BEST PRACTICES FOR TERRESTRIAL-SATELLITE COEXISTENCE DURING AND AFTER THE C-BAND TRANSITION

TECHNICAL WORKING GROUP #1

REVISION 1.8

Co-chairs:

Neeti Tandon

Robert Weller

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TECHNICAL WORKING GROUP #1

1.0 EXECUTIVE SUMMARY

Best practices are emphasized in boxed text at the start of each section. 3.7 GHz Service operators and earth station operators should work cooperatively to avoid interference problems during the network design stage and continue to work cooperatively to resolve interference problems that may arise.

2.0 BACKGROUND

2.1 The *C-Band Report and Order and Order of Proposed Modification*

On March 3, 2020, the Federal Communications Commission ("FCC" or "Commission") adopted a Report and Order and Order of Proposed Modification[1] to expand flexible use of the 3.7–4.2 GHz band. Prior to the *C-Band Order*, the 3.7–4.2 GHz band was allocated in the United States for non-Federal use on a primary basis for the Fixed Satellite Service ("FSS") and the Fixed Service. Among other things, the *C-Band Order* adds a primary frequency allocation to the Mobile Service in the 3700–4000 MHz band. The service rules adopted in the *C-Band Order* designate 3.7–3.98 GHz for a new 3.7 GHz Service to support terrestrial broadband 5G networks within the contiguous United States ("CONUS").[2] The Order also establishes a 20 MHz guard band at 3980–4000 MHz, between the 3.7 GHz Service and FSS operations in the 4000–4200 MHz band, and adopts technical rules to protect FSS users from the new service.

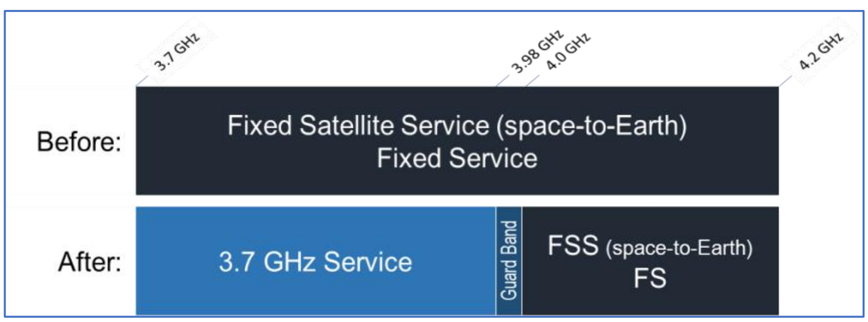

Figure 1: C-Band Reallocation

With the *C-Band Order*, and as shown in *Figure 1*, the FCC has reallocated the 3.7–4.0 GHz portion of the band for fixed and mobile use on a primary basis. The 280 megahertz from 3.7–3.98 GHz band will be auctioned by the FCC for wireless services in CONUS under the "3.7 GHz Service"

[1] *Expanding Flexible Use of the 3.7-4.2 GHz Band*, Report and Order and Order of Proposed Modification, 35 FCC Rcd 2343 (2020) ("*C-Band Order*"); *available at:* https://docs.fcc.gov/public/attachments/FCC-20-22A1_Rcd.pdf

[2] Sections 25.138(c) and 27.1411(b)(3) of the FCC's rules define which FSS earth station licensees and registrants are protected ("Incumbent Earth Stations"). 47 C.F.R. §§ 25.138(c), 27.1411(b)(3).

rules.[3] The 20 megahertz band (3.98–4.0 GHz) will serve as a guard band while existing FSS operations are repacked into the upper 200 megahertz (4.0–4.2 GHz) and afterward.

Noting that multi-stakeholder groups "have been successful in the past in providing the Commission with valuable insights and useful information regarding spectrum transitions for new uses," and believing "that such a multi-stakeholder group could provide valuable insight into the complex coexistence issues in this band and provide a forum for the industry to work cooperatively towards efficient technical solutions to these issues," the Commission "encourage[d] the industry to convene a group of interested stakeholders to develop a framework for interference prevention, detection, mitigation, and enforcement in the 3.7–4.2 GHz band."[4] The FCC "encourage[d] any multi-stakeholder group that is formed to consider best practices and procedures to address issues that may arise during the various phases of the C-band transition and to consider coexistence issues related to terrestrial wireless operations below 3.7 GHz."[5]

Technical Working Group #1 ("TWG-1") was formed as a subcommittee of the multi-stakeholder group convened following the adoption of the *C-Band Order* specifically to consider FSS-3.7 GHz Service coexistence issues and develop best practices for addressing interference resulting from 3.7 GHz Service deployments.

2.2 TWG-1 Scope of Work

When TWG-1 was convened in May 2020, the group members first decided upon the Scope of Work ("SOW") to be undertaken. The SOW was divided into four component functional elements based on the FCC's *C-Band Order*—specifically:

- Preventing interference
- Detecting interference
- Mitigating interference
- Interference "enforcement"

A number of issues were also initially identified that required clarification from the FCC. Each of the tasks under these elements are identified in Annex D.

2.3 Membership

In discussing the formation of a multi-stakeholder group, the FCC indicated that, "[t]o ensure that all viewpoints are considered, we encourage industry to include representatives of incumbent earth stations (including Multichannel Video Program Distributors ("MVPDs") and broadcasters), incumbent space station operators, wireless network operators, network equipment manufacturers, and aeronautical radionavigation equipment manufacturers."[6] As of October 29, 2020, there were 81

[3] 47 CFR Part 27.

[4] *C-Band Order*, 35 FCC Rcd at 2467 (¶ 333).

[5] *Id*.

[6] *Id*.

members of TWG-1, representing some 40 companies. A full list of the members of TWG-1 is provided as Annex B.

2.4 Contributions and Process

Written contributions within the agreed-upon SOW were solicited from TWG-1 members. A full list of contributions provided to TWG-1 is shown in *Table 1* below. All contributions are provided in the Annex shown in the table. Contributions were presented to the group by the author(s) and discussed by TWG-1 members, with revisions and edits made until the text was deemed acceptable by participants. It is important to note that while the participants were able to reach consensus on these contributions, not all concerns were fully resolved during the discussions and were ultimately not included in the consensus documents.[7] Also, some specific language in the consensus documents could not be fully agreed upon or was dependent upon information not available at the time they were presented and discussed. This non-consensus text is shown in [brackets] in the contribution documents. Non-consensus text was not used in developing these best practices.

Document No.	Contribution Description	Rev. Date	Annex
TWG1-001	TWG-1 Membership	9/30/20	B
TWG1-002	Scope of Work v1.2	5/18/20	D
TWG1-003	Carrier PFD and PSD Use in Prediction Models	7/16/2020	E
TWG1-004	Separation Distances	7/16/2020	F
TWG1-005	Interference Tracking Process	8/27/2020	G
TWG1-006	PFD Measurement Methodology	8/15/2020	H
TWG1-007	3.7 GHz Characteristics	7/2/2020	I
TWG1-008	Separation Distances based on AAS	9/10/2020	J
TWG1-009	Earth Station Passband Filters	7/22/2020	K
TWG1-010	PFD Measurement Concept	8/20/2020	L
TWG1-011	Interference at Low Elevation Angles	9/10/2020	M
TWG1-012	Mitigation Techniques	8/27/2020	N
TWG1-013	C-Band Filter Coupler Specifications	7/30/2020	O
TWG1-014	Temporary Fixed Earth Stations	9/9/2020	P

Table 1: TWG-1 Contributions

[7] Consensus refers to a group decision-making process in which participants develop and decide on proposals with the aim, or requirement, of acceptance by all. It does not emphasize the goal of unanimous agreement.

3.0 PREVENTING INTERFERENCE

The FCC adopted technical rules to encourage efficient use of spectrum resources and promote investment in the 3.7–3.98 GHz band while protecting incumbent users in adjacent bands. The *C-Band Order* adopted additional rules for 3.7 GHz Service licensees under Part 27 to implement safeguards to ensure that the potential for causing harmful interference to other services is minimized.

Key Best Practices for 3.7 GHz Service Licensees

- Each 3.7 GHz Service licensee should use the International Bureau Filing System ("IBFS") database to determine if its operations, in aggregate, would result in a Power Flux Density ("PFD") in excess of -124 dBW/m^2/MHz at the location of the receive antenna of any registered C-band earth station.
- For the purpose of interference modelling and to ensure co-existence between adjacent terrestrial and FSS systems, the 3.7 GHz Service network designs should incorporate FCC-mandated PFD limits (or equivalent calculated Power Spectral Density ("PSD") thresholds) into network designs to adequately protect C-band earth stations from potential interference.
- The predicted aggregate out-of-band emission PFD from all 3.7 GHz Service transmissions of an operator received in the FSS band (4.0 to 4.2 GHz) at incumbent protected FSS locations must remain below -124 dBW/m^2/MHz (typically equivalent to a PSD of -128 dBm/MHz).
- For the purpose of interference modelling, 3.7 GHz Service licensees should consider incumbent earth station sites within 26.6 km (free space value, assuming worst-case transmitter performance) for Out-of-Band Emissions ("OOBE") PFD compliance prediction.
- The predicted aggregate in-band PFD from all 3.7 GHz Service transmitters of an operator at incumbent protected FSS locations must remain below -16 dBW/m^2/MHz.
- OOBE levels, rather than in-band signal levels (receiver blocking limit), are likely to be the dominant factor in defining the minimum required separation distance from earth station locations.

Key Best Practices for FSS Operators

- FSS operators should ensure that information in the IBFS database, including contact information, is up-to-date and accurate since 3.7 GHz Service licensees will rely on that database for interference calculations during network design.
- FSS operators should ensure that a compliant 5G-rejection filter is installed on each antenna.
- In the event of interference, the earth station operator, using available equipment, should follow a process of elimination, clearing the easiest to identify potential interference sources first, then working to resolve increasingly difficult to clear sources.
- If monitoring indicates changes to terrestrial emissions in the 3.7–3.98 GHz band coincide with the interference event, then the earth station operator should follow the notification and resolution processes, providing available pre- and post-event monitoring data. If monitoring does not indicate any changes to the terrestrial emissions, earth station operators should proceed to next troubleshooting step.
- FSS operators experiencing interference should eliminate as many non-3.7 GHz Service sources as possible before contacting the 3.7 GHz Service licensee.

Key Best Practices Regarding Temporary Fixed and Transportable Earth Stations ("TES")

- To facilitate TES deployments, 3.7 GHz Service licensees are encouraged to consider potential TES locations during network design and to cooperate with TES operators when TES deployments are planned. TES operators are encouraged to provide best available deployment information for typical venues to 3.7 GHz Service licensees, and to pre-coordinate planned TES deployments with the point of contact ("POC") for local 3.7 GHz Service licensees.
- Each TES operator should provide an html link to a database containing the best available information on TES siting at common venues, including the associated Partial Economic Area ("PEA"). 3.7 GHz Service licensees are encouraged to review TES siting data for venues in their licensed markets to limit interference to TES sites where known.
- Consideration should be given to use of 5G rejection filters at the TES having performance better than required by the FCC and 3.7 GHz Service operators should consider external transmitter filters to reduce OOBE, but increased insertion loss and other factors may limit such options.
- Every effort should be made by both TES operators and 3.7 GHz Service licensees to resolve any potential interference prior to the commencement of TES operation.

3.1 3.7 GHz Service Licensee Responsibilities

The FCC's regulations imposed on 3.7 GHz Service licensees include both relevant technical operating rules and rules on operators with respect to how they design and operate their networks.

FCC Technical Operating Rules. To support robust deployment of next-generation mobile broadband services, the FCC rules allow base stations to operate at power levels up to 1640 Watts/MHz in non-rural areas and 3280 Watts/MHz Equivalent Isotropically Radiated Power ("EIRP") in rural areas. In addition, the FCC adopted mobile and base station OOBE requirements, similar to other services like the Advanced Wireless Service ("AWS"), to suppress emissions beyond their authorized bandwidth to a conducted power spectral density of -13 dBm/MHz.

FCC Rules on 3.7 GHz Service Network Operations. The FCC adopted technical rules governing how 3.7 GHz Service licensees must design and implement their terrestrial networks. In particular, the FCC's rules require 3.7 GHz Service licensees to deploy their base stations in a manner that protects FSS operations.

- *OOBE PFD Limit*. To protect Incumbent Earth Stations from OOBE from 3.7 GHz Service licensees, the FCC mandated that "the [PFD] of any emissions within the 4000–4200 MHz band must not exceed -124 dBW/m^2/MHz as measured at the earth station antenna."[8] While no specific limits have been provided, the FCC also cautioned that additional requirements may apply in Canadian and Mexican border regions due to international agreements.

- *Blocking PFD Limit*. It is possible that emissions operating at high power, even relatively removed in frequency, may overload an FSS receiving system in an adjacent band, also

[8] 47 C.F.R. § 27.1425(a). In the event of early clearing of the 3700–3800 MHz band, this limit will apply all emissions within the 3820–4200 MHz band. *C-Band Order*, 35 FCC Rcd at 2474 (¶ 360). The FCC found that "requiring compliance with a PFD limit is relatively simple and less burdensome on FSS earth station operators and 3.7 GHz Service licensees to implement than a [PSD] limit" and "avoids the complexity of registering complex antenna gain patterns for more than twenty thousand earth stations" and "avoids multiple angular calculations that would be necessary to predict PSD within each satellite receiver." *Id*., 35 FCC Rcd at 2475 (¶ 363).

known as “receiver blocking.” In addition to OOBE protection, the FCC adopted blocking limits applicable to all emissions within the 3.7 GHz Service licensee’s authorized band of operation. All 3.7 GHz Service licensee base stations and mobiles are required to meet a PFD limit of -16 dBW/m^2/MHz, as measured at the location of the earth station antenna, for all registered FSS earth stations. Such blocking effects can be mitigated with 5G-rejection filters designed to protect FSS earth stations from 3.7 GHz energy. FSS filter requirements and specifications are discussed in Section 3.2.2.

3.1.1 Calculation of Predicted PFDs in 3.7 GHz Service Network Design

The FCC based its PFD limit “on a reference FSS antenna gain of 0 dBi, interference-to-noise (I/N) protection threshold of -6 dB, a 142.8K FSS earth station receiver noise temperature, and results in a calculated PFD of -120 dBW/m^2/MHz.”[9] The FCC adjusted that PFD downward by 4 dB to obtain a PFD compliance limit of -124 dBW/m^2/MHz to protect earth stations from OOBE from all facilities of a single 3.7 GHz Service licensee.

Accordingly, each 3.7 GHz Service licensee should use the IBFS database to determine if its operations, in aggregate, would result in a PFD in excess of -124 dBW/m^2/MHz at the location of any registered C-band earth station. For the purpose of interference modelling and to ensure co-existence between adjacent terrestrial and FSS systems, the 3.7 GHz Service network designs should incorporate FCC-mandated PFD limits (or equivalent calculated PSD thresholds) to adequately protect C-band earth stations from potential interference.

The *C-Band Order* states that the FCC will use PFD measurements to determine compliance with the requirement to protect C-band earth stations from OOBE from terrestrial broadband networks deployed by 3.7 GHz Service licensees. The FCC adopted a PFD limit because compliance with a PFD limit can be measured independently using readily available test equipment (*e.g.*, spectrum analyzer or scanner) without requiring specific knowledge of either the design and engineering specifications of the terrestrial broadband network or the FSS equipment and antenna characteristics at the earth station site.

3.1.2 PFD to PSD Conversion

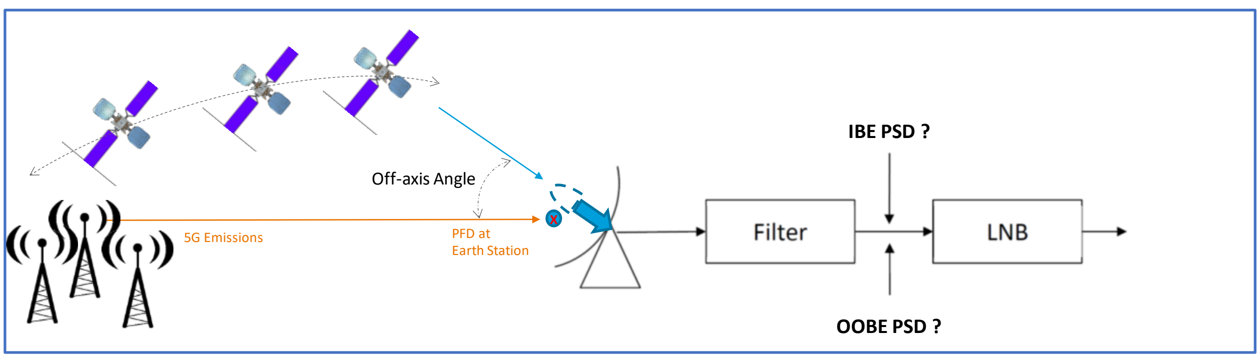

Figure 2: Calculation of aggregate In-Band and Out-of-Band 3.7 GHz Service PSD levels

As a practical matter, determination of the PFD from the OOBE of 3.7 GHz Service facilities is expected to involve measurement of PSD using a spectrum analyzer or scanner. This is illustrated in

[9] *Id*. The derivation of the FCC’s -124 dBW/m^2/MHz limit is discussed in Annex E.

Figure 2. *Equation 1* below calculates the aggregate PSD level (in dBm/MHz) at the low noise block downconverter ("LNB") input of the antenna corresponding to the PFD at the earth station.

$$PSD = \sum[PFD_i + G_{ES}] - L_F + A_e + C \qquad (1)$$

where:

G_{ES}	is the gain of the earth station antenna above an isotropic in the direction of the 3.7 GHz Service facility (*i.e.*, assumed to be 0 dBi in the *C-Band Order*)
PFD_i	is the maximum PFD per licensee (*i.e.*, -124 dBW/m^2/MHz for out-of-band emissions)
L_F	is the loss from the antenna feed to the LNA input, including filter, in dB (*e.g.*, 0.5 dB)
A_e	is the effective area of isotropic antenna in dB·m^2 (*i.e.*, for a 0 dBi antenna at 4 GHz, $10\log_{10}(\lambda^2/4\pi) \approx -33.5$ dB(m^2)
C	is the conversion from dBW/MHz to dBm/MHz (*i.e.*, 30 dB)

Thus, for the conditions assumed by the FCC, the maximum out-of-band emissions PSD from any one 3.7 GHz Service licensee is (–124 – 0 – 0.5 – 33.5 + 30) = -128 dBm/MHz at the earth station LNB input.

3.1.3 Use of PSD Threshold for Compliance Prediction in 3.7 GHz Service Network Design

For the purpose of predicting out-of-band emissions from 3.7 GHz Service networks, the interference power into a potential victim FSS receiver location is dependent upon the out-of-band emissions of the 3.7 GHz Service equipment, the path loss between the network and the FSS receiver location, and the gain of the 3.7 GHz Service antenna in the direction of the FSS location:

$$\mathrm{I} = \sum_{i=0}^{n} P_{TX,i} - L_{P,i} + G_{TX,i} \qquad (2)$$

where:

I	is the aggregated received interference PSD in dBm/MHz[10]
P_{TX}	is the conducted OOBE PSD in dBm/MHz from each transmitter of a 3.7 GHz Service licensee
L_P	is the propagation loss, including clutter losses as appropriate, between each antenna of a 3.7 GHz Service licensee and the FSS receiver in dB. No specific propagation model other than free space is considered in this document.

[10] Submissions in the C-band docket show that the OOBE level corresponding to -40 dBm/MHz can be achieved by 3.7 GHz service equipment with a 20 MHz offset from the band edge into the FSS band. *See, e.g.*, https://ecfsapi.fcc.gov/file/1081482808988/C-Band%20Reply%20Comments-Final.pdf; https://ecfsapi.fcc.gov/file/10807668903645/Nokia%20Comments%20on%203.7.pdf; https://ecfsapi.fcc.gov/file/12110329723187/Ericsson%203.7%20to%204.2%20GHz%20Reply%20Comments%20(12-11-2018).pdf.

G_{TX}	is the 3.7 GHz Service transmitter antenna gain in the direction of the FSS site in dBi (Note: OOB antenna gain/pattern may be different from in-band gain/pattern)

The predicted aggregate OOBE PSD from all 3.7 GHz Service transmissions of an operator received in the FSS band (4.0 to 4.2 GHz) at incumbent protected FSS locations must remain below -128 dBm/MHz assuming an earth station antenna gain of 0 dBi and a filter loss of 0.5 dB.

Equation 2 can also be applied to predict the aggregate in-band PSD from all 3.7 GHz Service transmissions of an operator in the 3.7 GHz band (3.7-3.98 GHz). The PFD limit ("blocking limit") is -16 dBW/m^2/MHz measured at the earth station antenna location, and the predicted aggregate in-band PFD from all 3.7 GHz Service transmitters of an operator at incumbent protected FSS locations must remain below -16 dBW/m^2/MHz.

3.1.4 Nominal Separation Distance Calculations

For network design purposes, TWG-1 calculated separation distances that may be required between a 3.7 GHz Service base station and FSS receivers to assist in defining the geographic scope of base stations for which routine interference calculations should be undertaken, based on OOBE from 3.7 GHz Service base stations. There is considerable variability in the required separation distances between 3.7 GHz Service and FSS systems, as the distance is highly dependent upon the 3.7 GHz Service equipment OOBE specifications, the 3.7 GHz Service antenna type, and the path loss between the 3.7 GHz Service transmitter and the FSS receiver. The analysis may be divided generally between 3.7 GHz Service passive antenna systems and active antenna systems ("AAS").

Passive Antenna systems. Commercially available passive base station antennas in the 3.7 GHz frequency range may have gains of 18.5 dBi or more.[11] The antenna gain outside of the intended in-band operating frequency range (3.7-3.98 GHz) likely will be no greater than the in-band gain for passive antenna types.

As shown in Annex F, assuming the maximum FCC-mandated OOBE of -13 dBm/MHz and a 3.7 GHz transmitting antenna having 18.5 dBi gain results in a calculation that beyond 26.6 kilometers (16.5 miles) it is unlikely that the OOBE PFD from a single 3.7 GHz Service facility would exceed -124 dBW/m^2/MHz, or that the PSD at the earth station LNB would exceed -128 dBm/MHz, assuming an earth station receive antenna gain of 0 dBi and a filter loss of 0.5 dB. Equipment manufacturers expect to produce base station transmitters having OOBE levels of -40 dBm/MHz or less, resulting in a lesser separation distance of about 1.2 km.

	3.7 GHz Antenna Gain = 18.5 dBi
OOBE Conducted Level	Distance
-13 dBm/MHz	26.6 km
-40 dBm/MHz	1.2 km

Table 2: Required Separation Distance Between Passive 3.7 GHz Service Antenna and FSS Site Based on Free-Space Conditions

[11] *See, e.g.*, PCTel base station antenna Model FP3637-18DP at https://www.pctel.com/wp-content/uploads/2018/11/VenU-FP-Series.pdf.

It should be noted that free-space calculations do not include the practical effects of terrain, clutter, etc. For example, the range of distances predicted using an implementation of the ITS Irregular Terrain Model reduces the free-space value of 26.6 km to 8.6–20.2 kilometers corresponding to situational variabilities (confidence levels) of 90% and 10%.[12] For the purpose of interference modelling, 3.7 GHz Service licensees should consider incumbent earth station sites within 26.6 km (free space analysis distance, assuming worst-case transmitter performance) for OOBE PFD compliance prediction.

Active Antenna Systems. Separation distances can similarly be derived between a single 3.7 GHz Service transmitter using an AAS that may be typical in 3.7 GHz Service networks and FSS earth stations. ITU-R Recommendation M.2101 states that the difference between a passive antenna system (*e.g*. based on Recommendation ITU-R Recommendation F.1336) and an AAS is that for the AAS, the unwanted (out-of-channel) emission will see a different antenna behavior compared to the wanted (in-channel) emission. The radiation pattern from non-correlated AAS elements can be assumed to be similar to that of a single antenna element.[13]

Using typical AAS antenna characteristics, Annex J models OOBE radiated from a single 3.7 GHz Service Sector antenna toward 1,000 randomly distributed earth stations placed within a 2.5 km radius of the base station and calculates the distribution of required separation distances shown in *Table 2*.

	AAS OOB Antenna Gain (Expected Fraction of Cases)		
OOBE Conducted Level	**≤ -23.6 dBi (7%)**	**≤ -5.6 dBi (49%)**	**≤ 4.4 dBi (96%)**
-13 dBm/MHz	0.2 km	1.5–2.0 km	5.5 km
-40 dBm/MHz	< 0.2 km	< 0.2 km	< 0.3 km

Table 2: Required Separation Distance Between 3.7 GHz Service AAS Antenna and FSS Site Based on Free-Space Conditions

Separation Distances Based on Blocking Limit. Distance separations can also be calculated between a compliant 3.7 GHz Service installation having an EIRP of 3280 or 1640 W/MHz and an earth station site, such that a PFD of -16 dBW/m^2/MHz is not exceeded at the site under free-space conditions. As shown in Annex F, a distance of 102 meters is obtained for 3280 W EIRP and a distance of 73.2 meters for an EIRP of 1650 W. These maximum distances are independent of the type of 3.7 GHz Service transmitting antenna.

In conclusion, OOBE, rather than the receiver blocking limit, is likely to be the dominant factor in defining the minimum required separation distance. Even so, there is a range of distances that can be calculated depending upon the 3.7 GHz Service equipment OOBE specifications and whether active or passive antenna systems are being used. In general, 3.7 GHz Service licensees are expected to use

[12] ITM v.1.5.5, Area mode, careful siting, TX and RX heights 15 m, Terrain roughness Δh = 12 m, Continental Temperate climate, Horizontal polarization, atmospheric refractivity 301 N-units.

[13] A 3.7 GHz system using an AAS will actively control all individual signals being fed to individual antenna elements in the antenna array in order to shape and direct the antenna emission diagram to a wanted shape, *e.g*. a narrow beam towards a user. In other words, the desired in-channel emissions are correlated among the antenna elements. The unwanted signal, caused by transmitter OOB modulation, intermodulation products and spurious emission components, will generally not experience the same degree of correlation from the antenna elements and will have a different radiation pattern with lesser gain.

the band to deploy advanced 5G networks that would utilize AAS and, therefore, have smaller required separation distances.

3.2 Obligations of FSS Incumbent Earth Station Operators

3.2.1 Accuracy of Information in IBFS database

FSS operators should ensure that information in the IBFS database, including contact information is up-to-date and accurate, since 3.7 GHz Service licensees will rely on that database for interference calculations during network design.

3.2.2 FSS Filter Requirements

A filter (5G-rejection filter) meeting certain requirements must be installed at the site of each incumbent earth station antenna at the same time or after it has been migrated to new frequencies to prevent harmful interference from licensees in the 3.7 GHz Service.[14] If an incumbent has not installed such a filter or is unable to demonstrate compliance with those requirements and the 3.7 GHz Service licensee can confirm it meets the blocking PFD level, the earth station operator will have to accept the interference.[15] For purposes of the interference protection criteria, the FCC specifies the 5G-rejection filter mask proposed by the C-Band Alliance as shown in *Table 3*.[16]

Frequency Range	**Attenuation**
From 3.7 GHz to 100 MHz below FSS band edge	-70 dB
From 100 MHz below lower FSS band edge to 20 MHz below lower FSS band edge	-60 dB
From 20 MHz below lower FSS band edge to 15 MHz below lower FSS band edge	-30 dB
From 15 MHz below lower FSS band edge to lower FSS band edge	0 dB

Table 3: FCC-Specified Minimum 5G-Rejection Filter Performance

For purposes of the transition, there will be two filters utilized by the satellite operators. The "Red" filter will have a passband of 3820–4200 MHz and will be used for certain earth stations during Phase I of the transition. The "Blue" filter will have a passband of 4000–4200 MHz and will be the end-state filter for the transition. The physical and performance characteristics of a current Red and Blue filter design are included as Annex K and a preliminary filter-coupler assembly specification as Annex O, which are provided for information purposes only. FSS operators should ensure that a compliant 5G-rejection filter is installed on each antenna.

[14] 47 C.F.R. § 27.1411(b)(5).

[15] *Id*.

[16] *C-Band Order*, 35 FCC Rcd at 2477 (¶ 367). The FCC stated, however, that "[w]e anticipate all stakeholders will work with manufacturers to obtain filters that have better performance characteristics than the baseline minimum specification if they are available." *Id*., 35 FCC Rcd at 2478 (¶ 371).

3.2.3 Elimination of Non-3.7 GHz Service Interference Sources

Earth station operators should recognize that if they experience interference, that interference may arise from sources that are unrelated to 3.7 GHz Service operations. Other interference sources can be divided into three categories: (1) noise or other unwanted emissions generated by the earth station equipment, (2) unwanted emissions generated by or retransmitted through the satellite being accessed or another satellite, and (3) emissions radiated from other (*i.e.*, non-3.7 GHz Service) terrestrially-based sources. The FSS operator, using available equipment, should follow a process of elimination, clearing the easiest to identify potential interference sources first, then working to eliminate increasingly difficult to clear sources.[17] This process should include: (i) looking for signs of terrestrial interference by monitoring 3.7–4.2 GHz; (ii) checking earth station equipment; (iii) checking the satellite link; and (iv) checking for other potential sources of interference. Each is discussed below.

Look for Signs of Terrestrial Interference by Monitoring 3.7–4.2 GHz. By monitoring the 3.7–4.2 GHz spectrum at the site/facility where interference is observed, earth station operators can compare pre- and post-incident spectrum captures to determine if significant changes occurred coincident with interference observations. If possible, FSS operators should document existing conditions across the 3.7-4.2 GHz spectrum prior to the likely deployment of any 3.7 GHz Service facilities. This monitoring can be accomplished in at least two different ways. First, if available, a spare earth station antenna at the site with no 5G rejection filter (*i.e.*, legacy 3.7–4.2 GHz filter/LNB) can be set up as shown in *Figure 3*, which allows for monitoring across 500 MHz (3.7–4.2 GHz) at the earth station for interference detection and resolution:

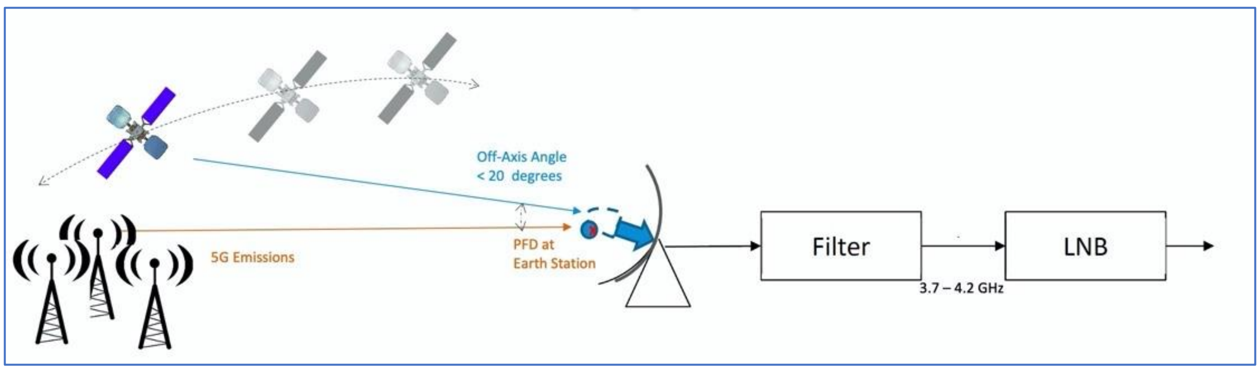

Figure 3: Interference Detection Using a C-Band Earth Station Antenna Without a 5G-Rejection Filter

A second option is to install a modified earth station filter[18] with coupled port to monitor 3.7–4.2 GHz (one per site), if available, as shown in *Figure 4*, which allows for full-band (3.7–4.2 GHz) monitoring through a -30 dB coupling port at the earth station for interference detection and resolution:

[17] Note that this section addresses only interference within the updated satellite C-band (4.0–4.2 GHz) from 3.7 GHz sources. If interference from an adjacent frequency source above or below this definition is identified, some version of filtering should be considered.

[18] See Annex O.

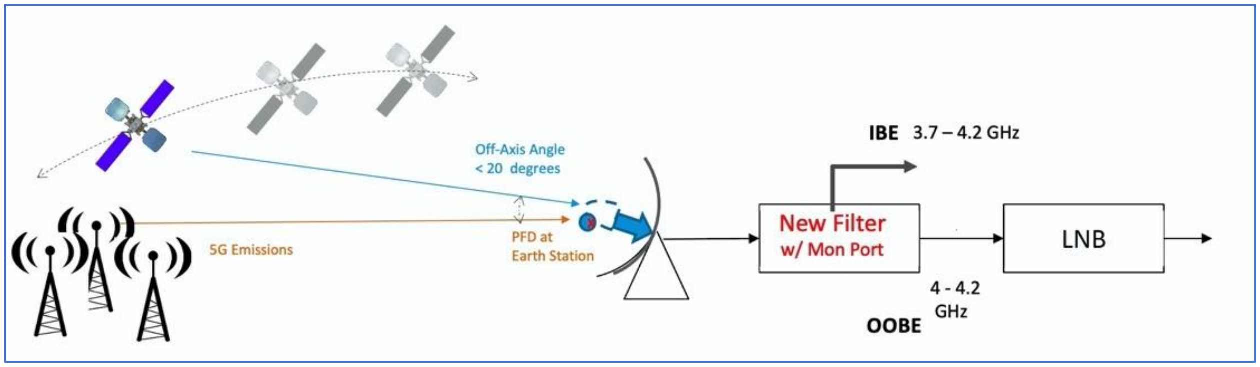

Figure 4: Interference Detection Using a Modified C-Band Earth Station 5G-Rejection Filter

If monitoring indicates changes to terrestrial emissions in the 3.7–3.98 GHz band that coincide with the interference event then the earth station operator should follow the notification and resolution processes discussed in Section 4, providing available pre- and post-event monitoring data. If monitoring does not indicate any changes to terrestrial emissions, earth station operators should proceed to the next troubleshooting step.

Check Earth Station Equipment. Earth station operators should consider whether there were any maintenance or operational changes in progress when the signal degradation started. If so, the operator should reverse the changes and confirm fault clearance. The operator should also investigate whether there were there alarms that would indicate equipment failure as opposed to only signal failure (interference) when the signal degradation started. If so, the operator should take action with the alarming equipment. Operators should also, if possible, look at the in-house signal flow with a tool such as a spectrum analyzer or network analyzer to understand where the interference is and is not.

Check the Satellite Link. If it seems the interference is not self-generated, or if an earth station operator does not have the proper testing tools to determine that,[19] the operator should begin coordinated efforts with the satellite operator to determine whether interference may be from the space segment. Satellite issues can include:

- *Satellite equipment failure*. If satellite equipment failure has occurred, the satellite operator should be well aware of the issue and will likely be busily responding to the problem when contacted.

- *Adjacent satellite interference ("ASI")*. If the cause is ASI, it is possible that either the earth station operator's receiving antenna is off peak and needs adjustment, or that a third-party is operating an uplink using a mis-pointed antenna. If an uplink is off peak, the satellite operator will be able to identify the issue and should be able to track down the offending earth station to get them to correct it.

- *Cross-Polarization interference*. Cross-Pol typically arises because either the polarization of an operator's receiving antenna is off peak and needs adjustment, or a third-party is uplinking with misadjusted polarization. If an uplink is not optimally polarized the satellite operator

[19] Looking at the signal with a tool such as a spectrum analyzer may confirm any signal distortion on the inbound and/or outbound signal.

will be able to identify the issue and should be able to track down the offending earth station to get them to correct the issue.

Check for Other Potential Sources of Interference. Interference from another earthbound emitter is referred to as terrestrial interference ("TI"). If an earth station operator is able to clear both its own facility and the satellite link, then some emitter in relatively close proximity to the satellite receiving antenna may be causing the interference. The FCC license database[20] may offer a list of licensed potential interference sources physically near the earth station location operating within, or close to, C-band. It is also possible the emitter is not individually licensed (which is the case with the 3.7 GHz Service), in which case a database will not help to identify specific base station locations but can provide information on the licensees authorized in an area.[21]

The use of a spectrum analyzer and directional antenna may help determine the direction of the interfering emitter. In some cases, the direction alone may be sufficient to visually identify the likely emitter. In other cases, taking bearings from more than one location and plotting the lines on a map can be used to locate the emitter.[22] The three-dimensional propagation of RF energy can complicate identification of such emitters. If either the earth station and/or the interfering emitter is located in an urban area with many flat reflective buildings, it may be challenging to locate the source. In such cases, or if the operator does not have directional antenna testing capabilities, a third-party technical resource may be helpful to track-down the source of interference. FSS operators experiencing interference should eliminate as many non-3.7 GHz Service sources as possible before contacting the 3.7 GHz Service licensee.

3.3 Coordination of Occasional Use Satellite Operations

Temporary Fixed and Transportable Earth stations (TES) do not operate at a fixed location (latitude and longitude) but instead can be authorized to operate anywhere within CONUS. TESs are often used for the origination of video content from sports venues or other locations where newsworthy events are occurring, often with minimal advance notice. As a result, locations for TES antennas are often determined in consultation with the owner of the venue, considering many location-specific factors including, among other things, satellite line-of-sight, prime power availability, connections to video/audio/data feeds, and local traffic laws. The locations used for TES antennas may not be the same from event to event at the same venue.

To facilitate TES deployments, 3.7 GHz Service licensees are encouraged to consider potential TES locations during network design and to cooperate with TES operators when TES deployments are planned. TES operators are encouraged to provide the best available deployment information for specific venues to 3.7 GHz Service licensees, and to pre-coordinate planned TES deployments with the POCs for local 3.7 GHz Service licensees.

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[20] Most terrestrial transmitters are licensed through the FCC's Universal Licensing System ("ULS") database. ULS permits the public to conduct "point-radius" searches within specified frequency bands. *See* https://www.fcc.gov/wireless/systems-utilities/universal-licensing-system?job=home.

[21] If the earth station operator has not already exchanged POC information with 3.7 GHz Service licensees, ULS can be used to identify the licensees in the area. Users should search for active 3.7 GHz Service licenses and specify a "geographic search," which will allow the user to specify the state and county of their earth station and retrieve a list of all market area licensees for that county.

[22] Further information is provided in Section 4.

Each TES operator should provide a link to an online database containing the best available information on TES siting at common venues, including the associated PEA of that venue. 3.7 GHz Service licensees are encouraged to review the TES database for venues in their licensed markets to limit the potential for interference to TES sites where known.

Generally, once a TES deployment is planned for a specific event at a venue, the 3.7 GHz Service licensee(s) should be notified of the date and times of the deployment, as well as the specific operating location and additional technical details, including satellite and transponder, if known. This notification could be done by a third-party, such as a frequency coordinator. When possible, TES operators should attempt to coordinate their antenna siting at the venue with 3.7 GHz Service Licensees and venue owners to minimize the potential for interference. Consideration should be given to selecting higher satellite transponders and frequencies, where possible, to minimize the potential impact of OOBE from 3.7 GHz Service operations. Where flexibility exists with respect to locating the TES antenna, measurements should be conducted to minimize the potential for interference.

The close proximity of 3.7 GHz Service operations to TES sites may increase the likelihood of both blocking and out-of-band interference. Consideration should be given to use of 5G rejection filters at the TES antenna having performance better than required by the FCC, and 3.7 GHz Service operators should consider external transmitter filters to reduce OOBE. It is noted that increased insertion loss and other factors may limit such options.

At many venues, the precise location and operational characteristics of TES are often determined with little advance notice and the duration of transmission is often limited to hours, such as the duration of a football game. Every effort should be made by both TES operators and 3.7 GHz licensees prior to the commencement of any TES operation to resolve any potential interference issues.

4.0 INTERFERENCE DETECTION

Should an incumbent earth station operator experience interference that it believes to be attributable to 3.7 GHz Service operations, procedures are defined below to guide resolution between the parties. The resolution processes describe slightly different procedures depending upon whether the 3.7 GHz Service licensee is engaged in the initial network roll-out (Section 4.1) or in the ordinary course of network operation (Section 4.2). A suggested method for measuring PFD and identifying potential sources of interference is also provided (Section 4.3). As an overarching matter, however, the procedures defined apply a business-to-business approach, where parties initially attempt to resolve interference in a timely manner without FCC intervention. Earth station operators should feel free to contact the FCC's Enforcement Bureau if interference from 3.7 GHz Service licensee's facilities is not resolved in a timely manner.

In order to accommodate this business-to-business approach, recognizing that earth station operators desire a rapid resolution to any interference from 3.7 GHz Service licensees upon detection, it is suggested that 3.7 GHz Service licensees have a single POC to enhance communication. 3.7 GHz Service licensees should further recognize that earth station operators will likely not have the test equipment necessary to make PFD measurements at earth station location(s) initially (although they may have this capability in the future). Contracting out the measurements to a third-party is an option but would likely be ineffective in identifying interferer(s) quickly, which may be necessary in urgent or complex interference cases. Initially, interference concerns will be treated the same by 3.7

GHz Service licensees in terms of response, regardless of severity. However, the process should evolve to a sliding schedule for urgent versus nuanced interference problems.

Earth station operators, in engaging this interference resolution process, should verify that they have installed a bandpass filter meeting the specifications of the *C-band Order*.[23] They should also recognize that the FCC's IBFS will be used by the 3.7 GHz Service licensee as the primary means to obtain incumbent earth station information (including location and height). Any differences between IBFS data and actual deployments should be reconciled by the earth station operator, and IBFS information should be appropriately maintained. Earth station operators should, however, reach out to 3.7 GHz Service Licensees at their single point of contact and provide local contact data for their own operations, which should be viewed as superseding the contact information in IBFS.

Incumbent earth stations are defined as those earth stations described the *C-Band Order*,[24] and set forth in the list published by the FCC's International Bureau on October 23, 2020,[25] as well as any subsequent modifications to that list that may be authorized or directed by the FCC. It is noted that the list includes both authorized and pending earth station data and that specific location information on 41 earth stations, including TES facilities, is not reflected in IBFS or in the published list.[26]

Key Best Practices

- 3.7 GHz Service licensees and earth station operators should exchange point-of-contact ("POC") information for all earth stations located inside or within 26.6 kilometers of the boundary of each PEA where the 3.7 GHz Service entity is licensed and may operate.
- POC information should be updated within [n1] days if needed by both earth station operators and 3.7 GHz Service licensees when contact information or personnel are changed.
- If an earth station operator experiences interference, the earth station operator should initially take steps to determine whether the interference is coming from a 3.7 GHz Service licensee or another source
- 3.7 GHz Service licensees identified as likely sources of the interference according to the measurement procedures shall demonstrate compliance with the -124 $dBW/m^2/MHz$ PFD per licensee aggregate limit.
- 3.7 GHz Service licensees will respond to the earth station POC within [n2] hours and will work in good faith with the earth station operator to resolve the interference issue within [n3] [hours][days], including in situations in which measured or predicted PFD levels at the earth station location are compliant, yet the earth station continues to experience interference.
- In cases where the earth station experiences a complete outage that is coincident in time with the commissioning of a new 3.7 GHz Service facility, the identified 3.7 GHz Service operator shall make prompt adjustments to determine the root cause and eliminate the interference in the fastest possible manner.

[23] *See id.*, 35 FCC Rcd at 2476-78 (¶¶ 367–370).

[24] *Id*., 35 FCC Rcd at 2392 (¶ 116).

[25] International Bureau Releases Updated List of Incumbent Earth Stations In The 3.7-4.2 GHz Band In The Contiguous United States, *Public Notice*, DA 20-1260 (rel. October 26, 2020); *available at:* https://docs.fcc.gov/public/attachments/DA-20-1260A2.xls (last visited November 4, 2020)).

[26] A request is pending with FCC staff for its opinion on whether certain other earth stations (not on the published list) are required to be protected with respect to PFD limits.

- In cases where the earth station experiences degradation (*e.g.*, increased error rate) that is coincident in time with the commissioning of a new 3.7 GHz Service facility but is nonetheless usable, the 3.7 GHz Service operator shall make appropriate adjustments to determine the sensitivity and interference impact.
- Earth station operators, prior to engaging this interference resolution process, should verify that they have installed a 5G-rejection filter meeting the specifications in the C-band Order.
- IBFS information should be appropriately maintained.

4.1 Resolution Process During Initial 3.7 GHz Service Network Site Builds

Recognizing that initial network deployments may reveal immediate issues that may be more likely to be the result of 3.7 GHz Service activity, an initial process is defined below and intended to specify procedures that would be followed as 3.7 GHz Service licensees are engaged in the initial deployment of terrestrial networks in a region (as opposed to the more steady-state, and routine expansion and reconfiguration of established 3.7 GHz Service networks). Even before this process is engaged, however, 3.7 GHz Service licensees and earth station operators should exchange POC information for all earth stations located inside or within 26.6 kilometers of the boundary of each PEA where the 3.7 GHz Service entity is licensed and may operate. That POC information should be updated within [n1] days by both earth station operators and 3.7 GHz Service licensees if contact information or personnel are changed.

If an earth station operator experiences interference, the earth station operator should initially take steps to determine whether the interference is coming from a 3.7 GHz Service licensee or another source, as discussed in Section 3.2.3. If the earth station operator experiences interference that appears to be from a 3.7 GHz Service facility, the earth station POC should contact the 3.7 GHz Service licensee POC with the following minimum information and any available supporting material on the nature of the interference observed.

Service Impact	
	Outage: satellite(s) and transponder(s) affected
	Degradation: satellite(s) and transponder(s) affected
Earth Station Antenna(s) Impacted	
	IBFS registration/callsign
	Location (Latitude and Longitude) of Earth Station
	Earth station azimuth/elevation angles to affected satellites
	Antenna height above ground
Time/Duration. Time when interference was observed and duration, if applicable (date/time in UTC)	
Supporting Details. Any supporting information, as available, that would help resolve interference	
	Pre- and post-interference spectrum plots at earth station location (3.7–4.2 GHz)
	SNR or E_b/N_o change at the receiver with respect to reference baseline (normal operating conditions), if available.

3.7 GHz Service licensees identified as likely sources of the interference according to the measurement procedure in Section 3.3 shall demonstrate compliance with the -124 dBW/m^2/MHz PFD per licensee aggregate limit.

3.7 GHz Service licensees will respond to the earth station POC within [n2] hours and will work in good faith with the earth station operator to resolve the interference issue within [n3] [hours][days]. This includes situations in which measured or predicted PFD levels at the earth station location are compliant with FCC rules, yet the earth station continues to experience interference from a 3.7 GHz Service licensee(s).[27]

In cases where the earth station experiences a complete outage that is coincident in time with the commissioning of a new 3.7 GHz Service facility, the identified 3.7 GHz Service operator shall make prompt adjustments to determine the root cause and eliminate the interference in the fastest possible manner. In cases where the earth station experiences degradation (*e.g.*, increased error rate) that is coincident in time with the commissioning of a new 3.7 GHz Service facility but is nonetheless usable, the 3.7 GHz Service operator shall make appropriate adjustments to determine the sensitivity and interference impact.

4.2 Ongoing Process Following Initial 3.7 GHz Service Network Site Builds

After 3.7 GHz Service networks are initially deployed, the process defined in this Section 4.2 will be used to resolve potential interference issues between terrestrial operators and earth stations. This process assumes the earth station operator has determined to the extent possible that the interference is coming from a 3.7 GHz Service licensee under the procedures defined in Section 3.2.3. In such cases, the earth station operator, to the extent technically feasible and consistent with good engineering practice, should make measurements to determine compliance with the PFD limits specified in FCC Rules 27.1423(a) and 27.1423(b).[28] The earth station POC should also contact the POCs for the local 3.7 GHz Service licensees to alert them of the interference. To assist in the identification and remediation of interference issues, the earth station operator should be prepared to provide the following information:

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[27] 47 C.F.R. §§ 27.1423(a), (b).

[28] *Id*.; *see also* Section 3.3.

Entity Information	
	Earth station operator
	Earth station type (MVPD, TV Broadcast, TES, *etc*.)
	Call sign
	Street address, city, state, zip
	Contact information (name, phone number, e-mail, as appropriate)
Interference location	
	Location(s) where interference is being received, including latitude and longitude
Services affected and interference description	
	Service(s) affected (*e.g*., video, audio, one transponder, all transponders, frequency range, *etc*.)
	Service down, service intermittent, more/less than 50% degradation, *etc*.
Additional information	
	Steps taken to diagnose the problem, results of test and measurements conducted, other remedial action taken, *etc*.
	Monitoring data of emissions in 3.7–4.2 GHz (if available)
	PFD measurements (if available)

3.7 GHz Service licensees should respond to any inference complaint within [n2] hours. 3.7 GHz Service licensees should also work in good faith with the earth station operator to resolve any interference complaint within [n3] [hours][days]. This process includes situations in which the PFD levels at the earth station location meet or exceed (comply with) the limits specified in FCC Rules 27.1423(a) and 27.1423(b), yet the earth station continues to experience interference from a 3.7 GHz Service licensee(s).[29] Resolution time may depend on severity of interference and the information provided.

4.3 PFD Measurement Concept and Identification of the Source of Interference

A methodology has been proposed to measure total out-of-band PFD from all received signals (including those belonging to different 3.7 GHz Service licensees) and identify the strongest in-band 3.7 GHz Service cell sites. This methodology cannot be directly translated and compared to FCC compliance thresholds that define an aggregate PFD per licensee.[30] For purposes of compliance determination, the procedure and setup in Section 6.1 would be followed.

This proposed method is technology neutral, oriented toward maximizing the accuracy of the measurements, and does not require information about the 3.7 GHz Service licensee base station characteristics (antenna height, power levels, transmitter spectral mask, location, etc.). At a high level, the methodology measures the PSD in any one megahertz in the 4000–4200 MHz FSS band, converts the measurement to an equivalent PFD, defines a geolocated area for likely 3.7 GHz Service

[29] 47 C.F.R. §§ 27.1423(a)-(b).

[30] *See, supra*, Section 3.1.1; 47 C.F.R. § 27.1425(a).

interference sources, and provides a list of the associated 5G-NR Physical Cell ID ("PCI") Synchronization and Signal Block ("SSB") beams.

As an overview, the PSD is measured using a Real Time Spectrum Analyzer ("RTSA"). The RTSA is fed by a very directive, high-gain, passive antenna that is directly connected to a bandpass filter ("BPF") and a Low Noise Amplifier ("LNA").[31] The directive antenna is installed on a computer-controlled antenna rotator. The signal from the LNA output is split two ways with one output connected to RTSA and the second output to an IMT scanner. The IMT scanner identifies the list of 5G-NR PCI SSB Beams.

Due to the BPF, the list of identified PCIs will be limited to the strongest base station signal levels at the measurement location. A Command and Control Unit (built using a laptop and special software) will be used to:

- Control the antenna rotator;
- Control the RTSA measurement of out-of-band PSD;
- Correlate the out-of-band PSD measurement with the position of antenna rotator and the list of 5G-NR PCI Beam SSBs; and
- Map the results as the azimuth of the antenna (at 1 dB beamwidth) at maximum out-of-band PSD with a list of the strongest observed 5G-NR PCI Beam SSBs.

A generated report may be sent to 3.7 GHz Service POCs. The high-level measurement concept is illustrated in *Figure 5*:

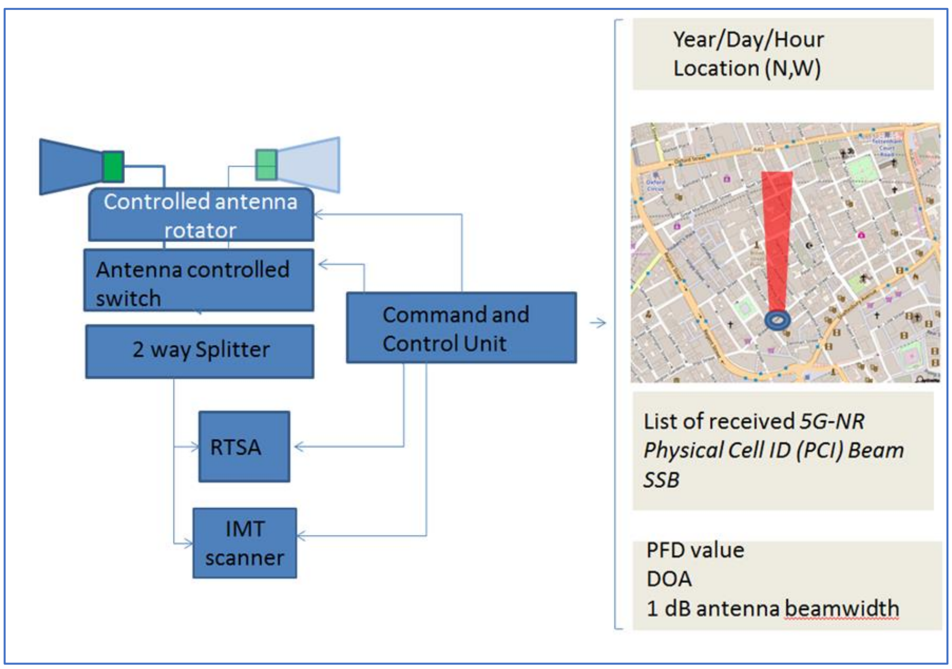

Figure 5: High-Level Measurement Description

[31] Considering the very low levels to be measured, the filter and the LNA must be directly connected to the antenna, since any supplementary attenuation on the RF chain between the antenna and LNA decreases the signal to noise ratio.

Notably, other relevant information from the IMT scanner (*e.g.*, SSB index) can be included if the 5G licensees find it helpful in more rapidly identifying cell sites. The method is described in greater detail in Annex L.

Interference hunting procedures may be necessary starting from this point. The association of a PCI on the same angle of arrival as the interference will generally facilitate the identification of the relevant base station. In some particular cases, such as when line-of-sight between the base station and earth station is obstructed or if the base station antenna sector is oriented in the opposite direction, the interfering signal can be received from a reflection point and further investigations should be conducted.

5.0 INTERFERENCE MITIGATION

This section discusses a variety of techniques that could be employed to mitigate interference at an FSS earth station due to 3.7 GHz Service base stations. This section offers a number of potential remediation mechanisms that might be undertaken by a 3.7 GHz Service licensee at its base station or, in some cases, at the earth station facility, to mitigate interference at the earth station. This is intended to be a toolbox of options for 3.7 GHz Service licensees to mitigate the impact of 5G base stations on earth stations. These options are non-exhaustive.

Key Best Practices

- Potential interference mitigation techniques for 3.7 GHz Service licensees include reducing base station power, improving base station filter rejection, reorienting base station antennas, implementation of 5G active antenna systems, engineering increased path loss using terrain and clutter, and beam nulling.
- Potential interference mitigation techniques for FSS operators include changing transponder or satellite, shielding FSS antenna, improving FSS link margin, and improving the 5G rejection filter.
- TES vehicles may require a spectrum analyzer, Mobile Network Scanner and other specialized equipment (including engineer training and specialized antennas) to rapidly identify 3.7 GHz Service operators and specific sites (*i.e*., capture PLMN identifier, System Information Blocks, Physical Cell Identifiers, etc.) that may be causing interference.
- Relocation of a TES antenna, even by a few feet when possible, may help reduce interference levels.
- TES operators are encouraged to include any site-specific mitigation and interference resolution measures that were previously successful in the TES venue database.
- Earth station operators and 3.7 GHz Service licensees in areas where low elevation angles are used should consider additional measures to mitigate potential or actual interference, including potentially recalculating the PFD at the earth station, making appropriate adjustments to eliminate the interference.

5.1 Mitigation Techniques at 3.7 GHz Service Base Stations

- ***Reduce Base Station Power***. OOBE should be directly related to base station power, so reduction of the operating power of a base station should reduce OOBE interference.

- ***Improved Base Station Filter Rejection***. In some cases, OOBE levels could be decreased by using/adding external filters to the 3.7 GHz Service transmitter.

- ***Reorienting Base Station Antennas***. Most 3.7 GHz Service antennas are likely to be directional, so it should be possible to adjust the main beam orientation to minimize the power directed at the FSS location. To the extent a site does not already employ a directional antenna, sectorized antennas can be deployed.

- ***Implementation of 5G Active Antenna Systems***. 5G systems deployed in the 3.7 GHz Service band are expected to be able to take advantage of new, high-performance AAS. Better OOBE performance in the direction of the earth station receiver may be possible by deploying an AAS at the offending base station if not already so equipped.

- ***Engineering Increased Path Loss by Taking Advantage of Clutter and Terrain***. In certain cases, a 3.7 GHz Service base station antenna could be relocated (*e.g*., side-mounting an antenna on a building rather than top mounting, decreasing base station height, etc.) to take advantage of natural and man-made clutter to attenuate transmissions in the direction of the FSS site.

- ***Beam Nulling***. For 5G base stations that employ AAS, modification of the Pre-Coder Matrix Index may be possible to create antenna "nulls" toward FSS antennas.

5.2 Mitigation Techniques at the FSS Earth Station

- ***Transponder/Satellite Change***. Consider changing the transponder or serving satellite used to avoid use of a channel that is close to the 3.7 GHz Service band, creating additional frequency separation and greater attenuation, or avoiding a satellite with a look angle that places the base station close to the main beam of the earth station antenna.

- ***Shielding FSS Antennas***. Depending upon the earth station site location and azimuth/elevation to the satellite in use, it may be possible to add additional shielding (such as a berm) at the earth station site between the 3.7 GHz Service transmitter and the FSS antenna.

- ***Improve FSS Link Margin***. In some cases, it may be possible to improve the link margin at an earth station facility by, for example, deploying a larger antenna with a narrower operating beamwidth, or replacing other equipment.

- ***Improved 5G Rejection Filter***. In some cases, it may be possible to employ a 5G-rejection filter having performance greater than required in order to further reduce in-band 3.7 GHz Service signal levels.

5.3 Mitigation Techniques for Occasional Use Deployments

Because of the limited duration of the events, TES and 3.7 GHz Service licensees should work together in good faith prior to the commencement of and during any TES operation to resolve any potential interference as rapidly as possible by using all interference mitigation tools available for both systems to coexist. TES vehicles may require a spectrum analyzer, Mobile Network Scanner and other specialized equipment (including engineer training and specialized antennas) to rapidly identify 3.7 GHz Service operators and specific sites (*i.e*., capture PLMN identifier, System Information Blocks, Physical Cell Identifiers, etc.) that may be causing interference problems.

Due to the likely close proximity of 3.7 GHz Service sites to TES facilities at major venues, mitigation performed solely by TES operators may not be adequate to eliminate the interference. Certain mitigation options (such as change of satellite, change of transponder frequency and/or polarization, use of terrestrial facilities, improvised interference shielding techniques, frequency band changes, and location moves) will not be available in many cases, due to restrictions described in Section 3.3, as well as restrictions due to the associated TES uplink frequency coordination requirement, which protects terrestrial fixed wireless licensees. Additionally, the close proximity of 3.7 GHz Service sites to TES increases the likelihood of multipath interference as described in Section 3.3 and may make some TES mitigation options ineffective. Relocation of the TES antenna, even by a few feet when possible, may help reduce interference levels.[32]

Additionally, event venues during major events are also locations where 5G coverage is critically needed and will likely be densely deployed, because such venues involve high densities of users anticipated to be engaged in a variety of multimedia activities (including AR/VR/video) and communications in support of public safety and welfare. Wireless providers during an event may have a limited ability to engage in *ad hoc* network changes to mitigate interference concerns. Physical mitigations such as antenna down tilting, reorienting sectors, or filter installation may be infeasible given the timing. The ability to perform 3.7 GHz Service network modifications during an event may be similarly restricted.

A process for Earth station and satellite operators experiencing interference to contact 3.7 GHz Service licensees with interference concerns is described in Section 3.3. The outcome of that process for specific TES venues should also document interference history by location, past complaints, actions taken to diagnose and mitigate the interference, and the final outcome of the interference case. This information can be used for mitigating future interactions between TES and 3.7 GHz Service facilities, but additional measures may be needed by both TES and 3.7 GHz Service licensees. TES operators are encouraged to include site-specific mitigation and interference resolution measures in the TES venue database that were found to be previously successful.

5.4 Mitigation Techniques and Low Look Angle Earth Stations

A possible scenario where interference from 3.7 GHz Service transmitters to FSS receivers can occur despite compliance with the PFD limits is in situations where the earth station antenna is oriented such that the gain is not 0 dBi in the direction of the 3.7 GHz Service facilities. This situation may arise particularly when an earth station in the eastern CONUS is receiving signals from a geosynchronous satellite stationed toward the Western end of the U.S. domestic satellite arc. As discussed more extensively in Annex M, such earth station antennas will have lower elevation angles above the horizon, which may place one or more 3.7 GHz Service facilities nearer to the main beam of the earth station antenna resulting in a gain in excess of the reference 0 dBi.[33]

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[32] Multipath or reflections present unique concerns for TES since they are often surrounded by vehicles, street signs, buildings and the like at a live entertainment or sporting event. This phenomenon is especially troublesome for TES operations near downtown urban locations and where 3.7 GHz nodes may be very close. When possible, prior to the event, measurements should be conducted to select the best possible location for TES to minimize potential interference, directly or indirectly from 3.7 GHz Service facilities.

[33] Similarly, Earth stations located in some southern CONUS regions might have higher elevation angles to satellites, which might result in gain below 0 dBi in the direction of 3.7 GHz facilities and would afford the Earth station with added margin. *See C-Band Order*, 35 FCC Rcd at 2474 (¶ 359).

Based upon the current list of incumbent earth stations published by the FCC, there are approximately 129 earth station sites corresponding to an elevation angle of 19° toward the 123°W orbital slot, and approximately 1813 earth station antennas corresponding to an elevation angle of 19° toward the 135°W orbital slot.[34] The list of incumbent earth stations in the 3.7–4.2 GHz spectrum may change. Earth station operators and 3.7 GHz Service licensees in these areas should consider the following recommendations to mitigate potential interference and to resolve actual interference:

- To avoid possible interference to earth stations having low elevation angles (and associated azimuth angles), a list of earth station locations can be developed and used to help avoid 3.7 GHz Service antenna orientations corresponding to FSS sites with low elevation angles. This list can be used by 3.7 GHz Service licensees in network designs to identify specific base station antenna orientations that may result in interference in excess of the I/N protection criteria of -6 dB (or increase the likelihood of blocking). An illustrative list of earth stations that have calculated elevation angles less than 19° toward the 135° W orbital slot is provided in Annex M.

- In the event interference from a 3.7 GHz Service facility (or facilities) is observed at an earth station and PFD levels are determined to be compliant, the 3.7 GHz Service licensee should check if the FSS is on the list of incumbent earth stations corresponding to low look angles. If so, a possible resolution to eliminate the interference could be to re-calculate the required PFD at the earth station and make appropriate adjustments in order to comply with other protection criteria, using the actual earth station orientation (azimuth and elevation angles). It is noted that TES antenna locations are not specified in the list of incumbent earth stations.

- Case-specific negotiations between 3.7 GHz Service licensees and FSS operators may be appropriate.[35]

6.0 INTERFERENCE "ENFORCEMENT"[36]

6.1 A Method for Measuring OOBE PFD

This section defines a methodology and test procedure to measure the OOBE PFD of 3.7 GHz Service licensees operating in the 3.7–3.98 GHz frequency band impacting FSS incumbents in the 4.0–4.2 GHz band. The methodology will result in a determination of compliance with the requirement that the maximum per licensee aggregate PFD is limited to -124 dBW/m^2/MHz at incumbent earth station sites. The methodology is defined assuming no knowledge of the specific site locations of each 3.7 GHz Service licensee.

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[34] International Bureau Releases Updated List of Incumbent Earth Stations in the 3.7–4.2 GHz Band in the Contiguous United States, *Public Notice*, DA 20-1260 (rel. October 26, 2020).

[35] *See id*.

[36] It is recognized that enforcement of the FCC's rules is the responsibility of the FCC and that there is no right of private action. However, proper PFD measurements conducted by qualified persons should be recognized by all parties as definitive (as opposed to predicted PFD values).

Key Best Practices

- Due to the complexities associated with directly measuring OOBE per licensee, PFD compliance is estimated from in-band 3.7 GHz Service licensee Received Signal Strength Indication ("RSSI") measurements, along with the application of the associated transmitter out-of-band emission masks.
- SSB measurements can help to identify a list of potential interferers from all 3.7 GHz Service licensee transmissions for mitigation purposes.
- All equipment should be calibrated prior to measurement execution.
- Channel power measured in PSD units should be converted to its PFD equivalent.

General Approach

1. Perform FSS in-band PSD (RSSI) measurement to assess impact of 3.7 GHz Service transmissions and convert them to PFD equivalents.

2. If the results of Step 1 show PFD levels above -124 dBW/m^2/MHz, then identify 3.7 GHz Service licensees with sites deployed within 26.6 km.

3. Perform in-band 3.7 GHz Service measurements for each licensee utilizing a 5G-NR capable scanner to measure cell/beam-specific 5G-NR Synchronization Sub Block ("SSB") Reference Signal Received Power ("RSRP"). This step enables the generation of a priority list of the strongest cell/beam contributors to enable licensee mitigation (possibly executed prior to Step 4). It is expected that there will be some correlation between the cells with the strongest measured SSB RSRP and those with the largest contribution to the OOBE interference in the FSS band.

4. Assess PFD compliance utilizing the following:

   a. Perform in-band 3.7 GHz Service RSSI measurements for each licensee identified in (2). Estimate the aggregate, per licensee PFD through application of a transmitter signal emission mask. Based upon filings with the FCC by three equipment manufacturers,[37] it is believed that conducted OOBE levels of -40 dBm/MHz or less will be achieved 20 MHz above the 3.7 GHz Service channel edge (*i.e.*, at 4.0 GHz for the highest 3.7 GHz Service channel) and beyond. This conducted PSD value can be used to determine a reference (assumed) mask if the actual transmitter OOBE performance is not available. The actual OOBE performance information may be provided by the licensee and may vary depending upon the deployed infrastructure. For a licensee's outdoor network deployments, however, it is likely that a common radio infrastructure and associated emission mask will be deployed within each geographic area. OOBE performance information may also be available from transmitter

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[37] *See* Comments of Ericsson (Dec. 11, 2018), available at: https://ecfsapi.fcc.gov/file/12110329723187/Ericsson%203.7%20to%204.2%20GHz%20Reply%20Comments%20(12-11-2018).pdf

Comments of Nokia (Aug. 7, 2019), available at: https://ecfsapi.fcc.gov/file/10807668903645/Nokia%20Comments%20on%203.7.pdf

Comments of Samsung (Aug. 14, 2019), available at: https://ecfsapi.fcc.gov/file/1081482808988/C-Band%20Reply%20Comments-Final.pdf manufacturer filings with the FCC. Per licensee compliance is determined by assessing adherence to a maximum PFD of -124 dBW/m^2/MHz.

b. If a 5G-NR scanner is available, information transmitted by the Sync Sub Block (SSB) and System Information Blocks (SIBs) can be used to determine an SSB reference signal conducted power level in the 3.7 GHz Service channel. For example, in 5G-NR standalone mode, if SIB1 shows +20 dBm for a 30 kHz subcarrier spacing system, this would correspond to a 3.7 GHz Service PSD of 35.2 dBm/MHz (20 dBm + $10log_{10}\left(\frac{1\,MHz}{30\,kHz}\right)$). Assuming -40 dBm/MHz as the OOB PSD gives a rejection of 75.2 dBr (35.2 – (-40) dBm/MHz), relative to the SSB power.

c. The ratio of a PSD or PFD measurement taken in a 3.7 GHz Service channel can thus be used to infer the OOBE PSD or PFD in the 4.0–4.2 GHz satellite band. Note that not all 3.7 GHz Service systems may use 30 kHz subcarrier spacing and there may be differences in the radiated power level of the SSB and traffic channels.

Step 1: PFD Utilizing 5G-NR Licensee In-band RSSI Measurements

In this step the RSSI in-band to each 3.7 GHz Service licensee is assessed at the FSS location. OOB PFD compliance in the FSS band is determined by applying an appropriate transmission mask to the measured values. The calculation methodology used to determine OOB PFD compliance is shown in *Table 5* and assumes that the base station antenna gain is identical both in-band and out-of-band.

	Parameter	**Value**	**Units**	**Comments**
a	Frequency	3800	MHz	Input (example)
b	Wavelength	0.079	m	
c	Measurement Antenna Gain	5.00	dBi	Input (example)
d	Gain - linear	3.16		
e	Effective Antenna Aperture	0.00157	m^2	$e = \frac{b^2}{4\pi} d$
f	Measured RSSI	-46.85	dBm	Input (example)
g	RSSI in dBW	-76.85	dBW	$g = f - 30$
h	Transmission mask attenuation at the FSS operating frequency	75.2	dB	Input (example, see text)
i	RX Power in FSS band	-152.05	dBW	$i = g - h$
j	Rx BW	1.00	MHz	Input (example)
k	Rx Power Flux Density	-124.00	dBW/m^2/MHz	$k = i - 10\log(e) - 10\log(j)$

Table 5: PFD determination utilizing in-band 3.7 GHz Service licensee measurements

Considerations for this approach include:

- Determination of appropriate OOBE transmission mask: Ideally, it would be provided by the licensee and may vary with the deployed infrastructure.

- The measured RSSI includes contributions from all sources associated with the 3.7 GHz Service licensee's band of operation that are within the measurement receiver's bandwidth. As stated earlier, the RSSI measurement will vary depending upon the loading of the 3.7 GHz Service licensee network (assuming 5G-NR is deployed).

- In this approach, an antenna with an omnidirectional pattern in the horizontal plane can be utilized without impacting the ability of the procedure to detect potentially interfering 3.7 GHz Service licensee signals.

Step 2: Utilization of 5G-NR Physical Cell ID (PCI) Beam SSB RSRP measurements to enable interference mitigation

In this step, individual base station sectors of each 3.7 GHz Service licensee are assessed for their likely contribution to that licensee's aggregate interference in the FSS band. Here, the RSRP of each SSB of the observed 5G-NR signals are measured. In 5G-NR, the SSB is transmitted periodically with a fixed power level that does not change as the traffic load on the cell varies. SSB RSRP measurements are therefore repeatable and have no dependence on system loading. Maximum potential total RSSI from any base station can be determined based on the known SSB RSRP, its configuration, and the potential beamforming methodology utilized for traffic carried on the data channel (Physical Downlink Shared Channel ("PDSCH")). An additional advantage of this approach is that interference assessment will only include contributions from the specific licensee that operates on the channel being measured.

The use of this approach also enables 3.7 GHz Service licensees to proactively monitor and mitigate changes in RSSI without repeating measurements. Provided there are no physical base station adjustments or beamforming configuration changes, the RSSI contribution of a base station can estimated based on maximum load or any load (present or future).

To assess the likely contribution of each site/sector to the measured PFD, a number of 5G-NR configuration details must be known as shown in Table 6. Both Beamforming Gain and out-of-band suppression (emission mask) typically require information from the licensee, whilst sub-carrier spacing ("SCS") and licensee center frequency of operation (defined by the New Radio Absolute Radio Frequency Channel Number ("NR-ARFCN")), can be easily determined through external measurement if necessary.

5G-NR Sub-Carrier Spacing (SCS)	Licensee input or determined through measurement
5G-NR Center Frequency (NR-ARFCN)	Licensee input or determined through measurement
Spectrum OOBE Mask	Licensee input (based on network configuration - cannot be easily measured)
Maximum 5G-NR Beamforming Gain (PDSCH over SSB)	Licensee input (based on network configuration - cannot be easily measured)

Table 6: 5G-NR required configuration details for PFD determination

The PDSCH beamforming gain over an SSB reflects the likely implementation of 5G-NR in the 3.7 GHz Service spectrum whereby a base station will transmit a number of relatively wide SSB beams for synchronization but will assign narrower, more directive (higher gain) traffic beams for user data transfer. Assessment of the likely contribution to aggregate PFD should therefore consider this potential gain differential between the measured SSB beams and traffic beams. In the worst case, a traffic beam within an SSB beam could be aligned directly with the FSS. In this case, the impact would be increased by the maximum beamforming gain.

The calculation methodology used to determine individual PFD contributions based on an assumed transmission mask and beamforming gain is shown in Table 7.

	Parameter	**Value**	**Units**	**Comments**
a	Frequency	3800	MHz	Input (example)
b	Wavelength	0.079	m	
c	Measurement Antenna Gain	5.00	dBi	Input (example)
d	Gain - linear	3.16		
e	Effective antenna aperture	0.00157	m^2	$e = \frac{b^2}{4\pi} d$
f	Measured RSRP	-68.10	dBm	Input
g	RSRP in dBW	-98.10	dBW	$g = f - 30$
h	Transmission mask attenuation	75.2	dB	Input (example, see text)
i	Beamforming Gain	6.00	dB	Input (example)
j	RX Power in FSS band	-167.30	dBW	$j = g - h + i$
k	SSB BW	0.03	MHz	Input (example)
l	Rx PFD (100% load)	-124.03	$dBW/m^2/MHz$	$l = j - 10\log(e) - 10\log(k)$

Table 7: Calculation of cell/beam potential contribution to PFD

Considerations for this approach include:

- Determination of an appropriate OOBE transmission mask: Ideally, it would be provided by the licensee and may vary with the deployed infrastructure.

- In this case, an antenna with an omnidirectional pattern in the azimuth plane can be utilized without impacting the ability of the procedure to detect potentially interfering licensee signals.

- The OOB PFD contribution for a given 5G-NR site, calculated as illustrated in Table 7, is the worst case, assuming 100% load at the service licensee's 5G-NR site with alignment of SSB and traffic beams in the direction of the FSS.

- An additional assumption is that the base station antenna in-band and out-of-band gains are the same. That assumption is likely to be incorrect in the case of AAS but should lead to a conservative determination of compliance (the calculated OOB PFD level is likely to be too high).

6.1 Conversion of Measured Channel Power in PSD to PFD Equivalent

The relationship between PFD and measured channel power in PSD is shown below. A more generic formulation is provided in Annex E.

$$PFD = P_{r(dBm)} + 20\log_{10}(f) - G_r + L_c - 68.55\ \text{dB}\ (\text{W/m}^2/\text{MHz}) \quad (3)$$

where:

P_r	is measured channel power (PSD) in dBm/MHz
f	is the measurement frequency in MHz
G_r	is antenna gain of the measurement antenna in dBi
L_c	is cable (and other) losses in dB

ANNEX A:
GLOSSARY

5G, 5G-NR	Fifth Generation Terrestrial Mobile Broadband Services.
AAS	Advanced Antenna System.
ASI	Adjacent Satellite Interference.
C-Band Order	*Expanding Flexible Use of the 3.7-4.2 GHz Band*, Report and Order and Order of Proposed Modification, 35 FCC Rcd 2343 (2020) ("*C-Band Order*"); *available at* https//docs.fcc.gov/public/attachments/FCC-20-22A1_Rcd.pdf (last visited Aug. 3, 2020).
Commission	Federal Communications Commission.
CONUS	Continental United States.
EIRP	Equivalent Isotropically-Radiated Power
FCC	The Federal Communications Commission.
FSS	Fixed Satellite Service.
gNB	gNodeB, or next generation NodeB, a 5G base station.
IBFS	International Bureau Filing System.
LNA	Low Noise Amplifier.
LNB	Low Noise Block.
NA-ARFCN	5G-NR Center Frequency.
OOBE	Out of band emissions.
PCI	Physical Cell ID.
PDSCH	Physical Downlink Shared Channel.
Phase I	The period following the Phase I deadline, as defined in Section 27.1412(b)(1) of the FCC's rules, 47 C.F.R. § 27.1412(b)(1).
PFD	Power Flux Density.
POC	Point of Contact.
PSD	Power Spectral Density.
RSRP	Reference Signal Received Power.
RF	Radiofrequency.
RSSI	Received Signal Strength Indication.
SCS	5G-NR Sub Carrier Spacing.
SNR	Signal-to-Noise Ratio.
SOW	Statement of Work.

SSB	Synchronization Sub Block.
SSB index	The index (designator) of a specific beam radiated by a base station antenna
TES	Temporary Fixed or Transportable Earth Station.
TI	Terrestrial Interference.
TWG-1	Technical Working Group #1.
TWG-3	Technical Working Group #3.
ULS	Universal Licensing System.
UTC	Coordinated Universal Time.

ANNEX B:
TECHNICAL WORKING GROUP 1 MEMBERSHIP

(As of October 29, 2020)

Name	Company
David Bellingham	A&E
Don Jarvis	A&E
Ross Lieberman	ACA Connects
Michael Perelshtein	Alga Microwave
Eric DeSilva	AT&T
Navid Motamed	AT&T
Neeti Tandon	AT&T
Raquel Noriega	AT&T
Brian Mengwasser	Aurora Insight
Greg Hull	Aurora Insight
Jennifer Alvarez	Aurora Insight
Rick Morse	Aurora Insight
Alexandra Mays	CCA
Alexi Maltas	CCA
Colleen King	Charter
John Gleason	Charter
Scott Schooling	Charter
Brian Josef	Comcast
Gary Edwards	Comsearch
Joe Marzin	Comsearch
Mark Gibson	Comsearch
Rhett Butler	Comsearch
Will Perkins	Comsearch
Doug Hyslop	CTIA
Kara R. Graves	CTIA
Mike Mullinix	CTIA
Kumar Balachandran	Ericsson

Name	Company
Mark Racek	Ericsson
Noman Alam	Ericsson
Hector Fortis	Eutelsat
Wladimir Bocquet	Eutelsat
Alastair Hamilton	Fox
Winston Caldwell	Fox
John Myhre	GCI
Mike Ayers	GCI
Adrian Herbera Gonzalez	Hispasat
Reza Arefi	Intel
Salim Yaghmour	Intelsat
Susan Crandall	Intelsat
IC Tellman	Keysight
Bob Potter	Kratos Defense
Marke Clinger	Kratos Defense
Carlos Nalda	LMI Advisors
Casey Joseph	LS Telcom
Marian Angheluta	LS Telcom
Peter Riemann	LS Telcom
Bob Paul	Microwave Filter
Paul Mears	Microwave Filter
Sam Fanizzi	Microwave Filter
Justin Terwee	Midco
Nicole Tupman	Midco
Alison Neplokh	NAB
Patrick McFadden	NAB
Robert Weller	NAB
Clarence Hau	NBC Universal
Margaret Tobey	NBC Universal
Mike Harrell	NBC Universal
Andy Scott	NCTA

Name	Company
Danielle Pineres	NCTA
Fabiano Chaves	Nokia
Prakash Moorut	Nokia
Mike Beach	NPR
AJ Miceli	PSSI
Brian Nelles	PSSI
Rob Lamb	PSSI
Dean Brenner	Qualcomm
Gene Fong	Qualcomm
John Kuzin	Qualcomm
Kevin Murray	Qualcomm
Rob Kubik	Samsung
Ramiro Reinoso	SES
Steve Corda	SES
Bertram De Jong	Telesat
Ahmad Armand	T-Mobile
Patrick Welsh	Verizon
Peter Tenerelli	Verizon
Ratul Guha	Verizon
Scott Townley	Verizon
Wes Burnett	Viaero
Benjamin Holden	Windstream
Richard Bernhardt	WISPA

ANNEX C: NON-CONSENSUS OR UNSPECIFIED ITEMS

A request is pending with FCC staff for its opinion on whether certain other earth stations (not on the October 23, 2020, list) are required to be protected with respect to PFD limits. (p. 15)

Time limits or requirements for certain actions are referenced in this document but are not specified. These are:

N1 – POC information update requirement (p.15, p.16)

N2 – 3.7 GHz Service licensee response requirement (p.15, p.17, p.18)

N3 – 3.7 GHz Service resolution requirement (p.15, p.17, p.18)

ANNEXES D – P ARE IN A SEPARATE DOCUMENT