against harmful interference from federal operations, and limited restrictions will be placed on non-federal operations.

These remaining limited federal operations occur only in identified geographic areas specifically identified as Cooperative Planning Areas (CPA) and Periodic Use Areas (PUA). The NTIA describes these areas as key military training facilities and important test sites. Commercial operations are not precluded within Cooperative Planning Areas and Periodic Use Areas. In these Periodic Use Areas, the DoD will need episodic access to all or a portion of the band in specific, limited geographic areas where it will coordinate with affected licensees for specific times and bandwidths. Access to CPA/PUAs will require prior coordination by 5G in the band. Some of the details of the coordination framework are yet to be defined other than the use of a portal (similar to what was used for AWS-3) to facilitate access to the CPA/PUAs. More details are available in the Second Report and Order.[22]

3.3 Maximize Spectrum Available

The goal for any wireless communications regulatory body should be to maximize the spectrum availability with limited restrictions and maximum power for mobile operators. As traffic growth increases with increased penetration of 5G devices, it is imperative that regulatory bodies focus on allocation of contiguous spectrum which can facilitate channel bandwidths of up to 100 MHz for each operator in mid-band and even larger bandwidths for mmWave to support multiple 5G use cases. Doing so will facilitate networks in meeting the IMT requirements.

4. C-band Coexistence with Radio Altimeters

4.1 5G and the Aviation Altimeter Band

5G is being deployed globally in 3300 – 4200 MHz (3GPP band n77), 3300 – 3800 MHz (3GPP band n78) and 4400 – 5000 MHz (3GPP band n79). The nearby 4200 – 4400 MHz band is home to Radio Altimeters (RA) used on aircraft and helicopters worldwide.

In the U.S., the FCC first sought comment on the re-purposing of the 3700 – 4200 MHz band through a Notice of Inquiry in August 2017. On February 28, 2020, the FCC adopted the Report and Order approving use of the 3700 – 3980 MHz band for commercial wireless service. The FCC recognized that "Radio altimeters are critical aeronautical safety-of-life systems primarily used at altitudes under 2500 feet above ground level (AGL) and must operate without harmful interference,"[23] but concluded based on the public record that "well-designed equipment should not ordinarily receive any significant interference (let alone harmful interference) given these circumstances."[24] The aviation industry was active in the FCC docket, and the FCC explicitly took their comments into account when making its determination.

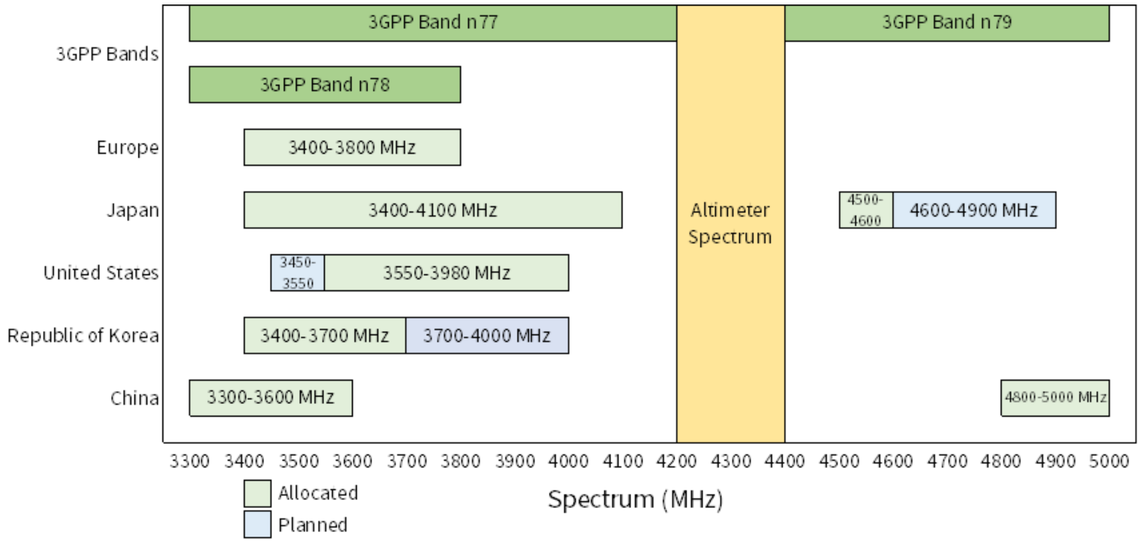
Furthermore, the FCC noted that they "expect the aviation industry to take account of the RF environment that is evolving below the 3980 MHz band edge and take appropriate action, if necessary, to ensure protection of such devices."[25]

Still, the FCC's Report and Order encouraged interested stakeholders to convene to further study coexistence of 3700 MHz Service operations with altimeters. Stakeholders then formed Technical Working Group 3 (TWG-3) for discussions on 5G and aviation coexistence. TWG-3 included representatives of 29 companies and associations across the aviation industry, wireless service providers and manufacturers, cable providers, Wireless Internet Service Providers (WISPs), and others. After the development of the scope of work for the group, TWG-3 had several calls to discuss and study the issue but was unable to reach consensus on the potential impact of 3700 MHz Service operations on existing altimeters operating in the 4200-4400 MHz band. As a result, the group did not submit any technical reports or recommendations to FCC. The TWG-3 Resolution Letter submitted to FCC on November 13, 2020 is available on the FCC website.[26]

4.2 Aviation's Assessment of 5G Coexistence

In parallel, the aviation industry has been providing studies to the FCC during the proceeding. However, these studies have significant shortcomings. In particular, engineering analyses indicate the October 7, 2020 study provided by the Radio Technical Commission for Aeronautics (RTCA)[27] was overly conservative, and when evaluating real-world conditions, conclusions of the study would be different as discussed hereafter. The same is true for other aviation studies provided on this issue. Global deployments in nearby bands further indicate the overly conservative nature of the RTCA and other aviation reports.

Fig. 4.1. 3GPP Bands and Spectrum Allocations Near the Altimeter Band



4.2.1 Timeline of Aviation's Altimeter Coexistence Studies

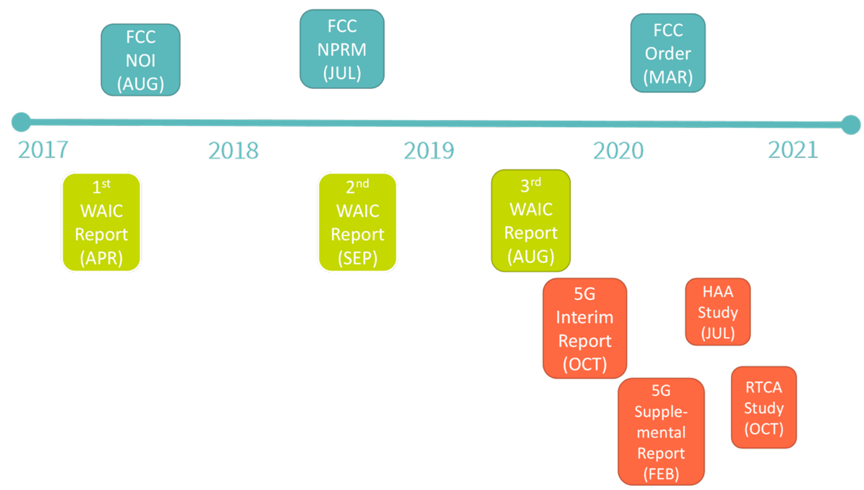
Aviation began assessing commercial use of spectrum near the altimeter band in 2011 as part of the NTIA Fast Track evaluation, which proposed re-allocating the lowest and highest 20 MHz of the altimeter band for commercial wireless services. Aviation's early study indicated that services operating directly adjacent to the Frequency-Modulated Continuous-Wave (FMCW) transmissions may cause intermodulation which could potentially interfere with altimeter operations.

Aviation subsequently evaluated coexistence between altimeters and Wireless Avionics Intra-Connectivity (WAIC) (a proposed wireless replacement for wired communications onboard aircraft). In April 2017, the Aerospace Vehicle Systems Institute (AVSI) submitted a test report to the International Civil Aviation Organization (ICAO) providing preliminary test results of WAIC coexistence when transmitting co-channel in spectrum, which completely overlapped the altimeter band. AVSI submitted an intermediate report to ICAO in September 2018. AVSI continued testing WAIC-altimeter interference susceptibility and submitted a further update to ICAO in August 2019, providing results for five Category 1 altimeters: Rockwell Collins LRA-900 and LRA-2100, Thales ERT-530 and 550, and Honeywell ALA-52B. Category 1 altimeters are designed for commercial transport and airline passenger aircraft.

The FCC first sought comment on the re-purposing of the 3700 – 4200 MHz band in August 2017. In May 2018, Aviation Spectrum Resources, Inc. (ASRI) confirmed that testing had been underway since 2016 to broadly assess commercial altimeter performance, and results for 5G coexistence were expected in Q1 2019.[28] Aviation subsequently submitted the initial 5G-altimeter test report to the FCC in October 2019, evaluating seven altimeter models whose identities were not disclosed.[29] Five altimeters were tested from Category 1 and two from Categories 2 and 3, defined as general aviation, business aviation, and helicopters. Aviation submitted a supplemental report to the FCC in February 2020[30], and provided further analysis of the helicopter use case in July 2020.[31] Subsequent testing post-July added two additional Category 2/3 altimeters, with the results reported in the RTCA study filed in October 2020.

The chronology of WAIC and 5G studies is summarized in Figure. 4.2.

Fig. 4.2. FCC and Aviation's Studies Timeline



4.2.2 Aviation Assessment Results

In December 2019, more than two years after the FCC's NOI considered re-allocating the 3700 – 4200 MHz band, RTCA established SC-239 to focus on "protecting future radar altimeters from existing and planned in-band and out-of-band interference."[32] SC-239 produced the RTCA report finalized on October 7, 2020, assessing 5G coexistence with altimeters.[33] When evaluating receiver overload, RTCA claimed that 5G would exceed the tolerable signal levels of Category 1 aircraft by 14 dB, and Categories 2 and 3 aircraft by more than 40 dB. The RTCA report's overload exceedance levels for 200 ft altitude in the Worst Case Landing Scenario (WCLS) is illustrated in Figure 4.3.

RTCA also modeled base station unwanted emissions within the 4200 – 4400 GHz band. With the assumed conducted emissions of -20 dBm/MHz, RTCA claimed an exceedance of 27.5 dB for Category 2, and 11 dB for Category 3. Category 1 did not have an exceedance for base station unwanted emissions.

The RTCA report noted that user equipment (UE) emissions on the ground did not exceed the criteria. For UEs transmitting onboard an aircraft, the aggregate emissions did not exceed the measured Interference Tolerance Mask (ITM) level for Category 1. For Categories 2 and 3, the aggregate emissions exceeded the measured ITM level by 34 to 47 dB. The modeling assumed the regulatory maximum EIRP of 30 dBm, and conducted emissions of -30 dBm/MHz, with five UEs transmitting simultaneously, each within a bandwidth of 20 MHz.

4.3 Technical Flaws with the RTCA Study

Multiple different factors observed in the RTCA study resulted in erroneous assumptions and artificial situations not resembling real-word landing scenarios and coexistence conditions for 5G and radio altimeters. These factors are addressed in the following sections, including the impact of erroneous assumptions in the studies.

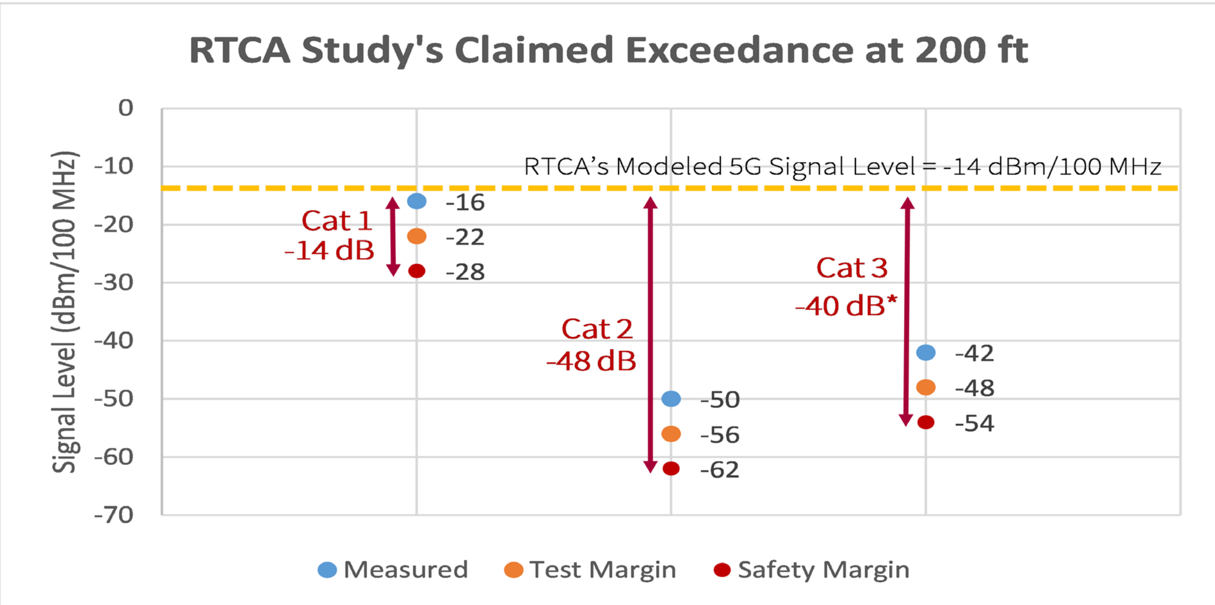
4.3.1 Lack of Documentation

AVSI conducted testing of nine altimeters and produced an Interference Tolerance Mask (ITM) for each of the three usage categories, representing the worst data point from all altimeters and test conditions. AVSI supplied the ITMs to RTCA, but AVSI did not share the underlying test data, the identity of the units tested, the age, or commercial status of the altimeters. RTCA SC-239 lacked the engineering data and details necessary to reach their stated conclusion that "5G telecommunications systems in the 3.7 – 3.98 GHz band will cause harmful interference to radar altimeters on all types of civil aircraft—including commercial transport airplanes; business, regional, and general aviation airplanes; and both transport and general aviation helicopters."[34] When examined more closely, aviation's inputs, methodology, and criteria were inappropriate, and lead to significantly inflated interference claims.

4.3.2 Inputs and Conditions for RTCA 5G Study

The inputs and conditions employed by the RTCA 5G study were much more restrictive than those used in studying WAIC, a service favored by aviation. The WAIC studies evaluated the risk to a victim altimeter from WAIC transceivers located on aircraft in-flight near the victim, or on the ground in a landing scenario. AVSI employed more favorable inputs and conditions in the WAIC testing than those employed subsequently in 5G testing. These differences make a large impact on the final results.

Fig. 4.3. RTCA Study's Claimed Receiver Overload Exceedance at 200 ft



*Cat. 3's highest claimed exceedance of 45 dB was at 2,000 ft. Cat. 3 at 200 ft had a claimed exceedance of 40 dB.

First, in WAIC testing, AVSI did not include a margin for cable loss.[36] In 5G testing, AVSI explicitly includes an additional 6 dB of cable loss. AVSI's inclusion of cable loss for 5G biases the test to a less favorable outcome because the altimeter is operating with a desired signal that is 6 dB lower.

Second, the WAIC testing only assessed the better-performing Category 1 altimeters. The Category 2 and 3 altimeters, introduced in the 5G testing, were not assessed in the WAIC study. If the WAIC study had included the worst-performing altimeter driving RTCA's Category 2 and 3 results, then WAIC would have shown a significant exceedance of the permissible energy level, as shown in Figure 4.4. WAIC's exceedance of 34 dB is 6.5 dB worse than RTCA's claimed exceedance in the 5G study for Category 2 for base station unwanted emissions.

Fig. 4.4. WAIC Performance for the Worst Category 2 Altimeter

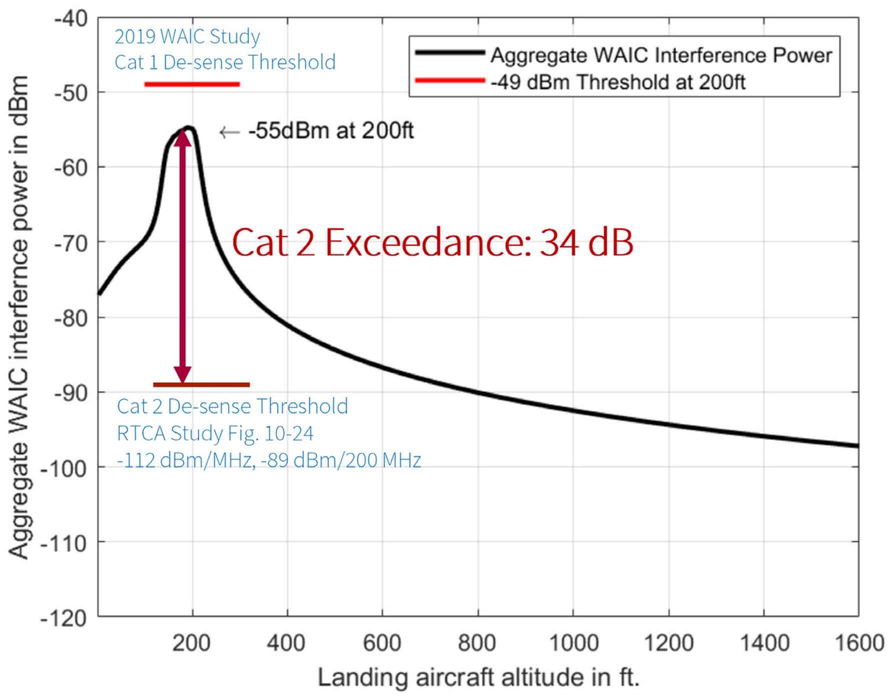
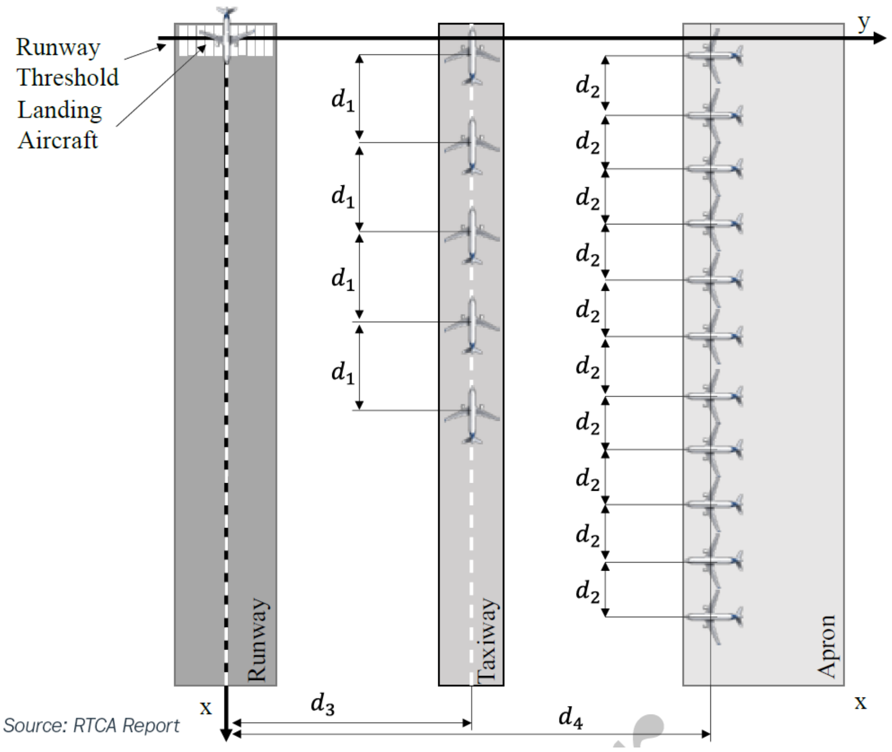


Fig. 4.5. WCLS Configuration for "Other RA" Interference



Source: RTCA Report

Third, when testing WAIC, AVSI determined that a 2 dB test margin was sufficient to account for "measurement inaccuracies"[37] but increased this margin to 6 dB in the 5G testing—a net difference of 4 dB worse.

The fourth difference between the WAIC and 5G coexistence studies was the addition of a 6 dB "safety margin" in the 5G study that was not included in the WAIC study.

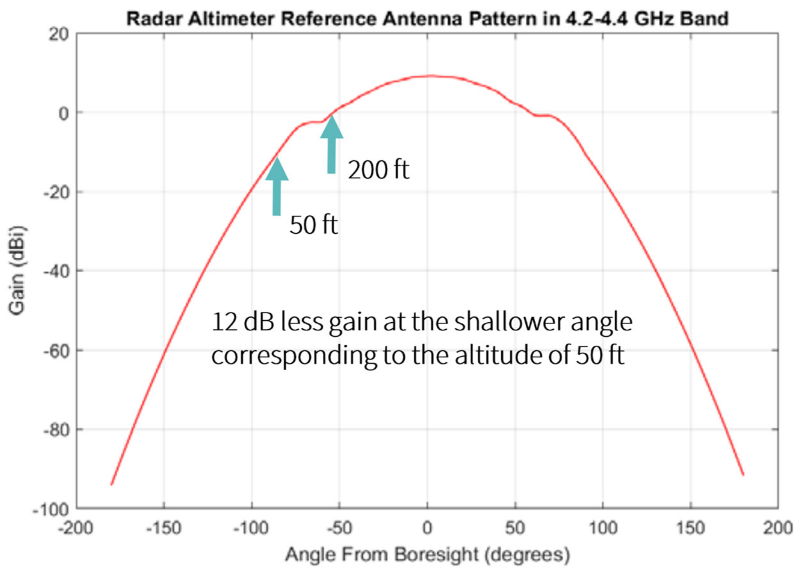
AVSI made the test inputs a total of 16 dB more stringent for 5G than in their prior testing of WAIC—an amount greater than their claimed exceedance for Category 1 aircraft.

4.3.3 Landing Scenario

The Worst-Case Landing Scenario (WCLS) used in AVSI's testing for the 200 ft height did not reflect realistic landing conditions. In the WCLS scenario, the landing aircraft is positioned over the runway threshold, with multiple aircrafts on the taxiway and apron as shown in Figure 4.5. Radar altimeters on the aircraft at the airport create in-band interference to the landing victim altimeters.

The main technical error in AVSI's WCLS is the height of the landing aircraft over the runway threshold, which AVSI assumed to be 200 ft. Per FAA Order 8260.3E, the maximum threshold crossing height for a landing commercial aircraft is 60 ft.[38] In the RTCA Study, the Chicago O'Hare example illustrated a landing approach in which the aircraft height over the runway threshold was 53 ft.[39] The WCLS landing height of 200 ft does not represent a real-world height for a landing aircraft. Instead, the 200 ft height was selected because the interference from the aircraft on the ground reached a maximum at 200 ft, an artificial construct.[40] The interference from other radar altimeters in a real-world landing scenario would be 24 dB less; at 50 ft,

Fig. 4.6. Altimeter Antenna Pattern for 4.2-4.4 GHz



the angle of reflection from the aircraft on the ground would be more shallow, reducing the altimeter antenna gain at both the aggressor and victim aircraft. Figure 4.6. illustrates the difference in antenna gain as a function of angle for the two heights. The delta of 12 dB in gain for each antenna equates to a reduction in interference of 24 dB.

Three potential airport scenarios should be examined: The first scenario is a normal approach, in which the aircraft is at 50 feet over the runway threshold. A second scenario is a go-around, during which the landing was aborted and the pilot is executing a climb over the airport. The third scenario is a normal approach, but evaluates the altimeter performance at 200 feet, farther up the glideslope at a greater distance from the airport. In each scenario, the terrain type, loop loss, and interference from other altimeters on the ground must be assessed to determine the proper input values. Table 4.1. compares the inputs for each scenario.

The landing aircraft's loop loss would be much less than AVSI's testing given the lower altitude. The difference in loop loss between 200 ft and 50 ft is 16 dB; the landing aircraft would be receiving a 16 dB stronger reflected signal making the altimeter performance more robust.[41] The Other RA interference would also be considerably less as derived above.

Furthermore, the runway threshold is a paved surface; according to DO-155, such a surface is considered smooth. By assuming rough terrain over the runway threshold, AVSI further worsened the WCLS scenario by up to 20 dB. For the landing scenario, this becomes a total difference of 36 dB in loop loss.

In the case of a go-around, the position of the aircraft above the airport results in a similar terrain adjustment of 20 dB to the loop loss due to the reflection coefficient. The airport aggressor interference (due to other altimeters on the ground) would represent the geometry of the AVSI testing if the landing aircraft reached an altitude of 200 feet during the go-around.

The third case of an aircraft at 200 feet altitude farther up the glideslope would result in much lower airport aggressor interference. In this case, the aircraft is more than 2,000 ft from the runway threshold, which increases the path loss by 16 dB relative to AVSI's runway threshold case. The antenna gain of victim and aggressor altimeters is also much lower given the shallow reflection angle of four degrees. These considerations reduce the airport aggressor interference level by more than 40 dB at the victim altimeter receiver.

Table 4.1. Airport Scenarios

Scenario	Landing Aircraft	Go-around	Glideslope Approach
Aircraft Altitude (ft)	50	200	200
Aircraft Location	Runway Threshold	Runway Threshold	Not at airport
Terrain Type	Smooth	Smooth	Potentially rough
Loop Loss (dB)	54	70	90
Other RA Interference	23 db less	AVSI level	40 dB less

Table 4.2. FAA Altitude Accuracy Requirements

System Type	Height Range	Accuracy of electrical data output	Accuracy displayed to the crew
Automatic Landing (ED-30 Table 1)	3 to 100 feet	+/- 3 feet	+/- 5 feet
	100 to 500 feet	+/- 3%	+/- 5%
	500 feet to the maximum of the scale	+/- 5%	+/- 7%
Ground Proximity Warning (ED-30 Table 2)	3 to 100 feet	+/- 5 feet	Not stated
	Above 100 feet	+/- 5%	

4.3.4 Pass/Fail Criteria

The FAA defined the minimum performance standards (MPS) for airborne low-range radio altimeters in TSO C87a, effective May 31, 2012. TSO C87a required altimeters to meet the MPS requirements in EUROCAE ED-30, Minimum Performance Standards for Airborne Low-Range Radar Altimeter Equipment, Edition 2, dated March 1980, clarifying in Appendix 1 that Categories A2 and C are not included. Thus, the FAA's minimum performance requirements may be summarized as shown in Table 4.2.

In the RTCA study, AVSI applied significantly more stringent criteria to all altimeters tested, as noted in Table 4.3. AVSI flagged an exceedance if any of their three criteria failed. AVSI considered a test to fail if the mean height accuracy varied from the baseline accuracy by more than 0.5%. This criterion of mean height accuracy is not referenced in aviation Multi-Pilot Simulations (MPS). The second criterion AVSI defined was if more than 2% of the measured data points fall outside of +/-2% of the baseline height. This criterion also does not appear in aviation MPS. The third criterion was if an altimeter failed to report an altitude reading, "Non-Computed Data (NCD)". AVSI noted that altimeters may not report data for a number of reasons, generally proprietary to the manufacturer.

Table 4.3. AVSI Pass/Fail Criteria

Criteria	Pass/Fail Threshold
Mean height error	>0.5%
98% of all heigh measurements	Within 2%
Height reading label	NCD (Non-Computed Data)

Importantly, AVSI's criteria could be exceeded by an altimeter that still meets the FAA's MPS. Radio altimeter manufacturer specifications summarized in Table 4.4. note that numerous altimeters were designed to meet C87a, but not AVSI's more stringent criteria considered in the RTCA study.

AVSI's pass/fail criteria employed in the RTCA study was more restrictive than the FAA requirements, the aviation MPS, and the manufacturer design tolerances for most altimeters. Since AVSI's test environment also went beyond the worst assumptions required by DO-155's lab test setup, the test data collected by AVSI is invalid, and their pass/fail determinations are incorrect.

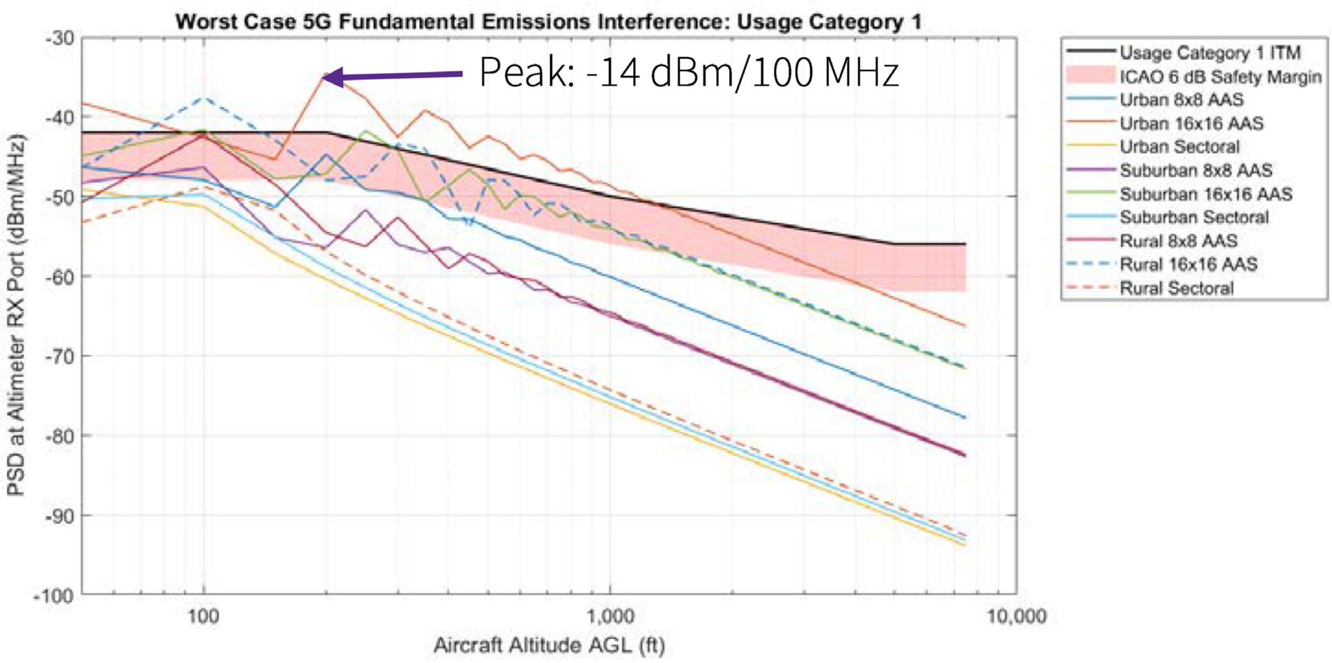
4.3.5 5G power levels

In section 10 of the RTCA report, 5G base station power levels received at an aircraft in flight are modeled as a function of altitude. The modeling indicated that the peak power level occurred at low altitude, in close proximity to the base station, as illustrated in Figure 4.7.

Table 4.4. Altimeter Manufacturer Tolerances

Manufacturer	Altimeter Model	Accuracy of electrical data output	Accuracy displayed to the crew
Collins	ALT-50A	+/-2 ft or 2%	0 to 500: +/-5% Above 500: +/-7%
Honeywell	KRA-405B	0 to 500: +/-3 ft or 3% 500 to 2500: +/-5%	0 to 500: +/-5% 500 to 2500: +/-7%
Bendix	ALA-51A	0 to 500: +/-2 ft or 2% 500 to 2500: +/-5%	Not stated
Bendix King	KRA 10	Not stated	0 to 100: +/-5 ft 100 to 500: +/-5% >500: +/-7%
Bonzer	Mark 10	40 to 100: +/-5 ft 100 to 2500: +/-5%	Not stated
Thales	ERT-530	+/5% over rough terrain	Not stated

Fig. 4.7. RTCA Modeled 5G Base Station Power Level Received at an Aircraft versus Altitude (with Erroneous Grating Lobe)



RTCA modeled a 16x16-element Urban Advanced Antenna System (AAS) base station antenna pattern assuming an electrical beam steering of 30 degrees below the antenna boresight. The antenna pattern exhibited a grating lobe above the base station as shown in Figure 4.8.

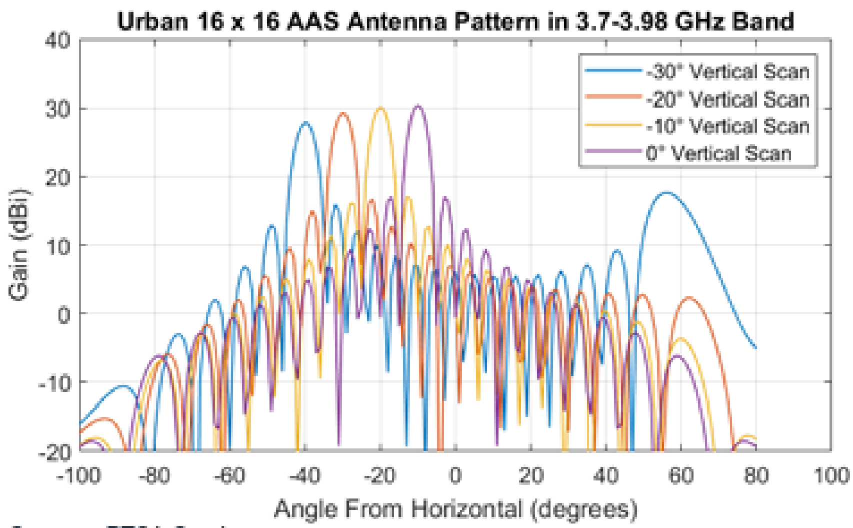
CTIA commented during adjudication that beam steering would include 10 degrees of mechanical tilt, which would alter the pattern and eliminate the grating lobe—a difference of 14 dB in the modeled 5G power level.

RTCA performed further modeling, included in Appendix D of the study and shown in Figure 4.9., to determine 5G base station power levels without the erroneous grating lobe. The Urban AAS power level is reduced by 14 dB as expected.

The gray shaded "Invalid Region" was added to the figure to note that the modeling in this region has two sources of error. First, the modeling assumed 20 degrees of pitch[42] or roll[43] at low altitudes. The RTCA report noted that significant roll during an approach can occur in some circumstances, such as at Washington Reagan National Airport (DCA), yet RTCA further noted that the roll would be completed by the time the descent reached a height of 250 feet. The figure improperly includes roll at heights lower than 250 feet.

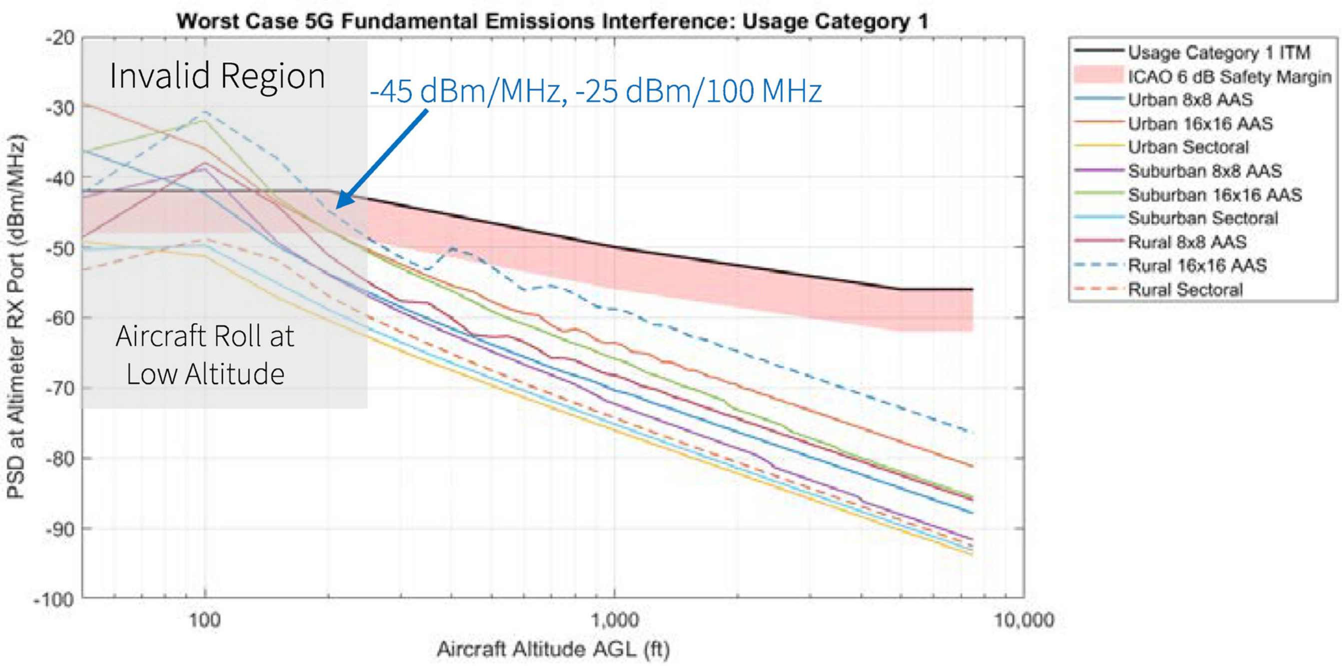
The second error in Figure 4.9. is the flat extension of the flawed 200 feet WCLS results. The real-world WCLS would perform significantly better than AVSI's ITM data point at 200 feet as noted above. Moreover, altimeter performance at lower altitudes, where the desired signal is significantly stronger, would be much better than RTCA assumed with the flat line ITM. AVSI did not provide measurement results for lower altitudes. RTCA's use of the incorrect 200 feet WCLS ITM at lower altitudes yielded incorrect results.

Fig. 4.8. 16x16-element Urban AAS Pattern with Erroneous Grating Lobe



Source: RTCA Study

Fig. 4.9. RTCA Modeled 5G Base Station Power Level Received at an Aircraft versus Altitude



4.4 Global Deployments providing Real-World Examples of Non-Interference to Radio Altimeters

Several countries have been deploying 5G in spectrum near the radio altimeter band with no reports of interference. In the United States, the federal government has operated radar and communications systems in spectrum near the radio altimeter band for decades.

4.4.1 Japan

Japan assigned the 3600 – 4100 MHz and 4500 – 4600 MHz bands for nationwide 5G deployment, with the auction completed in April 2019. The country has deployed more than 90,000 base stations in this frequency range. Location restrictions exist only for operations in the upper 100 MHz portion of the band, such as avoidance of base station deployments in the range of about 100 to 200 m around the approach route of the aircraft around the airport (about 1 km). Based on RTCA's claims, aircrafts should have regular complaints from the use of spectrum below 4000 MHz, but this has not been the case.

4.4.2 South Korea

In addition to the spectrum in 3420 – 3700 MHz formerly auctioned in 2018, South Korea announced plans to auction 3.7 – 4.0GHz band for nationwide 5G deployment. To protect radio-altimeter service in 4200 – 4400 MHz, 200MHz of guard band is assigned. In addition to the 200MHz guard band, the Ministry of Science and ICT (MSIT) is also studying if any additional requirement for 5G base stations is needed to protect radio-altimeter around airports and heliports. The detail regulation will be released before the 5G spectrum auction planned in 2021/2022.

4.4.3 Europe

The 74th meeting of the European Commission Radio Spectrum Committee (RSC#74) took place virtually on March 9 and 10, 2021. An extract from the Chairman's report on "5G potential interference to radio altimeters"[44] states:

> "The Commission Services informed the meeting about an EASA[45] workshop that took place (online) on 25 February. For the time being, EASA does not identify any conditions that compromise safety and reports no occurrences of interference from 5G base stations to aeronautical radio altimeters. EASA is following the issue closely and has issued a Continued Airworthiness Review Item addressed to all radio altimeter manufacturers. Airbus is meanwhile monitoring flights and collecting data which will be available by the end of March. Some Member States informed the meeting about their views on this issue. France, in particular, has taken some precautionary measures around main airports. The CEPT reminded that they have already opened a Work Item on possible interference from 5G to aeronautical Radio Altimeters."

The European Conference of Postal and Telecommunications Administrations (CEPT) has started a Work Item on "Compatibility between Mobile-Fixed Communications Networks (MFCN)[46] operating in 3400 – 3800 MHz and Radio Altimeters (RA) operating in 4200 – 4400 MHz". At the April 2021 meeting, a draft version of a technical report was created with the following scope:

- *Assessment of susceptibility of deployed RA receivers operating in 4200 – 4400 MHz, while taking into account any civil aviation initiatives on improving RA receivers in order to study the following compatibility scenarios:*
  - » *Unwanted emissions from MFCN operating in 3400 – 3800 MHz into 4200 – 4400 MHz radio altimeters band*
  - » *Impact of blocking of radio altimeters from 3400 – 3800 MHz MFCN in-band emissions*

5G parameters used in the study were included in the report. However, there were no inputs from the aviation side on radio altimeter parameters or measurements (which were identified as a critical element in CEPT in order to be able to start the studies). Without the data on altimeters, no assessment of the coexistence could start until the next meeting in September 2021.

The U.K. assigned the 3800 – 4200 MHz band in July 2019 for use under low and medium power local licensing.[47] Ofcom adopted a 5 MHz guard band at the bottom and the edge of the band. There is no antenna height or location restriction in the band. In their technical studies that served as support to the decision making, Ofcom stated: "We do not see any evidence that our proposed low or medium power technical conditions will lead to any interference at or around airports where aircraft have an altitude low enough to potentially suffer interference and where they rely heavily on the altimeters".[48] There has been no notice of interference complaints in the UK.

4.4.4 Federal Systems in the United States

Federal systems in the United States would be exceeding the levels suggested by the RTCA Study if RTCA's claims were correct. The SPN-43 radar emits gigawatts of energy in certain U.S. ports. The SPN-43 operating frequency extended to 3700 MHz from the 1960s into the early 2000s. The AEGIS Combat System radar, installed on Navy cruisers and destroyers, operates below 3500 MHz at gigawatt power levels, and there is a land-based test range in Kauai, Hawaii. The United States military also operate other ground-based and aeronautical radars in the 3 GHz band.

Federal operations above 4400 MHz include point-to-point links, ship-shore-ship operations, and air-ground-air operations.

4.5 Remarks on Altimeters

RTCA's conclusions in their October 2020 report were based on the ITMs developed from AVSI's testing. As discussed above, AVSI's testing contained flawed inputs which produced incorrect results. A number of factors resulted in artificial situations which did not resemble real-world landing scenarios and coexistence conditions for 5G and radio altimeters. A landing aircraft over the runway threshold would be at a lower height than 200 feet, with significantly better altimeter performance. Reflection coefficients over a smooth runway are significantly improved. Interference from ground-based altimeters to a landing aircraft is much weaker than AVSI assumed. The AVSI measurements for the WCLS case at 200 feet, and the Category 3 landing conditions are also incorrect. AVSI inaccurately extended their measurements to altitudes which were not measured, further exacerbating the errors in the RTCA report. AVSI compounded the testing issues through their adoption of pass/fail criteria which were more stringent than the tolerances guaranteed by the altimeter manufacturers. The technical errors indicated above led to significantly inflated interference claims.

The lack of an observed effect on altimeters in the presence of significant wireless deployments provides further evidence that the RTCA study is overly conservative. International 5G deployments in several countries have been operating without interference to altimeters, and the United States military and federal systems have operated near the altimeter band for decades.

Conclusion

This paper focuses on the low, mid, and high spectrum bands that are needed to support 5G deployments. It also discusses the global harmonization of spectrum to support a broad ecosystem driven by 3GPP specifications of new spectrum bands and wider bandwidths. This paper recommends that regulatory bodies ensure spectrum availability across low, mid, and high spectrum with timely allocations for 5G deployments.

In addition, spectrum usage in North America (United States, Canada, and Mexico) is also discussed at length. In the United States, there has been an extensive push towards spectrum allocation for 5G and recent activities have targeted mid-band spectrum to support 5G deployments. The FCC has also concluded its C-band (3700 – 3980 MHz) spectrum auction—the largest in FCC history—with gross proceeds of $81 B which illustrates the importance of mid-band for 5G deployments. The FCC is also planning another mid-band auction in 2021 for 3450 – 3550 MHz. In Canada, the primary spectrum regulatory body, ISED, has also been active in identifying and designating new spectrum for 5G broadband services, and included plans to release the 3450 – 3650 MHz band—a key band for 5G. As for Mexico, 5G services have not yet been launched, while the regulator makes spectrum available for 5G.

Finally, this paper also analyses the coexistence of 5G in mid-bands with radio altimeters. Particularly, it was noted on February 28, 2020, that the FCC adopted a Report and Order approving the use of the 3700 – 3980 MHz band for commercial wireless service without any constraints. The aviation industry was active in the FCC docket, and the FCC explicitly took their comments into account in making its determination. Further study of the RTCA report points to some significant shortcomings due to flawed input data and a pass/fail criterion that was more stringent than the tolerances allowed by the altimeter manufacturers.

Acronyms

3GPP: 3rd Generation Partnership Project

4G: Fourth Generation

5G: Fifth Generation Mobile Networks

5GC: Fifth Generation Core

AAS: Advanced Antenna System

AGL: Above Ground Level

ASRI: Aviation Spectrum Resources, Inc.

ATC: Air Traffic Control

AVSI: Aerospace Vehicle Systems Institute

AWACS: Airborne Warning and Control System

AWS: Advanced Wireless Services

BC: Broadcast

BCG: Boston Consulting Group

BSS: Broadcasting Satellite Service

CBRS: Citizens Broadband Radio Service

CEPT: European Conference of Postal and Telecommunications Administrations

CIoT: Cellular IoT

CPA: Cooperative Planning Areas

CTIA: Cellular Telecommunication Industry Association

DBS: Direct Broadcast Satellite

DoD: U.S. Department of Defense

DSCS: Defense Satellite Communications Systems

EASA: European Aviation Safety Agency

EBS: Educational Broadband Service

EESS: Earth Exploration-Satellite Service

EIRP: Effective Isotropic Radiated Power

eMBB: Enhanced Mobile Broadband

EPC: Evolved Packet Core also known as System Architecture Evolution (SAE)

ESC: Environment Sensing Capability

EPC/SAE: Evolved Packet Core/System Architecture Evolutions

ePDG: Evolved Packet Data Gateway

EPS: Evolved Packet System

ETSI: European Telecommunications Standards Institute

E-UTRA: Evolved Universal Terrestrial Radio-Access

E-UTRAN: Evolved Universal Terrestrial Radio-Access Network

FAA: Federal Aviation Administration

FCC: Federal Communications Commission

FD: Frequency Division

FDD: Frequency Division Duplex

FDM: Frequency Division Multiplexing

FMCW: Frequency-Modulated Continuous-Wave

FNPRM: Further Notice of Proposed Rulemaking

FR1: Frequency Range 1 (410 MHz – 7125 MHz)

FR2: Frequency Range 2 (24250 MHz – 52600 MHz)

FSS: Fixed Satellite Stations

FS: Fixed Service

FSMP: Frequency Spectrum Management Panel

GAA: General Authorized Access

GEO: Geosynchronous (Satellite) Orbit

GHz: Gigahertz

GMLC: Global Mobile Location Center

GNSS: Global Navigation Satellite System

HPHT: High-Power/High-Tower (broadcast scenario)

HSS: Home Subscriber Server

IAB: Integrated Access Backhaul

ICAO: International Civil Aviation Organization

IEEE: Institute of Electrical and Electronics Engineers

IFT: Federal Institute of Telecommunication

IMS: Internet Protocol Multimedia Subsystem

IMT: International Mobile Telecommunications

IIoT: Industrial Internet of Things

IoT: Internet of Things

IP: Internet Protocol

ISED: Innovation, Science and Economic Development Canada

ISM: Industrial, Scientific, and Medical

ISS: Inter-Satellite Service

ITM: Interference Tolerance Mask

ITU: International Telecommunications Union

LAA: License Assisted Access

LCS: Location Services

LEO: Low Earth (Satellite) Orbit (400 km to 2000 km)

LOS: Line-of-Sight

LPWA: Low Power Wide Area

LTE: Long Term Evolution

MC: Multicast

MCG: MeNB Cell Group

MCS: Modulation and Coding Scheme

MEO: Medium-Earth (Satellite) Orbit (2000 km to just below geosynchronous orbit)

MFCN: Mobile-Fixed Communications Networks

MHz: Megahertz

MIMO: Multiple-Input Multiple-Output

MME: Mobility Management Entity

mMTC: Massive Machine Type Communication

mmWave: Millimeter Wave

MPMT: Medium-Power/Medium-Tower (broadcast scenario)

MPS: Minimum Performance Standards

MPS: Multi-Pilot Simulations

MSS: Mobile Satellite Service

MVDDS: Multichannel Video Distribution and Data Services

MVNO: Mobile Virtual Network Operator

NB-IoT: Narrowband IoT

NCD: Non-Computed Data

NG: Next Generation

NGSO: Non-geostationary Orbit

NID: Network ID

NPN: Non-Public Network

NPRM: Notice of Proposed Rulemaking

NR: New Radio

NR-U: NR Unlicensed

NSSAA: Network Slice Specific Authentication and Authorization

NTIA: National Telecommunications and Information Administration

OCB: Occupied Channel Bandwidth

OFDM: Orthogonal Frequency Division Multiplexing

OOBE: Out-of-band Emission

OPEX: Operating Expenses

OTA: Over-The-Air

PAL: Priority Access License

PAPR: Peak-to-Average-Power Ratio

PCC: Policy and Charging Control

Pcell: Primary cell

PCS: Personal Communications Service

P-CSCF: Proxy Call Session Control Function

PDCCH: Physical Downlink Control Channel

PDCP: Packet Data Convergence Protocol

PDSCH: Physical Downlink Shared Channel

PEA: Partial Economic Area

PFD: Power Flux Density

PLMN: Public Land Mobile Network

PMCH: Physical Multicast Channel

PRACH: Physical Random Access Channel

PS: Packet Switched

PSBCH: Physical Sidelink Broadcast Channel

PSCCH: Physical Sidelink Control Channel

PSFCH: Physical Feedback Control Channel

PScell: Primary Scell

PSSCH: Physical Sidelink Shared Channel

PTRS: Phase-Tracking Reference Signal

PUA: Periodic Use Areas

PUCCH: Physical Uplink Control Channel

PUSCH: Physical Uplink Shared Channel

QoS: Quality of Service

R&O: Report and Order

RACH: Random Access Channel

RACS: Radio Capabilities Signaling Optimization

RAN: Radio-Access Network

RAS: Radio Astronomy Service

RIM: Remote Interference Management

RIT: Radio Interface Technology (IMT-2020 proposal)

RMSI: Remaining Minimum System Information

RNTI: Radio Network Temporary Identity

ROHC: Robust Header Compression

RRC: Radio Resource Control

RRM: Radio Resource Management

RSRP: Reference Signal Received Power

RSRQ: Reference Signal Received Quality

RSSI: Received Signal Strength Indication

RSTD: Received Signal Time Difference

RTCA: Radio Technical Commission for Aeronautics

RTOA: Relative Time of Arrival

RTT: Round Trip Time

Rx: Receive

SAL: Shared Access Licensee

SAS: Spectrum Access System

SBA: Service Based Architecture

Scell: Secondary cell

SCI: Sidelink Control Indicator

SCG: SeNB Cell Group

SCG: Secondary Cell Group

SCP: Service Communication Proxy

SC-PTM: Single-Cell Point-to-Multipoint

SFN: Single Frequency Network

SIM: Subscriber Identity Module

SINR: Signal-to-Interference-and-Noise Ratio

SL: Sidelink

SMR: Specialized Mobile Radio

SRIT: Set of Radio Interface Technologie(s)

SRS: Sounding Reference Signal

SRS: Space Research Service

SRVCC: Single Radio Voice Call Continuity

TA: Time Alignment

TDD: Time-Division Duplex

TDM: Time-Division Multiplexing

TDOA: Time Difference Of Arrival

TSC: Time Sensitive Communication

TSO: Technical Standards Order

TTI: Transmit Time Travel

Tx: Transmit

UAV: Unmanned Ariel Vehicles

UC: UniCast

UCI: Uplink Control Indicator

UCMF: UE (radio) Capability Management Function

UDM: Unified Data Management

UE: User Equipment

UL: Uplink

UMFUS: Upper Microwave Flexible Use Service

UPF: User Plane Function

URLLC: Ultra-Reliable Low-Latency Communications

V2P: Vehicular-to-Pedestrian

V2V: Vehicular-to-Vehicular

V2X: Vehicle-to-Everything

VN: Virtual Network

WAIC: Wireless Avionics Intra-Communications

WCLS: Worst Case Landing Scenario

WG: (3GPP) Working Group

WGS: Wideband Gapfiller Satellite

WI: Work Item

WID: Work Item Description

WRC: World Radiocommunication Conference

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38 FAA Order 8260.3E, Table 10-1-1 TCH Requirements.

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41 Appendix B page 9. Loop losses adjusted to a reflection coefficient of 0.01 per EUROCAE ED-30, as referenced by FAA TSO C87a.

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