UNITED STATES DEPARTMENT OF COMMERCE
National Telecommunications and Information Administration
Washington, D.C. 20230

March 4, 2026

The Honorable Brendan Carr
Chairman
Federal Communications Commission
45 L Street, NE
Washington, DC 20554

Re: Recommendations for Protecting GPS L1 from Interference from New Mobile Satellite Service Direct-to-Device Capability

Dear Chairman Carr,

To ensure protection of the GPS L1 signal at 1575.42 MHz from Mobile Satellite Service (MSS) providers' Direct-to-Device (D2D) user equipment operating in 1610-1660.5 MHz, I write to request that the Commission seek public comment on new or updated Knowledge Database (KDB) guidance,[1] as outlined in the Attachment to this letter.

MSS providers with operations near the GPS L1 signal are partnering with user device manufacturers to enable communications with both terrestrial wireless systems and directly with the MSS providers' satellites.[2] The rapid growth in the development of this MSS D2D capability brings a corresponding increase in the risk of interference to GPS receivers.

Following the evaluation of the potential impact of these developments by a special technical committee of the Space-based Position Navigation and Timing Executive Committee (PNT EXCOM), comprised of federal agencies including the Departments of Transportation and War and the National Aeronautics and Space Administration, NTIA issued a Request for Comment (RFC) on "the potential impact on the GPS L1 signal at 1575.42 MHz of the increasing deployment of mobile devices capable of operating on satellite systems in the L-band at 1610-1660.5 MHz."[3] The details of the PNT EXCOM's findings and our RFC are included in the first Attachment.

[1] *See, e.g.*, 273109 D02 Part 25 Supplemental Coverage from Space and CMRS-Bands v01r01 (Oct. 2, 2024).

[2] The current FCC rule – over twenty years old at this point – has an emission limit for mobile earth stations operating in 1610-1660.5 MHz of -100 dBW/MHz over any 2 millisecond active transmission interval.

[3] *See* Direct-to-Device Services Request for Comment, National Telecommunications and Information Administration, NTIA-2024-0005 (Dec. 19, 2024), https://www.ntia.gov/federal-register-notice/2024/direct-device-services-request-comment.

The results of those analyses lead us to request that the Commission seek public comment on KDB guidance to require D2D devices operating in 1610-1660.5 MHz whose out of band emissions exceed -100 dBW/MHz over any 2 millisecond active transmission interval to include the following showings:

(i) Ensuring the devices are incapable of operating in satellite mode on an airplane or when there are accessible terrestrial options for service.

(ii) Ensure that prior to operating in satellite mode the devices display a screen notifying the user of the prohibition of operating the device on an airplane and the risk of interference to nearby GPS operations.

Sincerely,

Arielle Roth
Assistant Secretary for Communications and Information

cc: Arpan Sura
Jay Schwarz
Andrew Hendrickson

Attachment 1: Review of PNT EXCOM Analysis and NTIA RFC

Attachment 2: Department of Transportation Analysis of Potential Interference to GPS/GNSS from Emerging L-band MSS D2D and IoT Services

Attachment 1

Comments were submitted by both those deploying L-band D2D services and GPS device manufacturers. What follows is the assessment of the special technical committee as to the risks of these deployments and its consensus recommendations for regulation to reduce the risk to an acceptable level.

We recognize the value that this MSS D2D capability provides in terms of increased access to wireless communications in remote areas, particularly during times of emergency. However, when the MSS rules were developed, there was an expectation that there would be relatively few user devices capable of causing interference to GPS receivers. Therefore, the out-of-band emission (OOBE) limit for these direct-to-satellite devices is substantially more relaxed (by more than 30 dB) than the rules that were later developed for user devices in these bands communicating with terrestrial base stations. The stricter OOBE limit was based in large part on the expectation that there would be a much larger number of terrestrial devices than devices operating in satellite-mode.

This 30 dB difference translates into a substantially greater risk of interference to nearby GPS receivers, at a distance of up to several hundred meters, an obvious problem, particularly in more densely-populated areas. Attached hereto is a technical analysis conducted by the U.S. Department of Transportation that describes in more detail the basis for our concern.

The business case for operation of the devices in satellite mode appears to be focused on situations in which terrestrial wireless service is unavailable, which is typically in areas with less intensive GPS use for critical service, but there is no certainty that will be the case.

One situation causing the greatest concern involves the use of such a device on an airplane. While the device manufacturer's user manual may provide a reference to an online guide containing the regulatory prohibition against operating the device on an airplane, few users are likely to be aware of that restriction. In most cases it appears that the capability is not functional in Airplane Mode, but there is no way to enforce a requirement that all devices on a plane must be switched to that mode.

NTIA's RFC asked a series of questions of both those deploying or planning to deploy L-band D2D services and those involved in the GPS industry. The RFC also asked for comment on the DOT technical analyses and invited parties to submit an alternative analysis.

Questions to those deploying L-band D2D services. The questions covered the actual out-of-band emissions of the devices; the potential for limiting those emissions further; the typical duration and frequency of occurrence of L-band transmissions supporting D2D services (including any automatic transmissions); expected geographic deployment patterns based on initial offerings of D2D services, as well as planned and/or potential service expansions; and any other information relevant to an evaluation of the likelihood that an L-band device will cause harmful interference to a nearby GPS receiver. The RFC also asked about the ability to limit L-band operations and attempted operations when on an airplane or near other critical GPS receivers (including information about the effectiveness of "airplane mode" or other similar settings); the options for educating users regarding the risks of operating near critical GPS receivers, including on-screen warnings and the likely effectiveness of these options; and any other mitigations that might reduce the risk of harmful interference to a nearby GPS receiver.

NTIA received responses from six companies involved in current or planned provision of L-band D2D service and from two satellite-oriented trade associations. (The Apple comments included a public version that contained redactions and an unredacted version accompanying a request for confidentiality.) Very few commenters provided information regarding either the actual OOBE levels of their devices, or the potential to reduce those levels, or the typical duration and frequency of L-band transmissions. A few companies indicated that some of their D2D devices would operate at lower power than the permissible limits and with lower than currently required out-of-band emissions into the GPS band. (As noted below, however, according to the DOT analysis, these devices would still be problematic when in proximity to some GPS devices.) Moreover, the comments indicated that some devices would operate at as much as 10 W EIRP. Two companies indicated that they are open to exploring options for better warnings to users.

Questions to the GPS industry. The RFC sought information on separation distances due to receiver selectivity, compared with the separation distances shown in the DoT technical analysis; GPS receiver overload limits; and industry standards and performance improvements achieved by the GPS industry to self-protect the various categories of GPS receivers to minimize receiver blocking and overload. The RFC also asked about any documented instances of harmful interference from MSS L-band devices and any mitigations that might be effective in reducing the risk of harmful interference while minimizing impacts on MSS service delivery.

One GPS manufacturer and the GPS Industry Association submitted comments. Comments received from the GPS industry (GPS Innovation Alliance and Garmin) shared the concern with the potential for interference to GPS/GNSS from the rapidly growing number of L-band MSS D2D devices. They noted that MSS transmission compatibility with GPS within an MSS device is often achieved by deactivating the GPS receiver during MSS transmission periods. Although this technique works well within the MSS device itself for those many applications where non-continuous GPS operation is adequate (e.g., asset tracking), it does not ensure compatibility of the MSS device with other GPS equipment that may be nearby and in use for a safety-critical application (e.g., navigation of a landing aircraft, or a ship passing under a bridge).

Questions about the DOT analysis. Comments received from the GPS industry were supportive of the DOT analysis. Comments received from the MSS/D2D industry generally criticized the DOT technical analysis. Their arguments focused on the analysis' reliance on the characteristics of a Ligado handheld device and the use of a 1 dB C/No interference criterion. These arguments overlook that many D2D devices operate at higher power than the Ligado device and that, although (according to the comments) some D2D devices have as much as 9 dB lower emissions into the 1559-1605 MHz band, the DOT analysis indicated that even a device performing better than the FCC -70 dBW/MHz limit by up to 16.5 dB could still result in interference if transmitting on an aircraft. Further, the onboard-aircraft analysis in the DOT analysis was not based upon the 1-dB criterion but rather based upon maximum interference requirements for certified aircraft with FAA Technical Standard Orders, on which the FCC has based transmitter limits.

The D2D proponents also made several less technical arguments in their critique of the DOT analysis, including pointing to the long-time coexistence of MSS and GPS without any significant interference issues, the low probability of D2D devices operating on airplanes or in proximity to critical GPS devices, and the need for D2D devices to protect against self-interference to their own GPS capability. The problem with these arguments is that they ignore the enormous increase in the deployment of D2D devices that is occurring and the lack of any certainty that these devices will be designed to protect nearby GPS or that their users will be aware of the risk to nearby GPS.

Based on these concerns and the input we received in response to the Request for Comments, ideally the FCC would guide those requesting 1610-1660.5 MHz user equipment authorizations for any such devices whose out-of-band emission limits into the nearby GNSS band exceed -100 dBW/MHz over any 2 millisecond active transmission interval to include the following showings:

(i) Ensuring the devices are incapable of operating in satellite mode on an airplane or when there are accessible terrestrial options for service.

(ii) Ensure that prior to operating in satellite mode the devices display a screen notifying the user of the prohibition of operating the device on an airplane and the risk of interference to nearby GPS operations

We are optimistic that these requirements can be implemented without practical consequence to the value of the devices and the remote-area service they are designed to provide. We further recommend that the FCC work with NTIA and industry to gather more information about these devices and their potential for causing harmful interference to critical GPS operations.

Attachment 2

Analysis of Potential Interference to GPS/GNSS from Emerging L-band MSS D2D and IoT Services

November 25, 2024

1 Overview

This paper assesses the potential impact of emerging L-band mobile satellite service (MSS) direct-to-device (D2D) and Internet of Things (IoT) services on Global Positioning System (GPS)/Global Navigation Satellite System (GNSS) receivers that are to receive interference protection in the 1559-1610 MHz Radionavigation Satellite Service (RNSS) allocation. The analysis considers only the emissions from terrestrial devices (e.g., D2D handsets and IoT equipment) up to the L-band MSS satellites. The main finding of this initial analysis as detailed in this paper is that emissions from L-band MSS D2D and IoT user equipment operating at 1610-1660.5 MHz, operating in compliance with the Federal Communications Commission (FCC) rules can result in interference to GPS/GNSS receivers operating in the 1559-1610 MHz RNSS band. The risks of interference to GPS/GNSS from L-band MSS Mobile Earth Stations (MES) are growing rapidly as D2D and IoT services are increasingly included in high-volume, daily-use consumer and industrial products (e.g., Apple phones and tablets).

Within this paper, MSS emissions in the 1559 – 1610 MHz RNSS band are hereafter referred to as out-of-band emissions (OOBE). Both OOBE and the fundamental transmissions in the 1610 – 1660.5 MHz MSS band are considered. The OOBE results apply to all L-band MSS operators. The fundamental transmission analysis in this paper was performed using available data for Ligado's specific uplink frequency bands of 1627.5 – 1637.5 MHz and 1646.5 – 1656.5 MHz. Results for other operators are not provided in the paper but are expected to be worse for operators using frequencies closer to the RNSS band.

FCC rules for L-band MSS mobile Earth stations that are applicable to emerging D2D and IoT services are summarized in Appendix A. A scenario in which MSS D2D equipment is operated onboard a commercial aircraft is presented in Appendix B.

2 Impact Assessments

2.1 Emissions in the GNSS Band

2.1.1 D2D Handset and IoT Device Emissions

D2D handset or IoT device emissions that fall within the 1559 – 1610 MHz RNSS allocation can cause degradation to GNSS receiver signal-to-noise-density (C/N0). The FCC rules for satellite services, contained within Part 25 of Title 47 of the Code of Federal Regulations (47 CFR Part 25)[1], include requirements applicable to D2D handset or IoT device emissions. 47 CFR 25.216, in particular, requires that the effective isotropic radiated power (EIRP) levels of MES with assigned frequencies within 1610 and 1660.5 MHz "…shall not exceed -70 dBW/MHz, averaged over any 2 millisecond active transmission interval, in the band 1559 – 1605 MHz."

Assuming a GNSS receiver noise floor of -201.5 dBW/Hz[2], Table 1 provides the separation distances needed to limit GNSS receiver C/N0 degradation to 1, 3, 6, and 10 dB assuming an isotropic receive antenna, free space path loss, and assuming a 3 dB polarization loss for linearly polarized transmissions being received by a right-hand circularly polarized antenna.

Table 1. C/N0 Degradation vs Separation Distance – GNSS Receiver with Isotropic Receive Antenna

Degradation to C/N0 (dB)	Received Interference Level (dBW/Hz)	Required Separation (m)
1	-207.4	79.1
3	-201.5	40.3
6	-196.8	23.3
10	-192.0	13.4

Using a model for the relative antenna gain pattern of a GNSS high precision receiver (HPR) towards a vertically polarized source at 1575.42 MHz[3] and assuming a maximum boresight gain of +3 dBic, Figure 1 shows the area around a single D2D device where the receiver could experience a 1, 3, or 10 dB C/N0 degradation. The plot assumes the D2D or IoT device is 2 m above the ground and that free space path loss conditions exist.

[1] https://www.ecfr.gov/current/title-47/chapter-I/subchapter-B/part-25.

[2] See, for example, ITU-R M.1903, https://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.1903-1-201909-I!!PDF-E.pdf. Five of 11 GNSS receiver types characterized in this recommendation have a system noise temperature of 513K, which equates to a -201.5 dBW/Hz noise floor. This level, -201.5 dBW/Hz, is also a standard noise floor assumption for certified GNSS equipment on aircraft; see, e.g., RTCA DO-235C.

[3] See Section 4.1.3.1 of the Department of Transportation (DOT)'s Global Positioning System (GPS) Adjacent Band Compatibility Assessment Final Report, https://rosap.ntl.bts.gov/view/dot/35535. Vertically polarized emissions for the D2D or IoT device is assumed.

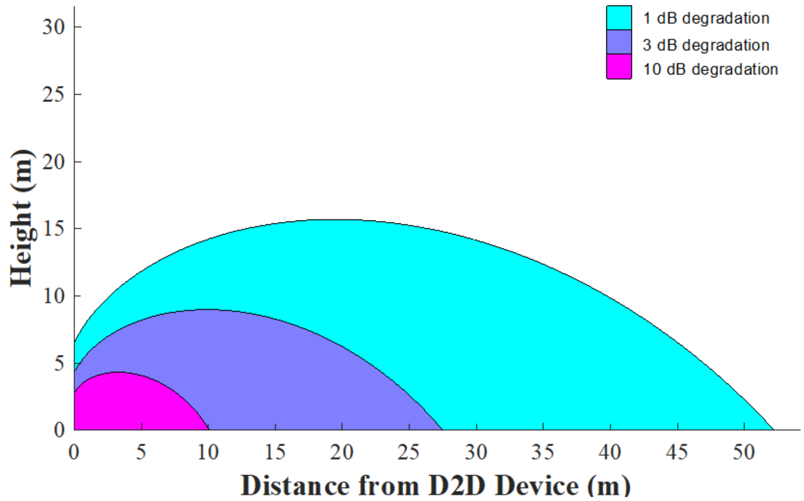


Figure 1. Impact on HPR due to -70 dBW/MHz Emissions in 1559 – 1605 MHz

The required lateral separations to keep a high precision GNSS receiver C/N0 degradation with the modeled antenna below 1, 3, or 10 dB shown in Figure 1 are slightly less than the results for a receiver with isotropic receive antenna in Table 1. This observation can be explained by the fact that a typical HPR antenna may have a gain towards a vertically polarized source at the horizon that is below 0 dBi. The results for other GPS/GNSS receiver classes are slightly worse (i.e., requiring additional separation for the same C/N0 degradation) since their noise floors are similar to HPR devices but they typically have higher antenna gain at low elevation angles (see Table 2). Sample calculations for the separation distances in Tables 1 and 2 are provided in Appendix C.

Table 2. Separation Distances from D2D Handset or IoT Device Necessary to Limit C/N0 Degradation for Various GPS/GNSS Receiver Classes

GPS/GNSS Receiver Class	Noise Floor, N0 (dBW/Hz)*	Required Separation to Limit C/N0 Degradation to 1, 3, and 10 dB (m)**
High precision (HPR)	-201.5	52.2 (1 dB), 27.5 (3 dB), 10.1 (10 dB)
General Location/Navigation (GLN)	-200.5	59.6 (1 dB), 31.0 (3 dB), 10.9 (10 dB)
Cellular (CEL)	-200.5 to -201.5	99.8 to 112.0 (1 dB), 50.9 to 57.1 (3 dB), 16.9 to 19.0 (10 dB)
Certified Aviation*** or General Aviation (GAV)	-201.5	66.7 (1 dB), 34.6 (3 dB), 12.2 (10 dB)

*Based upon receiver system noise temperature values in ITU-R M.1903.
**Using representative antenna gain patterns for each receiver class from https://rosap.ntl.bts.gov/view/dot/35535, and assuming the transmit antenna is at 2 m height above ground.
***See Appendix B for an assessment of a scenario in which the D2D equipment is operated by a passenger on a commercial aircraft.

A lower emission limit would reduce the impact area. For instance, Figure 2 shows the impacted area for HPR GNSS devices if the EIRP emissions in 1559 – 1605 MHz were reduced to -105 dBW/MHz (as required for Ligado ancillary terrestrial component [ATC] handset transmissions per the April 2020 FCC Order and Authorization[4]).

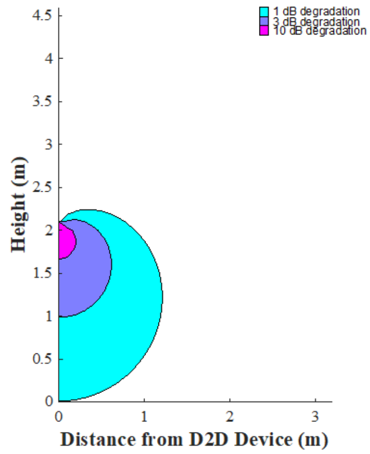
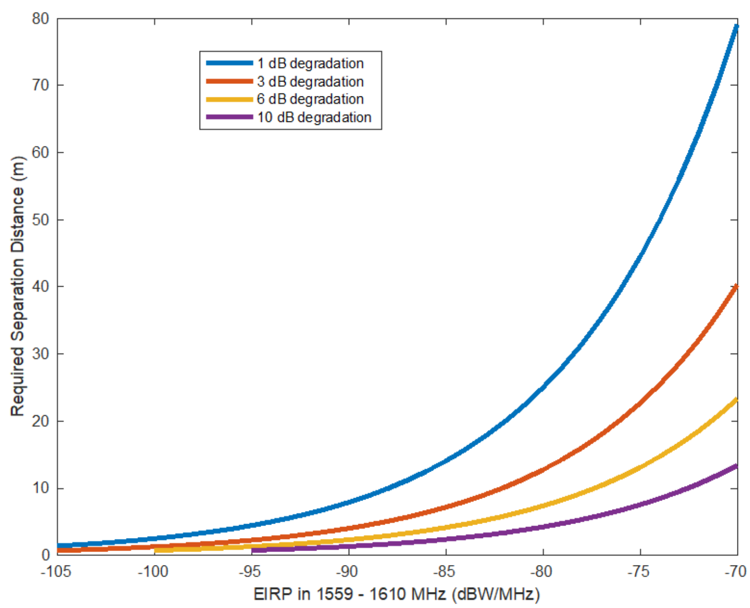


Figure 2. Impact on HPR due to -105 dBW/MHz Emissions in 1559 – 1605 MHz

For a GNSS device with an isotropic receive antenna and -201.5 dBW/Hz noise floor, Figure 3 presents required separation distances for 1, 3, 6, and 10 dB C/N0 degradations as a function of D2D and IOT device emission levels in 1559 – 1605 MHz.



[4] https://docs.fcc.gov/public/attachments/FCC-20-48A1.pdf.

Figure 3. Required Separation Distance vs D2D Emissions in 1559 – 1610 MHz to Limit GNSS Receiver C/N0 Degradation to 1, 3, 6, or 10 dB

The above results are similar to those provided to DOT GPS ABC Workshops by Greenwood Telecommunications Consultants LLC[5]. Greenwood additionally examined the impacts of multiple transmitters in the referenced presentations and recommended -105 dBW/MHz as a Ligado mobile device EIRP limit in 1559 – 1605 MHz.

2.2 Emissions in the Adjacent Band – Fundamental Emissions

2.2.1 D2D Handset and IoT Emissions

D2D handsets and IoT devices may operate with many center frequencies and at various power levels within the 1610 – 1660.5 MHz MSS band. In this section, one example is provided applicable to Ligado D2D operations. As noted earlier in Section 1, other L-band MSS operators are providing D2D/IoT services using frequencies closer to the 1559 – 1610 MHz RNSS band and may also utilize higher uplink transmit power levels. These services could therefore have a potentially greater impact on GPS/GNSS.

Again, as just one example of D2D/IoT operations, Ligado D2D handsets are expected to have a maximum EIRP of 23 dBm, use vertical polarization, and only operate in the 1627.5 – 1637.5 MHz and 1646.5 – 1656.5 MHz bands. These are the same emission characteristics as Ligado ATC handsets.

Extensive results for the impact of vertically-polarized, 23 dBm handset emissions at 1630 MHz are presented in Appendix I of the DOT GPS ABC Assessment Final Report (see footnote 3 for a hyperlink to this report). Some of these results, for the most sensitive device within each receiver class, are reproduced below. In these figures "ITM" corresponds to a 1 dB CNR degradation, "LOL_L" corresponds to loss of lock on low-elevation angle satellites, and "LOL_H" corresponds to loss of lock on high elevation angle (i.e., all) satellites. GLN = "General Location/Navigation" and TIM = "Timing" GNSS devices.

[5] See https://rosap.ntl.bts.gov/view/dot/34708 and https://rosap.ntl.bts.gov/view/dot/34710.

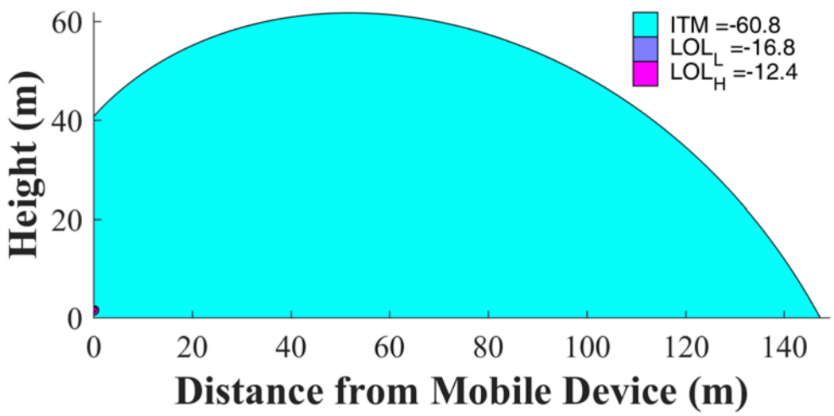


Figure I-124: Handset (EIRP = 23 dBm), Bounding GLN, 1630 MHz

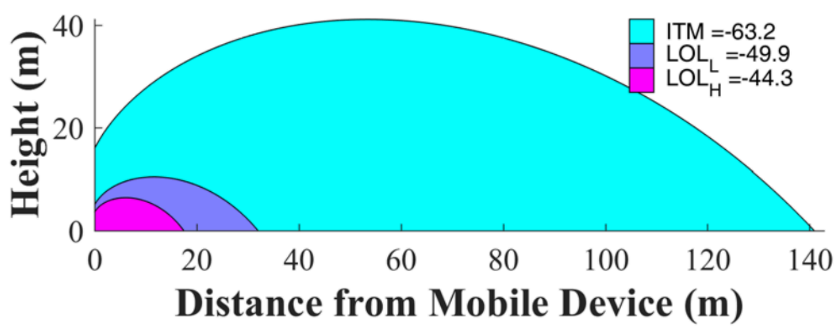


Figure I-132: Handset (EIRP = 23 dBm), Bounding HPR, 1630 MHz

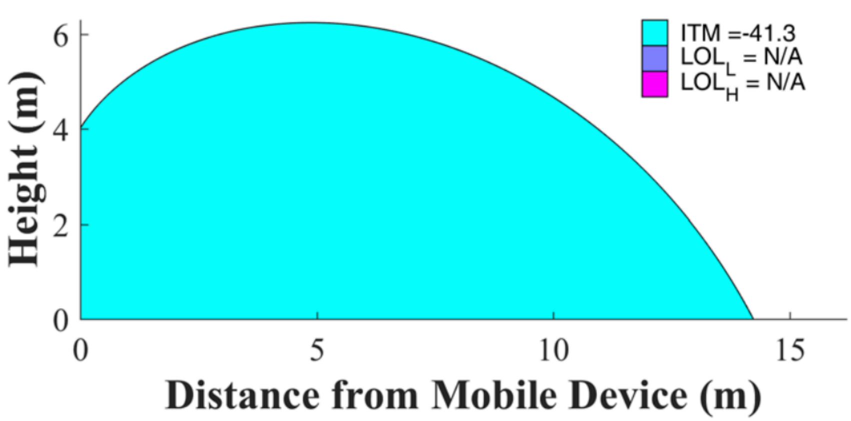


Figure I-140: Handset (EIRP = 23 dBm), Bounding TIM, 1630 MHz

IoT devices may transmit significantly higher power levels. For instance, on April 5, 2023, the FCC granted a blanket license to Skylo Technologies for up to 1,000,000 IoT devices to communicate to the Ligado Skyterra-1 and Inmarsat satellites in the 1525 – 1559 MHz and

1626.5 – 1660.5 MHz MSS bands[6]. The license permits EIRPs of up to 10W for IoT transmissions to Skyterra-1 and the Inmarsat MSS satellites. This EIRP limit is 50 times greater than the Ligado ATC handset EIRP limit of 200 mW and could impact sensitive GNSS devices at distances of up to almost 1 km. Each of the impact contour plots shown above would have the impacted region expand by a factor of 7 (since free space path loss falls off with distance to the transmitter squared and the IoT devices are approximately a factor of 7 squared more powerful than 23 dBm).

Importantly, the impact of the fundamental D2D handset and IoT device transmissions on GPS/GNSS receivers varies significantly with receiver model. The results presented above apply to the most sensitive device of all of those tested within each receiver class by DOT. As detailed in Appendix B of the DOT GPS ABC Assessment Final Report (link in footnote 3), for the HPR tand GLN receiver classes approximately a 50 dB difference in interference levels resulting in a 1 dB C/N0 degradation at 1630 MHz was observed between the most and least sensitive receiver.

3 Differences between L-band D2D and IoT Services and Historical Use of the Mobile Earth Stations

There have been MSS operations in the L band for over two decades now. Given that there have been no reports of interference from these operations to GNSS during this time, a reasonable question is: why should the GNSS community be concerned with interference at this point in time? There are several reasons for concern:

- Legacy L-band mobile earth stations (MESs) are expensive and sparse in number compared to anticipated D2D and IoT devices
    - We reviewed non-D2D/IoT products available from several prominent satellite equipment vendors[7], and L-band MES equipment are on the order of several hundred dollars or more. The equipment cost, and the additional costs for the required satellite service plan and usage fees limits the number of devices in use and also limits their operation in highly populated areas (where cellular communications is an available and cheaper option).
    - For comparison, D2D devices are anticipated to include millions of cellular phones that are owned and used on a daily basis by most U.S. citizens. Although D2D operations are expected to be mainly used when the users are out of cell coverage, with millions of devices in use it is likely that some transmissions will occur in populated areas (e.g., in cellular dead zones or when there is a radio propagation blockage in the direction of the cell tower). It is also possible that small D2D devices might be operated onboard aircraft (see Appendix B).

[6] https://docs.fcc.gov/public/attachments/DOC-392372A1.pdf.
[7] See, e.g., https://www.remotesatellite.com/collections/msat-tracking/ and https://satellitephonestore.com/catalog/search?q=msat.

- In addition to legacy MES and cellular phones with D2D capabilities, there are also emerging standalone L-band MSS D2D/IoT devices. Just one company, Skylo, has alone already received a blanket license for up to 1M IoT devices capable of transmitting to Skyterra-1. The Motorola Defy satellite link is a new D2D product that became available for purchase in the United States in June 2023. This device is small (3.4 × 2.5× 0.5 inches), battery-powered (with an advertised battery life of up to 4 days), and lightweight (2.5 ounces). It connects to iOS and Android smartphones through Bluetooth and enables smartphone users to send and receive text messages through MSS geostationary satellites, including those operated by Ligado and Viasat/Inmarsat. This device retails for $150 including a one-year service plan[8].

- Most existing MES include a GPS tracking capability. The vendor would thus have a need to ensure that MES emissions in the 1559 – 1605 MHz band are far below the -70 dBW/MHz level permitted by 47 CFR 25.216 in order to protect their own equipment's GPS operation. It is not clear that IoT device manufacturers would have the same incentive to achieve far better OOBE performance than required by the FCC rules, especially considering the market motivation to make IoT devices extremely low-cost.
- The FCC rules (47 CFR 25.285) prohibit MES capable of transmitting in the 1610 – 1660.5 MHz band from operating on civil aircraft unless its use is approved by the FAA or pilot. Further 25.285 requires that such MES cannot be "…sold or distributed to users unless it conspicuously bears the following warning: 'This device must be turned off at all times while on board aircraft.'" Unfortunately, the E-LABEL Act permits such warnings to be made available to the users of electronic devices digitally through a screen on a device display[9]. This digital display can oftentimes be difficult for users to find. For instance, on the iPhone 14, users would have to navigate to a "Legal & Regulatory" screen two levels deep under "Settings" to find the warning required per 47 CFR 25.285 against using on-board aircraft (see Figure 9).

[8] See, e.g., https://www.rei.com/product/227381/motorola-defy-satellite-link.
[9] https://www.govinfo.gov/content/pkg/COMPS-11324/pdf/COMPS-11324.pdf

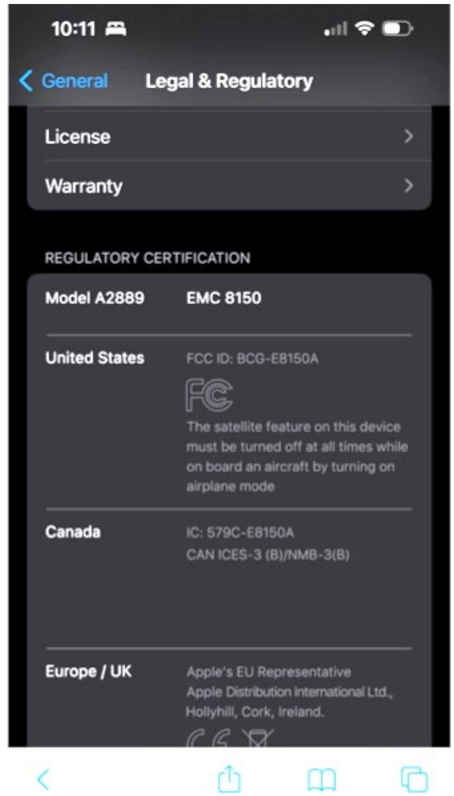


Figure 9. The Warning Against Use of the iPhone 14 Satellite Feature on Aircraft is Compliant with the FCC Rules after the E-LABEL Act but Obscured Two Levels Deep in the Settings Menu (Settings/General/Legal&Regulatory)

4 Summary

This paper assessed the potential impact of emerging L-band MSS D2D and IoT services on GPS/GNSS.

If D2D or IoT devices are minimally compliant with 47 CFR 25.216, out-of-band emissions from single or multiple D2D devices could degrade GNSS receiver performance at distances up to 50 m or more. Additional filtering cannot mitigate the problem since the interference is overlapping with the GNSS signals in frequency.

The fundamental emissions of L-band MSS terminals, including MES, D2D and IOT devices operating in the 1610-1660.5 MHz band can result in impact to GNSS devices at considerable distances. In this paper, as one example, 200 mW devices transmitting in 1627.5 – 1637.5 MHz were assessed to impact GPS/GNSS receivers at distances of up to 140 m. The FCC has authorized over 10 million mobile devices operate in L-band with EIRP of up to 10 W and at frequencies closer to the 1559 -1610 MHz band. These devices could cause GNSS receiver degradation at distances exceeding 1 km. The impacted distances are highly variable across

GNSS receivers, with the values cited above applying to the most sensitive receivers tested by DOT in 2016.

Finally, the paper identifies reasons why emerging L-band D2D and IoT operations may be problematic for GNSS even though reliant on existing MSS authorizations. Importantly, the primary concerns raised in this paper are applicable to MES, D2D and IoT devices with connectivity to any L-band MSS satellites with uplinks in the 1610 – 1660.5 MHz band. Thus, these issues are relevant to, e.g., Inmarsat/Viasat, Iridium, Ligado, and Globalstar MSS operations.

Appendix A. FCC L-band MSS Mobile Earth Station Rules

The FCC Rules for satellite services (47 CFR Part 25) include the following provisions related to L-band MSS operations:

- 25.216 – provides limits on mobile earth station emissions in the 1559 – 1610 MHz ARNS band. Per 25.216(c), “The e.i.r.p. density of emissions from mobile earth stations placed in service after July 21, 2002 with assigned uplink frequencies between 1610 MHz and 1660.5 MHz shall not exceed −70 dBW/MHz, averaged over any 2 millisecond active transmission interval, in the band 1559-1605 MHz. The e.i.r.p. of discrete emissions of less than 700 Hz bandwidth from such stations shall not exceed −80 dBW, averaged over any 2 millisecond active transmission interval, in the 1559-1605 MHz band.”
- 25.285 – prohibits operation of Earth stations capable of transmitting in the 1.5/1.6 GHz MSS frequency bands on board civil aircraft “unless the device is installed in a manner approved by the Federal Aviation Administration or is used by the pilot or with the pilot’s consent”. Further, portable Earth stations operating in these bands cannot be “…sold or distributed to users unless it conspicuously bears the following warning: ‘This device must be turned off at all times while on board aircraft.’”
- 25.287 – provides requirements for mobile Earth stations operating in the 1530 – 1544 MHz and 1626.5 – 1645.5 MHz bands to ensure compliance with Footnote 5.353A in 47 CFR 2.106 and US315.

Appendix B. MSS D2D Use on Commercial Aircraft

Overview

One location that many people encounter that is often without cellular or WiFi service is when flying aboard a commercial aircraft. Low-cost D2D equipment may easily be taken aboard an aircraft and a passenger may operate this equipment (without knowing it is illegal to do so) in the United States from a window seat. They might do so for a variety of reasons, e.g., to stay in touch with family and friends through text conversations while on the flight.

Potential for Interference

As noted in Section 2.1.1, MSS D2D devices are permitted to emit broadband noise in the GPS L1 band with an effective isotropic radiated power (EIRP) of up to -70 dBW/MHz from 1559 – 1605 MHz[10]. The path loss at the GPS L1 frequency from a vertically polarized antenna within a commercial aircraft to the right-hand circularly polarized GPS antenna on top of the aircraft fuselage can be as low as 54 dB[11]. This value was measured by Delta Airlines for a Boeing 737-800 aircraft. NASA, in cooperation with United Airlines, has measured values as low as 65 dB for Boeing 737 and 747 aircraft[12]. Figure 1 presents an example of these NASA path loss measurement results for a 737-200 aircraft measured from each window seat and also just inside each aircraft door.

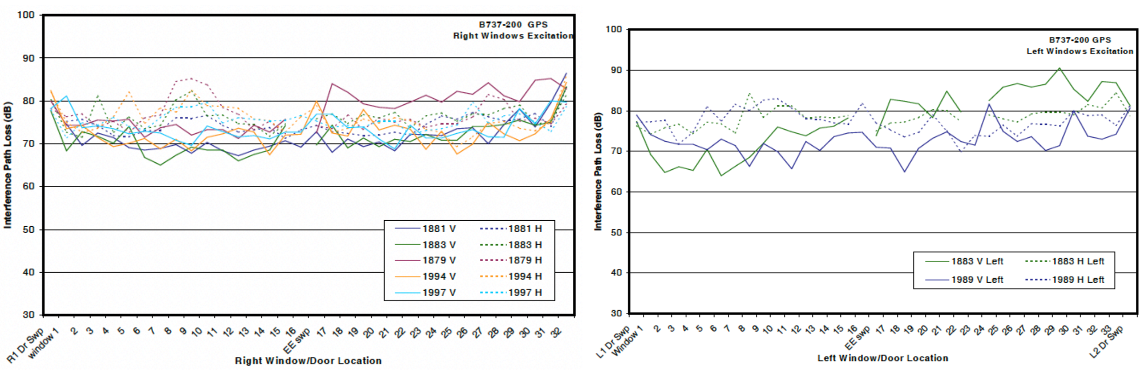


Figure 1. Measured Path Loss at 1575 MHz from Vertically Polarized Antenna Inside a Boeing 737-200 Aircraft to the Top-mounted GPS Antenna

Commercial aircraft GPS avionics are typically certified to able to tolerate in-band interference with a maximum power spectral density of -140.5 dBW/MHz at the output of the passive

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[10] See 47 CFR 25.216.

[11] See, e.g., Section E.5.2 of RTCA Document DO-235C, "Assessment of Radio Frequency Interference Relevant to the GNSS L1 Frequency Band,"

[12] See for instance https://ntrs.nasa.gov/api/citations/20030067884/downloads/20030067884.pdf and other NASA reports referenced within RTCA DO-235C.

antenna element while meeting all performance requirements after initial acquisition[13]. The interference from MSS D2D equipment could be much higher than this maximum tolerable level. For instance, for the worst-case location in a 737-800 aircraft measured by Delta Airlines, the -70 dBW/MHz permissible D2D equipment EIRP level within 1559 – 1605 MHz would result in -124 dBW/MHz received interference (16.5 dB higher than the required avionics tolerance). A more typical path loss from a window seat to the GPS antenna, based upon NASA's measurements (see Figure 2), is on the order of 70 dB. D2D equipment with a -70 dBW/MHz EIRP would still result in an excessive level of interference, -140 dBW/MHz, just above the maximum tested level for certified avionics[14].

Legality of Operating MSS D2D Equipment on Civil Aircraft

The FCC rules (47 CFR 25.285) prohibit operation of MSS equipment capable of transmitting in the 1.5/1.6 GHz MSS frequency bands on board civil aircraft "unless the device is installed in a manner approved by the Federal Aviation Administration or is used by the pilot or with the pilot's consent". Further, portable Earth stations operating in these bands cannot be "…sold or distributed to users unless it conspicuously bears the following warning: 'This device must be turned off at all times while on board aircraft.'"

Unfortunately, many consumers are not familiar with the FCC rules. Furthermore, the E-LABEL Act permits warnings such as that required in 47 CFR 25.285 to be made available to the users digitally through a screen on a device display. This E-LABEL provision makes it unlikely that the warning will be seen by most users. For instance, despite the Motorola Defy Satellite Link dongle being compliant with 47 CFR 25.285, nowhere in the user manual is it mentioned that the equipment should not be operated on an aircraft. The manual includes a cryptic section entitled "Viewing the E-label" that informs the user that an "E-label" can be found under a "Settings" menu within the Bullitt Satellite Messenger app used to send text messages on the users' smartphone. Only a user that bothers to look at this screen would find the warning shown towards the bottom of Figure 2.

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[13] See, e.g., Federal Aviation Administration Technical Standard Orders (TSO)-C145, -C146, -C161, -C196, -C204, -C205 and also International Civil Aviation Organization (ICAO) GNSS Standards and Recommended Practices (SARPs). Certified GPS equipment are less tolerant of interference during initial acquisition and are only required to perform this function with in-band interference at a level of -146.5 dBW/MHz.

[14] Note that the International Telecommunication Union (ITU) recommends a 6 dB safety margin between permitted interference levels and maximum tolerable levels for safety applications of GNSS such as aircraft navigation. See, e.g., ITU-R M.1903. Application of this safety margin would result in a much larger, 6.5 dB, excess of interference in this scenario.

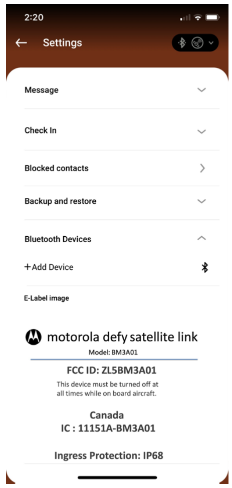

Figure 2. The Warning Against Use of the Motorola Defy Satellite Link aboard an Aircraft is Compliant with the FCC Rules, but Obscured in a Smartphone Application Settings Screen Unlikely to be Noticed by Most Consumers

Potential Mitigations

Equipment Performing Better than FCC Rules

The -70 dBW/MHz EIRP emission limit for broadband noise in the 1559 – 1605 MHz band is required by the FCC rules (47 CFR 25.216) for all L-band MSS transmitters including D2D devices. It is possible that some devices may perform substantially better than this limit. One Motorola Defy device that was tested for FCC equipment authorization appears to have broadband emissions that are ~10 dB better than the -70 dBW/MHz limit (see Figure 3). Unfortunately, this is not sufficiently lower to preclude the concern of interference if operated aboard a civil aircraft described above.

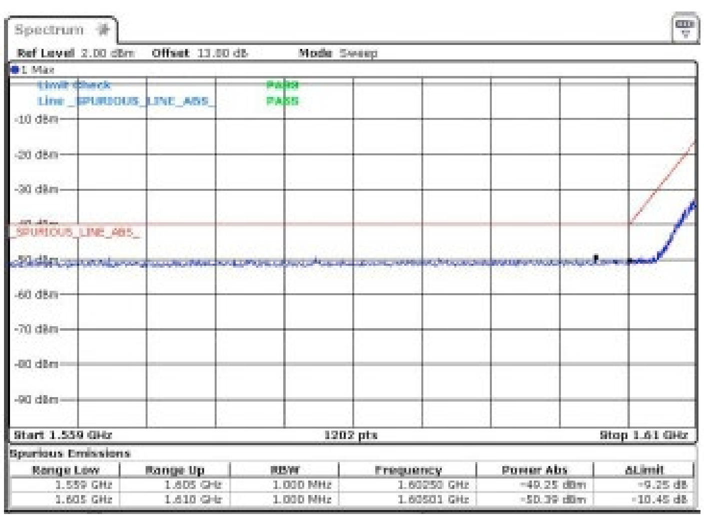

Figure 3. Measured Motorola Defy Satellite Link Broadband Emissions from 1559 – 1610 MHz from FCC Equipment Authorization Filing. Device appears to have lower emissions than the FCC -70 dBW/MHz limit in 1559 – 1605 MHz by ~10 dB.

Time Duration of Emissions

Currently available MSS D2D devices only permit short messages to be sent (e.g., ~140 characters for the Motorola Defy Satellite Link). MITRE has obtained two Motorola devices to measure the time duration of emissions (both the fundamental within the MSS band and also the out-of-band emissions within the 1559 – 1610 MHz GPS/GNSS band).

Noting that the use of GPS for aircraft navigation has some very strict continuity requirements, it is unlikely that even a short duration of emissions will be tolerable. For instance, for precision approach operations the International Civil Aviation Organization (ICAO) has adopted a continuity requirement that the probability that GPS is lost over an exposure period of 15 seconds must not exceed 8E-6. Furthermore, certified GPS avionics are not required to be able to continue to track GPS signals in the event that broadband interference exceeds -140.5 dBW/MHz, except if pulsed with pulse widths less than 125 microseconds and duty cycle less than 1%. Once tracking is disrupted, reacquisition within 20 seconds is only required if the receiver continues to track a set of satellites with good geometry and up to 5 minutes if not.

Summary

This appendix has identified a concern of interference from MSS D2D devices to GPS avionics on commercial aircraft. Such devices have only very recently become available at very low cost in the United States. This concern is currently unmitigated from such devices that do not operate with significantly lower RNSS band emission limits than the FCC RNSS emission limit contained within 47 CFR 25.216 for L-band MSS transmitters, including D2D and IOT equipment.

Appendix C. Separation Distances: Sample Calculations

Table 1 assumes a GNSS receiver with a right-hand circularly polarized isotropic receive antenna and a noise floor, N0, of -201.5 dBW/Hz referenced to the output port of the antenna. MSS MES emissions are assumed to be at the 47 CFR 25 limit of -70 dBW/MHz (= -130 dBW/Hz) and the MES is assumed to use a vertically polarized antenna. As an example of the calculations resulting in the separation distances within Table 1, consider the first row. A degradation of 1 dB in C/N0 results when the received interference power density, I0, at the output of the GNSS receiver antenna reaches a level of -207.4 dBW/Hz[15]. This received interference power density occurs at a distance, d, of 79.1 m using free space propagation loss for the GNSS center frequency of 1575.42 MHz with corresponding wavelength, λ = 0.1903 meters:

$$I0 = -130 \text{ dBW/Hz} - 20 \log_{10}(4\pi d/\lambda) - 3 = -207.4 \text{ dBW/Hz}.$$

The subtraction of 3 dB in the above equation is to account for polarization mismatch loss between an assumed vertically polarized MSS MES signal and the right-hand circularly polarized GNSS receive antenna.

Table 2 presents refined separation distance results using an average of representative measured GNSS receiver antenna gain patterns from Section 4.1.3.1 of the Department of Transportation (DOT)'s Global Positioning System (GPS) Adjacent Band Compatibility (ABC) Assessment Final Report, https://rosap.ntl.bts.gov/view/dot/35535. Vertically polarized emissions and a height of 2 meters for the MSS MES are assumed. As an example of the calculations, the first row in Table 2 assumes an HPR receiver with a -201.5 dBW/Hz noise floor. From the DOT's ABC report, and based upon measurements of multiple HPR antennas, Figure 1 below shows a modeled GNSS HPR receiver antenna gain pattern for a vertically polarized source. At a lateral distance of 52.2 meters the gain of this antenna on the ground towards a MSS MES at 2 m height is approximately -6.6 dBi. With this geometry, the slant range distance is ~52.2 meters and the received interference strength is:

$$I0 = -130 \text{ dBW/Hz} - 20 \log_{10}(4\pi d/\lambda) - 6.6 = -207.4 \text{ dBW/Hz},$$

resulting in a 1 dB increase over N0 (as explained in the footnote).

Note that since the GNSS antenna gain pattern that was used in this instance is based upon measurements with a vertically polarized source, no further polarization mismatch adjustment is required.

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[15]A detailed numerical explanation follows. $\left(\frac{N_o+I_o}{N_o}\right)_{dB} = 1\,dB \therefore \ (N_o + I_o)_{\frac{dBW}{Hz}} - N_{o,\frac{dBW}{Hz}} = 1\,dB \ \therefore$ $(N_o + I_o)_{\frac{dBW}{Hz}} = -200.5\ \frac{dBW}{Hz} \ \therefore \ N_o + I_o = 10^{-\frac{200.5}{10}}\frac{W}{Hz} \therefore I_o = \left(10^{-\frac{200.5}{10}} - N_o\right)\frac{W}{Hz} \therefore \ I_{o,\frac{dBW}{Hz}} = 10 * \log_{10}\left(10^{-\frac{200.5}{10}} - 10^{-\frac{201.5}{10}}\right)\frac{dBW}{Hz} = -207.4\ \frac{dBW}{Hz}$

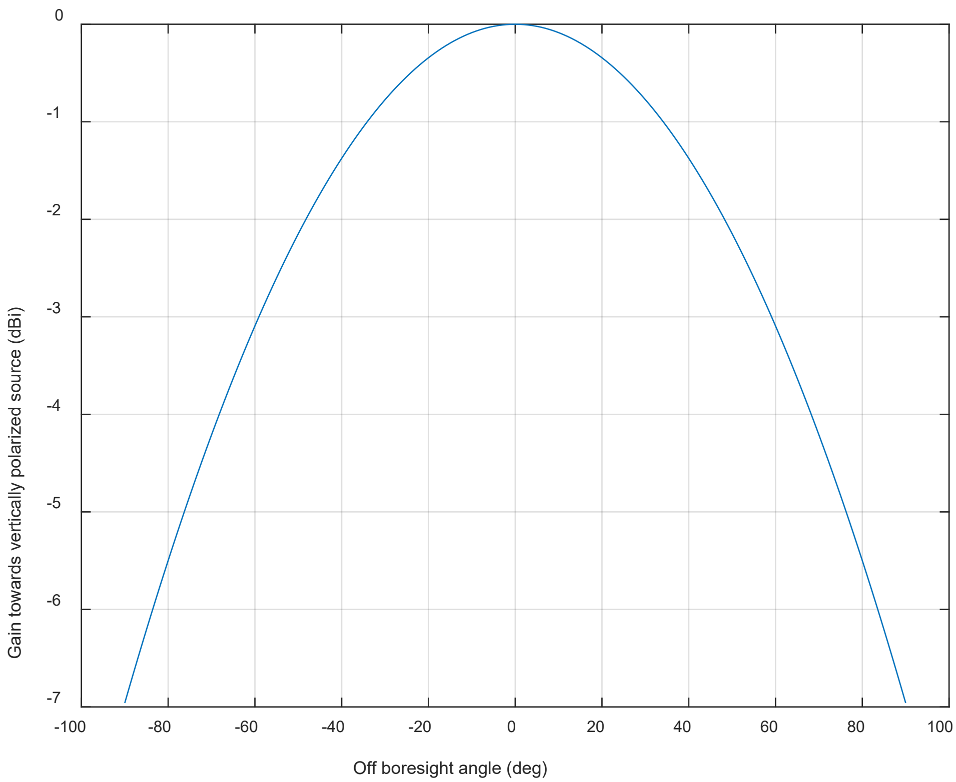

Figure 1. Representative HPR Antenna Gain Pattern towards Vertically Polarized Source