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June 17, 2016

VIA ELECTRONIC FILING

Marlene H. Dortch
Secretary
Federal Communications Commission
445 12th Street S.W.
Washington D.C. 20554

Re: Written *Ex Parte* Notice, GN Docket No. 14-177, IB Docket Nos. 15-256 and 97-95; RM-11664; and WT Docket No. 10-112

Dear Ms. Dortch:

The Boeing Company ("Boeing"), through its counsel, hereby responds to the recent filing of Straight Path Communications, Inc. ("Straight Path") challenging Boeing's technical findings that spectrum sharing is readily achievable between terrestrial 5G systems and downlink-only transmissions of broadband fixed satellite service ("FSS") systems operating in the 37.5-40.0 GHz ("37/39 GHz") band.[1] Straight Path argues that the Commission's consideration of Boeing's spectrum sharing analysis will somehow delay the advent of 5G terrestrial services in the 37/39 GHz band and effectively "cede" the leadership position of the United States in the deployment of 5G systems.[2] Nothing could be further from the truth.

Straight Path's technical arguments misstate the capabilities of phase array technologies, do not accurately address the existing and planned satellite uses of the 37/39 GHz band, and fail to acknowledge relevant spectrum studies underway within the International Telecommunication Union ("ITU") Radiocommunication Sector ("ITU-R"). Straight Path further argues that the Commission should not consider the potential for spectrum sharing in the 37/39 GHz band because satellite systems are not yet operating in this spectrum.[3]

[1] Letter from Davidi Jonas, CEO and President, Straight Path Communications, Inc., to Marlene H. Dortch, Secretary, Federal Communications Commission, at 1(June 14, 2016) ("*Straight Path Letter*").

[2] *Id*.

[3] *See id.*

Experimental V-band satellite systems are already operating in other regions of the world,[4] and U.S. government satellite systems, many of them developed by Boeing, are using the V-band. The ITU-R's Space Network System database identifies numerous plans for the launch and operation of additional satellite networks using the V-band to provide communications services in the United States and around the world.[5] In addition, the 2015 World Radiocommunication Conference ("WRC-15") adopted Resolution 159[6] and WRC-19 agenda item 1.6[7] (both championed by the United States) to develop a regulatory framework for the operation of non-geostationary satellite orbit ("NGSO") satellite systems in the V-band, including in the 37.5-40.0 GHz portion of the spectrum. Thus, Straight Path is demonstrably incorrect in asserting that the satellite industry "has made no use of the 37/39 GHz band and has done nothing to seek any imagined regulatory changes necessary for additional use."[8]

In addition, as Straight Path appears to concede, Boeing is developing a NGSO satellite system that would operate in the V-band. Boeing's proposed NGSO FSS system would provide very high data rate services to all Americans regardless of their location, finally resolving the tremendous disparities that exist in the availability of broadband services between urban and rural populations. In contrast, as CTIA has repeatedly acknowledged, terrestrial 5G services are "unlikely to deliver extensive coverage in a market, but instead will be best suited . . . in densely populated areas"[9] and will be used "primarily for adding capacity and high-speed data"[10] to existing networks in areas "with the greatest population density."[11]

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[4] Letter from Tom Stroup, President, Satellite Industry Association, to Marlene H. Dortch, Secretary, Federal Communications Commission, GN Docket No. 14–177, et al. (May 10, 2016), Attachment 1, "Creating a Framework that Enables Co-Primary Access to Spectrum for Satellite and UMFU Service" at 5 (noting that Alphasat, Eutelsat, and SSL are experimenting with V-band payloads).

[5] *See* http://www.itu.int/pub/R-SOFT-SNS.

[6] Resolution 159 (WRC-15), Studies of Technical, Operational Issues and Regulatory Provisions for Non-Geostationary Fixed-Satellite Services Satellite Systems in the Frequency Bands 37.5-39.5 GHz (space-to-Earth), 39.5-42.5 GHz (space-to-Earth), 47.2-50.2 GHz (Earth-to-space) and 50.4-51.4 GHz (Earth-to-space) (available at http://www.itu.int/dms_pub/itu-r/oth/0c/0a/R0C0A00000C0006PDFE.pdf).

[7] *See* ITU-R Resolution 809 (WRC-15).

[8] *Straight Path Letter* at 2.

[9] Letter from Brian M. Josef, Assistant Vice President, Regulatory Affairs, CTIA, to Marlene H. Dortch, Secretary, Federal Communications Commission, at 2 (May 24, 2016).

[10] *Id.*

[11] Letter from Scott K. Bergmann, Vice President, Regulatory Affairs, CTIA, to Marlene H. Dortch, Secretary, Federal Communications Commission, at 2 (May 20, 2016).

Fortunately, the Commission does not need to make a choice between promoting 5G terrestrial systems or broadband satellite systems in the 37/39 GHz band. Both services can and should share the 37/39 GHz band to provide the greatest array of choices and broadband opportunities for American consumers. As explained in detail below, Straight Path's technical arguments do not suggest otherwise.

5G Base Station Isolation of Satellite Transmissions

Isolation of 5G Base Station Antennas. Straight Path first attempts to challenge Boeing's showing that 5G base stations will be able to suppress transmissions from co-frequency satellites in the 37/39 GHz band by at least 20 dB. Straight Path argues that Boeing's analysis assumes the use of 5G base station antennas that are minimally capable of avoiding interference from undesired sources, an assumption that Straight Path calls "restrictive" and argues would "prohibit contemplated 5G deployment scenarios."[12]

Straight Path points instead to a 5G antenna radiation pattern identified in a recent 3GPP technical report, which Straight Path suggests is more representative of 5G deployment scenarios.[13] Importantly, the 3GPP antenna radiation pattern that Straight Path identifies is for a *single* antenna element, not the entire antenna.[14] The 3GPP Technical Report that Straight Path references clearly explains that it is anticipated that 5G base stations will employ antennas with large numbers of elements, as depicted in Figure 7.3-1 of the 3GPP Technical Report, which is copied below.

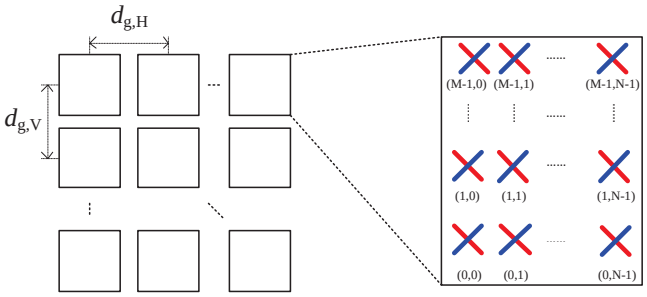

Figure 7.3-1 of the 3GPP Technical Report Showing Antenna Elements

[12] *Straight Path Letter* at 2.

[13] *See id.* (citing 3GPP TR 38.900 V1.0.0, "Channel model for frequency spectrum above 6 GHz," at 21-22 (Section 7.3, "Antenna modeling), available at http://www.3gpp.org/ftp//Specs/archive/38_series/38.900/38900-100.zip ("*3GPP Technical Report*").

[14] *See 3GPP Technical Report* at 22 (explaining that the identified equation describes the "[a]ntenna radiation pattern of each antenna element" and not the entire antenna).

Consistent with the 3GPP Technical Report, Boeing assumed the use of a 5G base station antenna with an effective beamwidth and aperture size of about 8 centimeters (corresponding to a 128- to 256-element base station array). The resulting isolation capability and roll off pattern of the 5G base station antenna is identified in ITU-R Recommendation S.1428 and was used by Boeing to conservatively conclude that 5G base stations will be able to suppress transmissions from co-frequency satellites – including those operating at the 12 dB higher ITU PFD limits – by at least 20 dB. Figure 2a illustrates the ITU-R S.1428 roll-off pattern and overlays the suggested 3GPP pattern referenced by Straight Path, adjusted to the proper size of the base station phased array aperture. Figure 2b also shows base station patterns scanned up to 45 degrees off-boresight. These figures confirm Boeing's finding that 5G base stations will receive at least 20 dB of isolation from the transmissions of co-frequency satellites operating at the higher ITU PFD levels. Thus, Straight Path is incorrect in arguing that 5G base station operators will need to implement additional interference suppression measures (beyond the inherent 5G beamforming capability) to avoid interference from broadband satellite systems operating in the 37/39 GHz band.

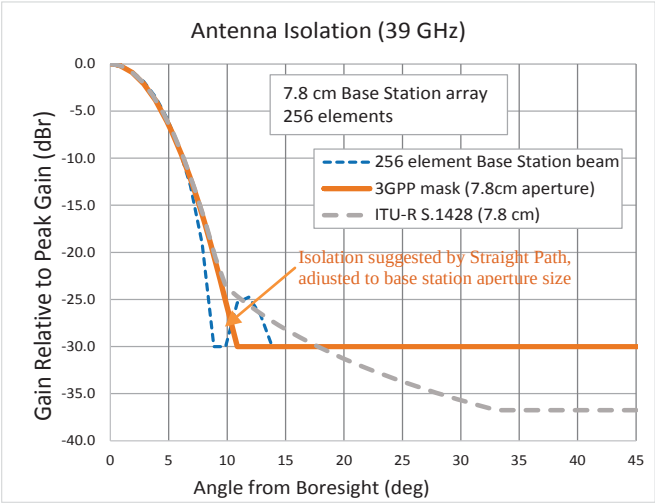

Figure 2a – Base Station beam with 3GPP mask overlaid

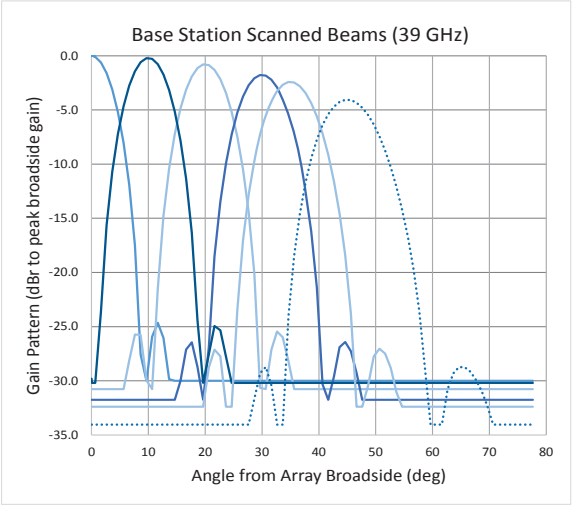

Figure 2b – Scanned base station beams maintain isolation

Time Varying Nature of Satellite Signals. Straight Path also argues that 5G base stations may have difficulty suppressing transmissions from satellites due to the "time-varying" nature of such transmissions, *i.e.*, that the satellite signals would be coming from different directions as the satellites move across the sky.[15] One of the principle advantages of phased array antennas is their ability to form beams and constantly adjust those beams in the direction of their intended users in order to maintain connectivity with mobile terminals. 5G systems will be able to use

[15] *See Straight Path Letter* at 2-3.

these same capabilities to concurrently avoid interference from undesired mobile sources, be they other nearby 5G devices or NGSO FSS satellites high overhead.

Indeed, 5G systems inherently must establish and maintain connections with "time varying" (*i.e.* mobile) user handsets as well as reliably reject interfering signals from other mobile handsets connecting to the same base station. Given the fact that the NGSO FSS satellites will operate only high above the horizon (using space-to-Earth transmit powers that are well below those of nearby 5G mobile terminals), 5G base stations employing modern phased array antenna algorithms will be fully capable of avoiding interference from satellite systems without the need for any special suppression of satellite signals.

5G Beams Pointed Above the Horizon. Straight Path further argues that it may be desirable in some situations for 5G base stations to form beams above the horizon, such as upwards towards a tall building or to exploit a diffraction path across a roof or tree top to get to a non-line-of-sight user.[16] Straight Path claims that, in such cases, the 5G beams "would be significantly affected by satellite interferences under Boeing's proposal."[17]

5G base stations will receive significant isolation from overhead satellites simply by being positioned at horizontal or down-tilted angles. This will be the case for the vast majority of 5G base stations. In unusual cases, this isolation will be reduced somewhat when a 5G base station directs a beam above the horizon. Nevertheless, several factors ensure that, even in these unusual cases, sufficient isolation will continue to exist to enable 5G base stations to reject transmissions from co-frequency satellite systems. For example, a 5G base station with a modest-sized array (8 centimeters with 128 to 256 elements) can form a directive beam with a 7 degree beamwidth. As shown in Figure 2b, these base station beams will achieve an isolation of 20 dB at approximately 10 degrees off boresight even when scanned to 35 degrees off-broadside. Therefore, a 5G base station operating co-frequency with a satellite system transmitting at elevation angles of at least 45 degrees could form a beam in a direction of 35 degrees upwards, which is substantially non-horizontal, while still maintaining at least 20 dB of isolation.

Further, the extreme uptilt scenarios described by Straight Path are highly unlikely to be used in practice. Transmitting upwards toward a building would be largely ineffective because of the substantial attenuation that results in these frequency bands from building materials (including the high reflectivity of windows at small angles of incidence). It is also highly unlikely that a 5G system would steer a beam to exploit a diffraction path involving any extreme uptilt angle because the effectiveness of propagation by knife-edge diffraction diminishes rapidly

[16] *See id.* at 3.

[17] *Id.*

with increasing angle. Thus, although modest uptilt angles – substantially below the angles of satellite line-of-sight – could potentially be useful, paths involving extreme uptilt angles would be unlikely to be effective even in the absence of co-frequency satellite operations. The usefulness of such paths are also diminished due to the time-constant of the multi-path losses, which are normally addressed using a RAKE receiver and adaptive filtering in the time/frequency domain within 5G channels and are not addressed by spatial beamforming.

Off-axis Sidelobes of a Phased Array due to Beamforming Algorithms. Straight Path further argues that the side lobes of 5G antennas may receive significant interference from co-frequency satellite systems even when the base station is not directing beams above the horizon. Straight Path suggests that " [d]ue to the amplitude and phase error of the transceiver chains, it is often difficult to keep the side lobes 20 dB below the main beam, especially when the base station steers the main beam away from the broadside of the antenna array."[18]

It is unclear why Straight Path believes that phased array technologies are incapable of providing modest beamforming and sidelobe control performance. These capabilities are essential for successful 5G system operation. Existing high quality, mature hardware operating at 37/39 GHz is available for 5G terrestrial system deployment, including GaAs, GaN, SiGe, and CMOS-based technologies as described by other 5G proponents active in this proceedings.[19] Accurate amplitude and phase control devices along with digital converters are common items available at millimeter wave ("mmW") frequencies and necessary for successful 5G operation. Further, appropriate error control techniques[20] and simple algorithms for self-calibration of the array[21] are available if needed, and are similar to those used for beamforming the 5G user signals.

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[18] *Id*. at 3.

[19] *See*, *e.g.*, Letter from Mark Racek, Senior Director, Spectrum Policy, Ericsson, to Marlene H. Dortch, Secretary, Federal Communications Commission, GN Docket 14-177, et al. (May 25, 2016), Attachment 1, "On mm-wave technologies for NR," 3GPP TSG-RAN Working Group G4, document R4-164226 (23-27 May 2016).

[20] *See* Smith, M.S. and Guo, Y.C. "A Comparisons of Methods for Randomizing Phase Quantization Errors in Phased Arrays." IEEE Transactions on Antennas and Propagation, Vol. AP-31, No. 6, November 1983.

[21] Erik Lier et. al., "Phased array calibration and characterization based on orthogonal coding: Theory and experimental validation" 2010 IEEE International Symposium on Phased Array Systems and Technology (ARRAY); Tim Cooper et. al., "Toward Scalable, Automated Tower-Top Phased Array Calibration", 2007 IEEE 65th Vehicular Technology Conference – VTC 2007.

Satellite Earth Station Isolation of 5G Base and Mobile Transmissions

The second half of Straight Path's letter addresses the potential for 5G base stations and mobile units to cause interference to receive-only satellite earth station terminals in the 37/39 GHz band. Boeing is obviously strongly motivated to ensure that its satellite earth station terminals can operate successfully in the 37/39 GHz band without receiving excessive interference from 5G systems. Therefore, Straight Path's challenge of Boeing's assumptions and analysis in this regard should be viewed with some skepticism.

5G Separation Distance to Satellite Earth Stations. Straight Path observes that Boeing's spectrum sharing analysis is not worst case because it assumes a separation distance of at least 100 meters between 5G transmitters and satellite user terminals, resulting in a 130 dB path loss. Boeing is obviously aware that the separation distance between 5G transmitters and its satellite user terminals will often be much less than 100 meters. This is the case, however, primarily with respect to 5G mobile units, and not 5G base stations, which are more likely to be stationary, allowing Boeing to locate its satellite earth station receivers a sufficient distance from the base stations (or with sufficient shielding) to avoid interference. It is for this reason that Boeing has requested that the locations of 5G base stations be confidentially disclosed to satellite system licensees operating in the 37/39 GHz band. Further, Boeing can employ directional nulling and dynamic frequency selection to avoid interference from nearby base stations.

Interference from 5G mobile units may pose a more significant issue if a 5G mobile unit operates extremely close to a satellite earth station receiver, such as on the same rooftop. Boeing anticipates, however, that such interference will be temporary and transient and could be addressed in most cases through directional nulling or dynamic frequency selection.

Line-of-Sight and Non-Line-of-Sight Path Loss. Straight Path questions Boeing's use of non-line-of-sight ("NLOS") path loss modeling and contends that additional interference can be introduced into satellite earth station receivers by 5G transmissions when subject to line-of-sight ("LOS") or near-LOS conditions.[22] NLOS conditions, however, have been widely identified within this proceeding as the anticipated deployment scenario for 5G systems, including in filings made by CTIA and in the models used in a letter submitted by five 5G proponents. In particular, as these parties observe regarding the 5G to FSS earth station analysis that they prepared for the 28 GHz band, "it is unlikely that LOS channel conditions will occur with high probability at 28 GHz, where signal propagation characteristics are adversely affected not only by blockage due to buildings and other structures but also by vegetation."[23] The 5G proponents

[22] *See Straight Path Letter* at 3.

[23] Letter from Joint Filers (AT&T, Nokia, T-Mobile, Samsung, and Verizon) to Marlene H. Dortch, Secretary, Federal Communications Commission, at 9 (May 6, 2016) ("*Joint Filer's Letter*") (discussing FSS/UMFU co-existence simulations).

further observe that "any assumptions employing a large percentage of LOS sites appears unrealistic given real-world vegetation/foliage losses and likely 5G deployment cases."[24] Such obstructions will have an even greater impact in the 37/39 GHz band. Therefore, Straight Path's references to a statistical model for LOS losses in rural conditions is inconsistent with the system characteristics and deployment locations identified by the rest of the wireless industry.

5G Aggregate Interference. Straight Path also observes that Boeing's spectrum sharing analysis assumes there will be only one interfering 5G base station or mobile station at any one time.[25] Boeing recognizes that countless 5G transmitters (base and mobile) may be operating in and near a particular location. For this reason, aggregated interference from multiple sources has been considered by Boeing, and is addressed in the filings of other parties, such as Nokia.[26] Interference from additional sources, however, will have a significantly reduced impact on the earth station receiver because, as Straight Path acknowledges, the other 5G transmitters "may be further away from the FSS ground station."[27]

Further, unlike CDMA-based systems – in which each additional transmitter raises the overall level of "noise" into a particular frequency band and time segment – 5G systems are being designed to employ sophisticated measures to avoid intra-system interference into their own networks. For example, 5G systems are expected to employ highly directional beams and, often, Time Division Duplexing ("TDD"), to ensure that no two desired transmissions are arriving at a particular 5G base station from the same angle using the same time segment in a particular frequency band. For this reason, Boeing's technical analysis was based on flux density over the entire bandwidth, with only one signal per base station (or, one bi-directional link from one 5G mobile unit to each base station) assumed to be present at any time and at any portion of the frequency band. Although it is statistically possible that two or more 5G mobile units in the same area could communicate with different 5G base stations using the same time segments and frequencies, these 5G mobile units will be directing their transmissions toward their respective base stations, which will likely be in substantially different directions. Thus, although there is some potential for aggregation of 5G interference into satellite earth stations, Boeing's statistical analysis indicates that the potential additional noise is negligible and can be disregarded.

Satellite Earth Station Side Lobes. Finally, Straight Path argues that Boeing is being overly optimistic in asserting that its satellite earth stations terminals can reject 5G interference by 50 dB.[28] Straight Path claims that "[i]t will be difficult to guarantee that the side lobes

[24] *Id*. at 5

[25] *See Straight Path Letter* at 4.

[26] *See Joint Filer's Letter* at 10 (considering a 7-site layout example within a 19-site 3GPP UMi scenario).

[27] *See Straight Path Letter* at 4.

[28] *See id.*

towards the hundreds or thousands of interfering 5G base stations and mobile stations are always 50 dB below the main beam as the FSS ground station tracks the movement of the satellite."[29] Boeing, a global leader in satellite system design and implementation, disagrees.

Boeing's satellite earth station receivers will not need to monitor or individually null signals of 5G transmitters. Properly designed phased array technology can track and directionally steer beams towards a desired signal, while maintaining high isolation outside of the desired coverage. The satellite earth stations are specifically designed to maintain low-sidelobe performance while tracking the satellite. In fact, the core element of the 5G business case is the fact that phased array technology can track and directionally steer beams to and from large numbers of users. Boeing's satellite earth station receivers similarly will be able to track and communicate with any of the half a dozen satellites in view at any moment above 45 degrees, thereby avoiding interference from 5G transmitters within close proximity of the receivers.

The Way Forward

Given the extraordinary potential for co-primary spectrum sharing between 5G terrestrial and satellite systems in the 37/39 GHz band, the Commission should adopt modest service rules – including measures proposed by the Commission in the NPRM necessary to ensure 5G self-compatibility – that will facilitate the robust deployment of both services and ensure the availability of very high data-rate, satellite-delivered broadband services to all consumers in the United States and globally. Specifically, Boeing requests that the Commission adopt the following reasonable provisions:

- Adopt a 5G base station power limit of 62 dBm EIRP, as proposed in the NPRM,[30]
- Require 5G systems to use beam forming and power control,
- Require the confidential disclosure of 5G base station locations,
- Lift the prohibition on satellite end user receivers in the 37/39 GHz band,[31]
- Impose no limits on receive-only gateway facilities in the 37/39 GHz band, and
- Permit satellites to transmit in the 37/39 GHz band at the ITU power levels.

[29] *Id.*

[30] *See* Use of Spectrum Bands Above 24 GHz For Mobile Radio Services, GN Docket No. 14-177, Petition for Rulemaking of the Fixed Wireless Communications Coalition to Create Service Rules for the 42-43.5 GHz Band, RM-11664, et al., *Notice of Proposed Rulemaking*, FCC 15-138, ¶ 274 (2015).

[31] *See* 47 C.F.R. § 25.202(a)(1), footnote 3.

These measures would result in no appreciable harm to 5G system operators. In fact, some of these measures (such as beam forming and power control) are likely to be uniformly employed by 5G system operators to avoid causing interference into their own systems.

Straight Path claims that mutually beneficial spectrum sharing is an idea that Boeing and the Satellite Industry Association somehow "concocted at the eleventh hour of this proceeding."[32] In fact, the directive to facilitate spectrum sharing came directly from Chairman Wheeler, who instructed the satellite industry "to work with the mobile industry and quickly come back to us with realistic sharing ideas for the coexistence of satellite and mobile" in the 28 and 37/39 GHz bands.[33] Boeing and the rest of the satellite industry took this message to heart and engaged in significant analysis regarding the technical capabilities that can be employed to make robust spectrum sharing in mmW bands a reality. Boeing therefore urges Straight Path to embrace, as Chairman Wheeler suggests, the significant public interest benefits of enabling spectrum sharing in mmW spectrum. Boeing also urges the Commission to promptly adopt the modest measures that Boeing has proposed to facilitate co-primary spectrum sharing in the 37/39 GHz band. At the very least, the Commission should adopt a Further Notice of Proposed Rulemaking to thoroughly explore these important issues.

Thank you for your attention to this matter. Please contact the undersigned if you have any questions.

Sincerely,

Bruce A. Olcott
Counsel to The Boeing Company

[32] *Straight Path Letter* at 1.

[33] Remarks of Chairman Tom Wheeler, 19th Annual Satellite Leadership Dinner (March 7, 2016) (available at https://apps.fcc.gov/edocs_public/attachmatch/DOC-338135A1.pdf).