Before the
Federal Communications Commission
Washington DC 20554

In the Matter of	)	
	)	
Expanding Flexible Use in Mid-Band	)	GN Docket No. 17-183
Spectrum Between 3.7 and 24 GHz	)	

COMMENTS OF THE
FIXED WIRELESS COMMUNICATIONS COALITION

Cheng-yi Liu
Mitchell Lazarus
FLETCHER, HEALD & HILDRETH, P.L.C.
1300 North 17th Street, 11th Floor
Arlington, VA 22209
Counsel for the Fixed Wireless
Communications Coalition

October 2, 2017

TABLE OF CONTENTS

Before the
Federal Communications Commission
Washington DC 20554

In the Matter of	)	
	)	
Expanding Flexible Use in Mid-Band Spectrum Between 3.7 and 24 GHz	)	GN Docket No. 17-183
	)	

COMMENTS OF THE
FIXED WIRELESS COMMUNICATIONS COALITION

The Fixed Wireless Communications Coalition, Inc. ("FWCC")[1] files these comments on the Notice of Inquiry in the above-captioned docket.[2]

A. SUMMARY

The caption above references spectrum between 3.7 and 24 GHz, but the NOI proposes new applications in just three bands—all of them allocated to and used by the Fixed Service (FS): 3.7-4.2 GHz, 5.925-6.425 GHz, and 6.425-7.125 GHz.[3] Links in these bands carry applications that are critical to the safety of life and property, and operate at extremely high levels of reliability. These are the only FS bands suitable for long links—a matter of physics, not

---

1 The FWCC is a coalition of companies, associations, and individuals actively involved in the fixed services—*i.e.*, terrestrial fixed microwave communications. Our membership includes manufacturers of microwave equipment, fixed microwave engineering firms, licensees of terrestrial fixed microwave systems and their associations, and communications service providers and their associations. The membership also includes railroads, public utilities, petroleum and pipeline entities, public safety agencies, cable TV providers, backhaul providers, and/or their respective associations, communications carriers, and telecommunications attorneys and engineers. Our members build, install, and use both licensed and unlicensed point–to–point, point–to–multipoint, and other fixed wireless systems, in frequency bands from 900 MHz to 95 GHz. For more information, see www.fwcc.us.

2 *Expanding Flexible Use in Mid-Band Spectrum Between 3.7 and 24 GHz*, GN Docket No. 17-183, Notice of Inquiry, FCC 17-104 (released Aug. 3, 2017) ("NOI").

3 In the last band, the FS operates heavily in 6.525-6.875 GHz and has limited use of 6.875-7.125 GHz.

regulation. Range at higher frequencies is limited by rain fade and by greater free-space attenuation.

The 4 GHz band has relatively light FS use, due to the difficulties of coordinating with earth stations in the Fixed Satellite Service (FSS). There are proposals to allow point-to-multipoint operation in the band for broadband Internet access, and to introduce mobile use. The FWCC will not oppose new applications, provided that existing links are fully and reliably protected from interference.

The FS bands at 5.925-6.425 and 6.525-6.875 GHz are densely used, with 94,000 transmit frequencies operating nationwide. The NOI's proposal for unlicensed operation may not be feasible. An unlicensed transmitter using just 10 milliwatts of power could cause interference to an FS receiver from at least 5.5 miles away. To adequately protect the FS would require unlicensed devices to use real-time frequency coordination at levels of reliability that have not yet been demonstrated.

It may be possible, though costly, to clear the 4 GHz band of FS incumbents by relocating links to 6 GHz. But clearing the 6 GHz FS bands is not feasible, because there are no options for relocation. No other FS band has the propagation characteristics needed to accommodate the long links that are routine at 6 GHz.

The FWCC currently takes no position on Commission action at 6.425-6.525 GHz and 6.875-7.125 GHz.

B. INTRODUCTION: ABOUT FIXED SERVICE SPECTRUM.

The NOI give FS old-timers a sense of déjà vu. Twenty years ago, the Commission met the demand for new mobile and satellite services by requiring the FS to vacate its 2 GHz band.

That caused great disruption as operators relocated and realigned their services into other bands—in most cases, the same bands the Commission now targets in the NOI.

Applications for FS links include:

- synchronizing the movement of railroad trains;
- control of petroleum and natural gas pipelines;
- control of the national electric grid;
- backhaul to dispatch public safety and emergency vehicles;
- Internet and telephone carriage;
- backhaul for consumer cellular systems, including voice and 3G/4G data;
- connecting commercial centers with real-time financial and market data;
- vast amounts of business data.

Because many of these applications are critical to the safety of life and property, FS systems are typically designed for at least 99.999% ("five nines") availability; some are designed for 99.9999% ("six nines"). These correspond to total outages per year from all causes of just five minutes (99.999%) or thirty seconds (99.9999%).

The NOI acknowledges critical FS applications,[4] but as we show below, sets out proposals that jeopardize their reliability.

Spectrum is not fungible. The physics of radio waves dictate that long links must use low frequencies. Higher frequencies experience greater free-space attenuation;[5] frequencies above about 10 GHz see additional attenuation from "rain fade." While higher-frequency FS bands offer the benefits of smaller, lighter antennas and greater data bandwidths, links that must span tens of miles can use only the 4 GHz or 6 GHz bands.

---

[4] NOI at ¶ 9.

[5] Free-space attenuation increases with the *square* of the frequency, and so rises quickly as frequencies increase.

The 2 GHz band, once a workhorse for intercity FS links, has since been repurposed for mobile voice and text, mobile data, and mobile satellite service. The 4 GHz band, also formerly a good option for long paths, has become largely unavailable to the FS. Downlink earth stations in the FSS share the band on a co-primary basis. There would be ample room for both services, were it not for the FS having to protect every FSS earth station against interference across the entire 3.7-4.2 GHz band and the entire geostationary arc—even if the earth station communicates with only one transponder on one satellite.[6] This requirement makes it impossible to coordinate 4 GHz FS links across most of the country. Today the 6 GHz bands are usually the only option for long links.

If the Commission adds other services to the 4 GHz and 6 GHz bands, it must take into account FS users' needs for extremely high reliability. Systems that run year after year with downtime not exceeding (literally) one minute in a million are expensive. They reflect skilled engineering and demanding standards of fabrication. Users are willing to pay high prices because their applications cannot tolerate failure. The need for near-perfect reliability leaves no room for disruptions due to interference from other services.[7] The frequency coordination techniques used by the FS (and the FSS, in shared bands) result in essentially zero interference. Any systems used

---

[6] For details on the FS/FSS coordination issues, *see* Petition for Rulemaking of the Fixed Wireless Communications Coalition in RM-11778 (filed Oct. 11, 2016). Making matters worse, almost two-thirds of the earth stations the FS must protect in fact do not exist or are licensed at a wrong location. *See* Letter from Andrew Kreig, Co-Chair, FWCC to Mindel De La Torre, Chief, International Bureau, FCC (Sept. 30, 2016) (presenting data on missing and mislocated earth stations).

[7] Many FS systems are networks of interconnected links. Even a brief outage to one link can require the entire network to shut down while it resynchronizes, which can take several minutes.

to coordinate and control the transmitters in a new service will have to achieve this same demanding level of performance.

Measures of band occupancy. The NOI counts FS "licenses" in each band. These numbers understate usage because a single license can include multiple channels of communication. Here we count instead the numbers of transmit frequencies, which gives a more realistic indication of band occupancy.

C. THE 3.7-4.2 GHZ BAND

The FS has 96 links in this band using 993 transmit frequencies.[8] The numbers are small, compared to other FS bands, due primarily to the difficulties of coordinating with FSS earth stations.

There have been several recent proposals for other uses of the band. Parties commenting on the FWCC's petition for a change in the FSS full-band, full-arc coordination regime offered ideas for more intensive use of the band.[9] A bill pending in Congress would require the Commission to evaluate the feasibility of commercial wireless services, licensed or unlicensed, at 4 GHz.[10] Commissioner O'Rielly published a blog post that suggests repurposing the 4 GHz band through "market-based arrangements," citing instances of band-clearing through financial

---

8 Except as noted, data on band activity counts are current as of September 5, 2017, provided courtesy of Comsearch.

9 *See* FCC Docket RM-11778.

10 MOBILE Now Act, S.19, 115th Cong. § 5.3(b) (2017).

incentives.[11] The Broadband Access Coalition requested point-to-multipoint authority in the band for the delivery of Internet services.[12] The NOI asks about mobile broadband use.[13]

In view of the FS's difficulties in adding new links at 4 GHz, and the widespread interest in adding other services, the FWCC will not oppose the introduction of new applications. But our acquiescence comes with a condition: that existing FS links be fully protected from harmful interference, and that new services be required to accept any interference received from those links.[14] Needed protection will require a technical solution that sets the probability of interference low enough to preserve the present one-in-a-hundred-thousand or one-in-a-million FS tolerances.

D. The 5.925-6.425 GHz and 6.425-7.125 GHz Bands

The 6 GHz FS bands see consistently heavy use. The densest link concentrations occur in and around population centers, where demand for other services is also likely to be greatest. Sharing at 6 GHz will have to accommodate not only the existing links, which are far more numerous than at 4 GHz—93,961transmit frequencies nationwide—but also the steady expansion of service.

The NOI proposes unlicensed operation in these bands.[15]

---

11 Michael O'Rielly, *A Mid-Band Spectrum Win in the Making* (July 10, 2017). https://www.fcc.gov/news-events/blog/2017/07/10/mid-band-spectrum-win-making

12 Petition for Rulemaking of the Broadband Access Coalition, RM-11791 (filed June 21, 2017). The FWCC supported the petition, with reservations. *See* Comments of the Fixed Wireless Communications Coalition in RM-11791 (filed Aug. 7, 2017).

13 NOI at ¶¶ 19-20.

14 More specifically, we request these protections for FS links licensed or applied for on the effective date of a Commission order authorizing new services.

15 NOI at ¶¶ 26-30, 36. The NOI also mentions licensed mobile service, *Id*. at ¶¶ 41, 36. The technical issues are the same.

1. 6-7 GHz spectrum usage

The 5.925-6.425 GHz band ("Lower 6 GHz") is the most heavily used FS band for long links, with 63,260 transmit frequencies in use. The only other significant application in the band is FSS uplink earth stations.[16] As these have no receive capabilities at 6 GHz, they require no protection from the FS. But they do have the potential to cause interference to FS receivers. Like 4 GHz downlink earth stations, the uplink earth stations always have the right to operate on any frequency in the band, pointing to anywhere in the entire geostationary arc, at any time and without notice. Even so, it is far easier to site FS links for reliable operation at 6 GHz than at 4 GHz.[17]

The NOI also refers to the 6.425-7.125 GHz band.[18] This comprises three segments having different applications.

The 6.425-6.525 GHz segment has a mobile allocation with Broadcast Auxiliary Service and Cable TV Relay applications. There is no FS allocation. The FWCC currently takes no position on its use.

The 6.525-6.875 GHz segment is the "Upper 6 GHz" FS band. It has less intensive use by earth stations but is narrower than the Lower 6. Only in the past few years have operators been

---

[16] A waiver granted earlier this also year permits the operation of mobile satellite terminals. *Higher Ground LLC*, Order and Authorization, 32 FCC Rcd. 728 (IB, OET, WTB 2017).

[17] Coordination with earth stations is easier at 6 GHz than at 4 GHz because there are fewer earth stations (many at 4 GHz are receive-only), the coordination zones are smaller, and a 6 GHz FS operator can choose to accept the risk of incoming interference from an uplink earth station. Many transmit to only one transponder on one satellite for decades at a time. An FS user can opt to assume that other frequencies and pointing directions will remain vacant. At 4 GHz, in contrast, the FS must always protect even portions of the band and arc that the earth station never uses.

[18] NOI at ¶¶ 32-35.

able to use Upper 6 channels wider than 10 MHz, while the Lower 6 has long had 30 MHz channels available, and 60 MHz channels more recently. Accordingly, the Upper 6 has less total activity than the Lower 6, with about half as many transmit frequencies. But usage is growing.

The remaining segment, 6.875-7.125 GHz (the “7 GHz” band) primarily serves the Broadcast Auxiliary Service and the Cable TV Relay Service. FS links are permitted, but may not intersect with the service areas of television pickup stations[19]—a limitation that severely restricts FS access. The FWCC currently has no opinion on future uses of this band

Following the reallocation of the former 2 GHz FS band, and given the problems at 4 GHz in coordinating with FSS earth stations, the Upper and Lower 6 GHz are the *only* remaining FS bands having frequencies low enough to span tens of miles. The two have similar technical characteristics and are used for similar purposes. The FS links in both, present and future, will require the highest levels of protection from other services.

2. Constraints on spectrum sharing

The NOI proposes unlicensed use of the 6 GHz bands. Two main factors limit the interference from an unlicensed transmitter into an FS receiver antenna. One is distance: an unlicensed transmitter that is farther away from the FS antenna causes less interference. The other is a Commission requirement that FS antennas be highly directional. The antenna must suppress signals coming from the sides or the back by specified amounts, with the required suppression being higher at angles more toward the back.[20]

---

[19] 47 C.F.R. § 101.147(a) (Note 34),

[20] 47 C.F.R. § 101.115(b) (table).

For discussion purposes we assume an unlicensed transmitter near ground level, and an FS receive antenna on a tower 100 feet off the ground. See Figure 1. We also assume the antenna complies with the Commission's Category B2 standards for off-axis suppression.[21] The antenna is aimed horizontally.

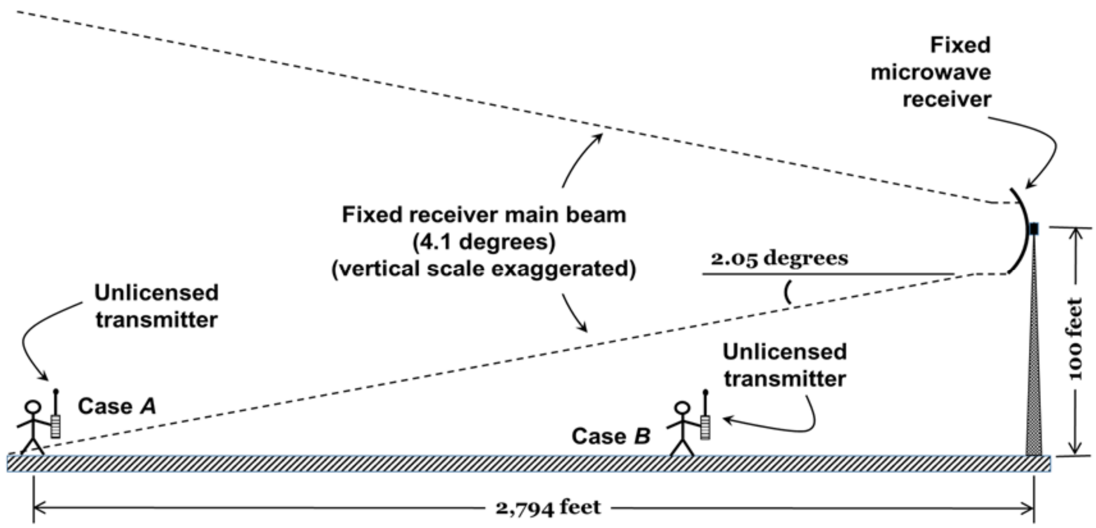

Figure 1
Frequency Sharing Between
Unlicensed and FS

Figure 1 shows two representative cases. In case A, the unlicensed transmitter is far from the FS receive antenna but within its main beam, the region where the antenna is most sensitive. Case B has the unlicensed transmitter closer in but outside the main beam.

The Commission's rules limit the FS antenna main beam to a maximum width of 4.1 degrees.[22] The lower edge of the main beam makes an angle with the horizontal of half that value, or 2.05 degrees. With the receive antenna on a 100 foot tower, an unlicensed transmitter near the ground in front of the antenna comes within the main beam at distances of 2,794 feet or

---

21 *Id*. The same standards apply to both transmit and receive antennas.

22 *Id*. More precisely, 4.1 degrees is the maximum 3 dB beamwidth.

greater. This is Case A. If the unlicensed transmitter operates at a minimally useful power level—say, 10 dBm (10 milliwatts)—then to avoid causing interference it must be kept at least 5.5 miles from the microwave receive antenna.[23]

Next, consider an unlicensed transmitter placed 1,000 feet from the base of the FS receiver tower (Case B in Figure 1). It makes an angle with the antenna of 5.7 degrees (not shown on the diagram). At this angle, the Commission's B2 standard requires the antenna to suppress the incoming signal by a factor of at least 32 (equivalent to 15 dB). But that is not enough to compensate for the unlicensed transmitter being close to the antenna. The Case B unlicensed transmitter will also cause interference.[24]

---

23 The interference estimate assumes the following:

Frequency	6.175 GHz
FS receiver nominal bandwidth	30 MHz
FS short-term interference objective	-85 dBm
FS antenna	ITU Main Beam & FCC Cat B2
FS antenna gain	32.3 dBi
FS antenna height	30 m AMSL
FS victim antenna elevation	0 degrees
Unlicensed transmitter antenna height	2 m AMSL
Unlicensed transmitter EIRP	10 dBm

A distance of 8.9 km (5.5 mi) is needed to satisfy the -85 dBm objective:

$$\begin{aligned} I &= TX\ EIRP\ (dBm) - Free\ Space\ Loss + FS\ Antenna\ Gain\ (dBi) \\ &= 10 - \left(92.5 + 20 * log_{10}\left(8.9(km)\right) + 20 * log_{10}\left(6.2(GHz)\right)\right) + 32.3 \\ &= -85\ dBm \end{aligned}$$

Here we assume the interference statistics justify using a relaxed "short-term" objective. An objective as low as 10 dB below the receiver thermal noise power level (*e.g.* -105 dBm) may be necessary in cases of long-term or constant interference.

24 At 1,000 feet from the tower base, the Case B transmitter is 1,005 feet from the FS antenna. A transmitter at 1,005 feet, attenuated by the required 15 dB, delivers the same interfering signal as a Case A transmitter at a distance given by:

20 log(equivalent Case A distance) = 20 log(1,005) + 15 dB

Repetition of the same analysis confirms that a 10 milliwatt transmitter will cause interference anywhere in front of the FS receive antenna, out to a distance of 5.5 miles. To the sides of the FS antenna, the interference distance drops to 1,000 feet. (Behind the antenna, it drops to 20 feet from the tower base.)

The particular assumptions used here are relatively unimportant. The numbers are a little better for FS receive antennas on higher towers, but do not significantly alter the outcome. Of course a higher-powered unlicensed transmitter will cause interference at greater distances. For comparison, a device operating at the maximum power allowed for Wi-Fi could cause interference out to 110 miles in front of the antenna.[25]

To avoid causing interference to the fixed service, unconstrained unlicensed transmitters would need a power limit in the vicinity of -80 to -60 dBm. Taking terrain and ground clutter into account might raise this by a few tens of dB at most. See the Appendix for details.[26]

It follows that non-interfering unlicensed operation in the fixed service bands, at commercially useful power levels, will need some form of active frequency coordination, such as geolocation with database lookup. As at 4 GHz, the system will need high levels of reliability to

---

This gives an equivalent Case A distance of 5,652 feet—far short of the 5.5 mile safe distance.

25 The maximum EIRP for 5.8 GHz U-NII Wi-Fi systems is 36 dBm (30 dBm output power plus 6 dBi antenna gain). 47 C.F.R. § 15.407(a)(3). Relative to a 10 dBm transmitter at 5.53 miles (analyzed above), the distance *D* that delivers the same signal strength at Wi-Fi power is given by

$$20 \log(D) = 20 \log(5.53) + 36 \text{ dB} - 10 \text{ dB}$$

This gives *D* = 110 miles. The calculation ignores ground clutter and curvature of the Earth.

26 Consistent with these calculations, the FWCC did not oppose the adoption of Section 15.250 of the Commission's rules, which allows wideband operation in the 6 GHz FS bands at a power level of -41.3 dBm/MHz.

avoid cutting into the small numbers of seconds or minutes per year of downtime these systems can tolerate. We are not confident that available technology is adequate to the task.

E. Clearing the 6 GHz FS Bands is Not a Practical Option.

It is much easier to implement new mobile services in vacant spectrum than to work around incumbents. The Commission has sometimes been able to clear occupied spectrum for mobile use. In the 1990s, the high demand for voice cell service prompted the relocation of FS links out of 2 GHz to make room for the Personal Communications Service, and also for mobile data and mobile satellite services. The digital TV transition and subsequent channel repack emptied the 700 MHz band for mobile 4G services, among other applications. The incentive auction is doing the same at 600 MHz.

Commissioner O'Rielly's July 10, 2017, blog post, cited above, suggests using market incentives to clear the 4 GHz band, and possibly the 6 GHz FS bands as well. The NOI does not raise this option expressly. Still, an early evaluation of its feasibility may be helpful to the Commission.

FS usage at 4 GHz is dropping steadily. Although the rate of decline has slowed in recent years, today there are only seven percent as many licensed channels as there were two decades ago.[27] If the downward trend continues (which is not at all certain), there will be little FS use left a few years from now. It may then be possible to relocate the remaining 4 GHz links to 6 GHz. All relocation costs will have to fall on the proponents of new services in the band.[28]

---

[27] Data as of December 31, 2016, courtesy of Comsearch. We explained above that the decline is due largely to the difficulty of coordinating new FS links around full-band, full-arc FSS downlink earth stations.

[28] The Commission similarly required incoming services to pay the costs of relocating 2 GHz FS facilities to other bands. *See* 47 C.F.R. § 101.69.

The case at 6 GHz is dramatically different. The Upper 6 and Lower 6 bands combined have 93,961 transmit frequencies carried over 38,669 links. Figure 2 shows the links in both bands.[29]

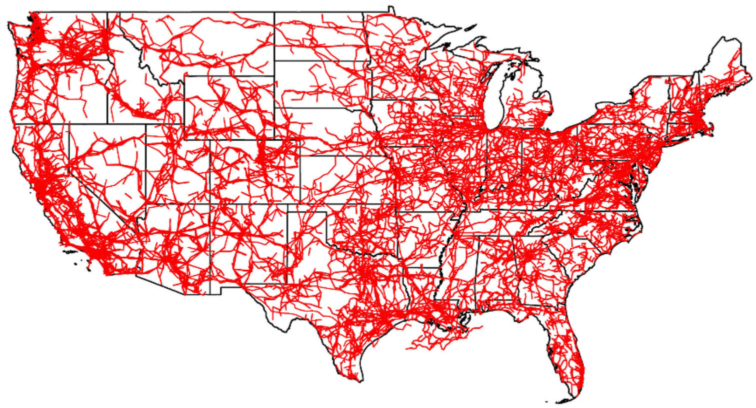

Figure 2
Combined Lower and Upper 6 GHz FS Usage

Most 6 GHz links cannot be relocated because they have nowhere to go. The 2 GHz relocation moved links to 4 and 6 GHz; a 4 GHz relocation—if it is possible—will move links mostly to 6 GHz. But the buck stops there. The next useful band, at 11 GHz, is already crowded with 102,700 transmit frequencies and a steep growth curve.[30] Worse, the impaired propagation and existence of rain fade at 11 GHz makes it unsuitable for links to cover the long distances that work well at 6 GHz.

All things being equal, a designer will opt for the highest frequency band that can accommodate the needed link length. Higher frequencies use smaller, lighter antennas that are less expensive to buy, ship, and install, and cost less in tower fees. Higher frequencies also allow greater radio bandwidths, and hence higher data rates.[31] If a given 6 GHz link could have worked

---

[29] Map data from FCC ULS database as of May 2015, graphic courtesy National Spectrum Management Association. Data in text as of September 5, 2017, except as noted, courtesy of Comsearch.

[30] Usage of the 11 GHz band increased nine-fold over the past twenty years. Data as of December 31, 2016, courtesy of Comsearch. There is also an FS band at 10.55-10.68 GHz, but it is far narrower than those discussed here. The maximum permitted bandwidth is only 5 MHz, inadequate for many modern applications. *See* 47 C.F.R. § 101.147(m).

[31] For example, the 18 GHz band allows bandwidths of 80 MHz, compared to 20 MHz in the 4 GHz band.

satisfactorily in a higher frequency band, odds are the designer would have put it there in the first place.

Because the extensive FS operations at 6 GHz cannot be relocated, any new services in those bands will have to share the frequencies, subject to the demanding requirements outlined above in Part D.2.[32]

CONCLUSION

The 4 GHz FS band may be a suitable home for some new services, if existing FS links can be adequately protected or relocated. To relocate the 6 GHz FS bands at 5.925-6.425 and 6.525-6.875 GHz is not possible. To provide 6 GHz links with the necessary level of protection may not be technically feasible.

Respectfully submitted,

Cheng-yi Liu
Mitchell Lazarus
FLETCHER, HEALD & HILDRETH, P.L.C.
1300 North 17th Street, 11th Floor
Arlington, VA 22209
Counsel for the Fixed Wireless
Communications Coalition

October 2, 2017

[32] The FWCC has pending a Petition for Rulemaking that would allow non-Government use of the Government FS band at 7.125-8.5 GHz. A grant of the petition would open possibilities for additional flexibility in the 6 GHz FS bands. *See* Petition for Rulemaking of the Fixed Wireless Communications Coalition, RM-11605 (filed March 16, 2010).

APPENDIX

Frequency Sharing Study for Notice of Inquiry GN Docket No. 17-183, Expanding Flexible Use in Mid-Band Spectrum between 3.7 and 24 GHz

George Kizer

September 19, 2017

The Commission requests comments regarding potential for sharing the 4 (3.700 - 4.200) GHz, lower 6 (5.925 - 6.425) GHz and the upper 6 (6.525 - 6.875) GHz bands. This paper explores the potential for sharing the bands with existing radio systems.

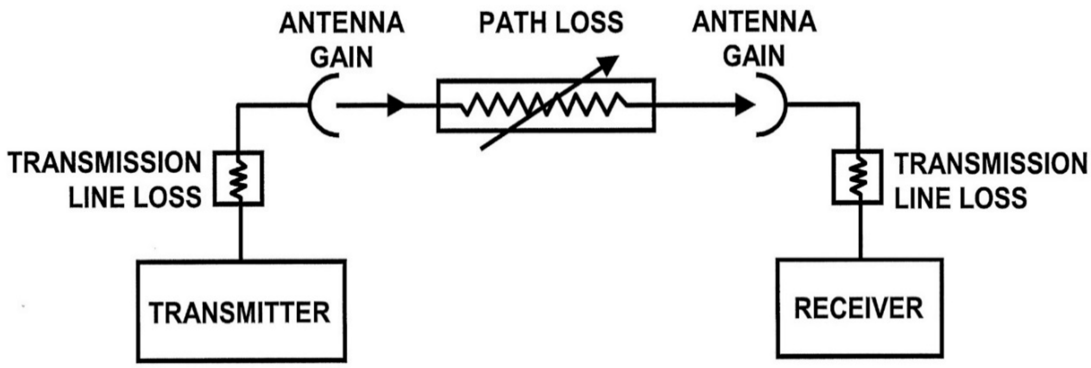

Figure 1 – Typical Radio Path

A typical radio path, whether intended or not, could be diagramed as shown in Figure 1. We will assume a new potentially interfering transmitter sharing spectrum with an existing radio receiver which is operating in conjunction with another licensed transmitter. **We wish to estimate the maximum transmitter power that will not adversely affect the operation of the receiver under the assumption that the transmitter may be placed anywhere with relation to the incumbent system's receive antenna.**

Determining Maximum Permissible Transmit Power P_t with No Constraints

For the typical radio path, transmission line losses may be ignored. They are insignificant relative to the other losses in the path. If both antennas are operating in their far fields, the receive power appearing at the receiver is simply the transmitter power (dBm) plus the sum of both antenna gains (dBi) minus the free space and atmospheric losses (dB). Atmospheric losses for the frequencies under consideration are insignificant and may be ignored.

Received Power (dBm) = transmitter power (dBm) + transmit antenna gain (dBi)
+ free space loss (dB) + receive antenna gain (dBi) (1)

The most interference will be introduced into the receiver when the transmit antenna is near and directly in front ("boresight") of the receive antenna. In that case, one or both antennas may be in their near field and far field power calculations do not apply. The transmitter is assumed to be a small device (e.g., a mobile phone or data device). The transmitter will be connected to a small antenna. Its near field distance will be on the

order of a few inches so that antenna will be operating in the far field region for all situations we will consider. The victim receiver is typically connected to a relatively large antenna so near field considerations will need to be addressed for that antenna.

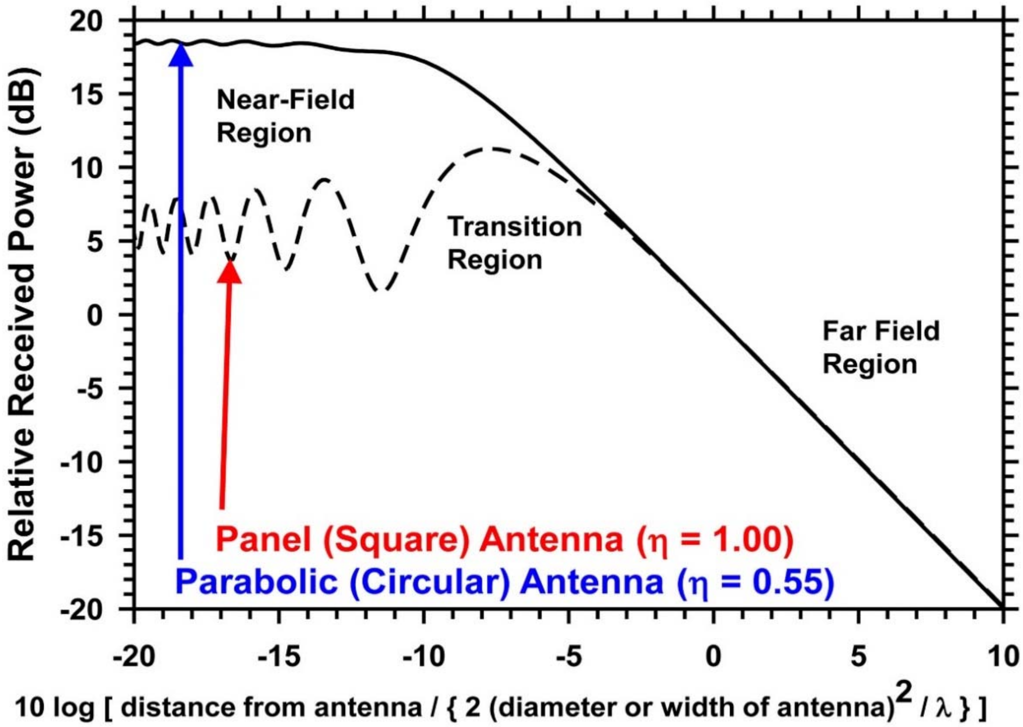

Figure 2 – Antenna Boresight Received Power

All the incumbent receive antennas in the frequency bands of interest are circular (square antennas are limited to unlicensed bands). As the small transmit antenna (operating as a point source since it is in its far field) approaches the larger receive antenna, at first the received energy increases directly as the inverse of the square of the distance between the two antennas. Eventually the transmit antenna enters the near field region of the receive antenna. As the separation distance continues to be reduced, the receive energy reaches a constant value. For the typically 55% illumination efficiency parabolic antenna, the limiting value is 18.5 dB greater than the receive power at the conventional far field crossover point of the antenna ($2\ D^2 / \lambda$ where λ is free space wavelength and D is diameter). For details, see [1], pages 256 to 295.

We will consider worst case conditions in which the transmit antenna is directly in front of the receive antenna ("boresight" conditions).

$$\text{Received Power} = \text{transmitter power} + \text{transmit antenna gain} + \text{antenna near field effect} \quad (2)$$

When sharing spectrum, the standard approach is to engineer interference so that the interference increases the receiver front end noise a tolerable amount. Most national and international administrations allow a receiver front end noise to be increased 1 dB for an intra-system interferer or 0.4 dB for an inter-system ("foreign") interferer. This implies the

interference must be 6 dB or 10 dB respectively less than the receiver front end noise. The following levels are accepted engineering practice (Reference, page 672, formula (A.44)) for the situation we are investigating:

$$\text{[Allowable] Foreign System Interference} = \text{Radio Front End Noise} - 10\text{ dB} \quad (3)$$

Receiver front end noise N is given by the following (Reference, page 674, formula (A.54)).

$$N(\text{dBm}) = -114 + NF(\text{dB}) + 10\,\text{Log}(B) \quad (4)$$

NF = receiver noise figure (dB)
B = receiver bandwidth (MHz)

Since the typical receiver noise figure in this band is about 4 dB (Reference, page 674), the allowable foreign system interference would be the following.

$$N(\text{dBm}) = -120 + 10\,\text{Log}(B) \quad (5)$$

The transmitter will usually be a mobile device requiring an omnidirectional antenna. The theoretical maximum gain for this type of antenna is a dipole (2.2 dBi gain). That is the best that can be done with a small device if approximately omnidirectional service is required.

If both antennas are operating in the far field region, free space path loss (dB) is given by the following formula (reference, page 670, formula (A.28)).

$$92.5 + 20\,\text{Log}\,F\ (\text{GHz}) + 20\,\text{Log}\,d\ (\text{kilometers}) \quad (6)$$

F = Frequency of radio wave
d = Distance between antennas

The conventional near field cross-over distance (Reference, pages 272 and 273) is $2D^2 / \lambda$ where λ is free space wavelength and D is the antenna diameter.

$$\lambda\ (\text{meters}) = 0.29980 / F\ (\text{GHz}) \quad (7)$$

If only the receive antenna is operating in the near field, the antenna near field effect mentioned in the above formula is the following:

Free space loss at far field cross-over (dB) + antenna far field gain (dBi) + 18.5 dB (8)

We can now implement the equation describing the allowable transmit power P_t.

Received Power = transmitter power + transmit antenna gain + near field received energy

$$[\,-120 + 10\,\text{Log}\,B(\text{MHz})\,] = P_t + 2.2 + [\ Gr\ (\text{dBi}) + 18.5 \quad (9)$$

$$- \{92.5 + 20 \text{ Log } F \text{ (GHz)} + 20 \text{ Log } [\, 2\, D^2 / \lambda \text{ (kilometers)}] \}$$

$$P_t \text{ (dBm)} = -108.2 - Gr \text{ (dBi)} + 20 \text{ Log } F \text{ (GHz)} + 20 \text{ Log } [\, 2\, D^2 / \lambda \text{ (meters)}] + 10 \text{ Log } \{B \text{ (MHz)}\} \quad (10)$$

The gain of a typical parabolic antenna can be given by the following:

$$G \text{ (dBi)} = 17.9 + 20 \text{ Log } F \text{ (GHz)} + 20 \text{ Log } D \text{ (meters)} \quad (11)$$

See Reference, page 675, equation (A.63), with E = 55.:

Using this equation, we can infer the minimum size of antennas which meet the various category requirements of FCC rule §101.115 (b) (1) [6]. For lower 6 GHz (≈ 6.175 GHz) Category A and B1 antennas have a minimum gain requirement of 38 dBi. Equation (11) suggests the minimum antenna diameter will be 1.64 meters (5.4 ft). Category B2 antennas have a minimum gain requirement of 32 dBi. This yields a minimum antenna diameter of 0.82 meters (2.7 ft). Actual commercial antennas for these Categories have sizes of 1.83 meters (6 ft) and 0.91 meters (3 ft) respectively.

Combining equations (10) and (11) we obtain the following:

$$P_t \text{ (dBm)} = -109.6 + 20 \text{ Log } F \text{ (GHz)} + 20 \text{ Log } D \text{ (meters)} + 10 \text{ Log } B \text{ (MHz)} \quad (12)$$

Now we need the necessary parameters for the frequency bands of interest:

Band Name	4 GHz	Lower 6 GHz	Upper 6 GHz
Frequency Range (GHz)	3.700 - 4.200	5.925 - 6.425	6.525 - 6.875
Center Frequency (F)	3.95 GHz	6.175 GHz	6.7 GHz
Bandwidth	500 MHz	500 MHz	350 MHz
Free Space Wavelength	0.0759 meters	0.0485 meters	0.0447 meters

Table 1 - Band Characteristics

Channel Bandwidth (MHz)	4 GHz	Lower 6 GHz	Upper 6 GHz
60		X	
30		X	X
20	X		
10		X	X
5		X	X
3.75*		X	X
2.5*		X	X
1.25*		X	X
0.8*		X	X
0.4*		X	X

Table 2 - Band Channel Bandwidths (MHz)
* of little commercial significance

Size (Feet)	Size (Meters)	4 GHz	Lower 6 GHz	Upper 6 GHz
4	1.22		X	X
6	1.83		X	X
8	2.44	X	X	X
10	3.05	X	X	X
12	3.66	X	X	X

Table 3 – Typical Receive Antenna Sizes

Size (Feet)	Size (Meters)	4 GHz	Lower 6 GHz	Upper 6 GHz
4	1.22		61.2	66.4
6	1.83		137.8	149.5
8	2.44	156.7	244.9	265.8
10	3.05	244.8	382.7	415.3
12	3.66	352.5	551.1	598.0

Table 4 - Far Field Crossover Distance ($2 D^2 / \lambda$, meters)

4 GHz (≈ 3.95 GHz) has a channel bandwidth of 20 MHz and antenna diameters in the range of 2.4 to 3.7 meters. Applying these values to equation (12) suggests P_t would be in the range of -77 to -74 dBm.

Lower 6 GHz (≈ 6.175 GHz) has practical channel bandwidths from 5 MHz to 60 MHz and antenna diameters in the range of 1.2 to 3.7 meters. Applying these values to equation (12) suggests P_t would be in the range of -78 to -47 dBm.

Upper 6 GHz (≈ 6.7 GHz) has practical channel bandwidths from 5 MHz to 30 MHz and antenna diameters in the range of 1.2 to 3.7 meters. Applying these values to equation (12) suggests P_t would be in the range of -77 to -52.3 dBm.

Based upon this data we would expect the acceptable range of transmitter power P_t (dBm) to be on the order of -50 to -80 dBm. The larger (less negative) values are associated with wider channel bandwidths and larger antennas. While wider channel bandwidths are the norm, most users are trying to use the smallest antenna possible. If we consider that most modern systems use small antennas, the practical range of P_t is on the order of -60 to -80 dBm. From a practical perspective, these power levels are rather restrictive.

Mitigation Possibilities

If we assume the interfering signals are relatively narrow bandwidth, **wideband signals** could be used to reduce interference. If a narrow bandwidth interfering signal is spread across an entire frequency band then interference reduction would be a function of the ratio of the frequency spread bandwidth (frequency band of 350 to 500 MHz) divided by

the victim receiver bandwidth (10 to 60 MHz).

Interference Reduction (dB) ≈10 Log [band bandwidth / receiver channel bandwidth] (13)

This could reduce interference on the order of 9 to 17 dB. Of course, the frequency spread repetition frequency must be at least the baud rate of the victim received signal (approximately the inverse of the receiver bandwidth) to be effective.

Real transmitters and receivers are generally located around **trees and buildings**. Consideration could be given to losses induced by these environmental factors. In [2] residential and high-rise buildings were measured for RF attenuation. At 5.99 GHz, median non-line-of-sight penetration losses into high rise buildings was 20 dB and into residential buildings was 16 dB. If both line-of-sight and non-line-of-sight paths were considered the high-rise results were the same but residential building loss was reduced to 12 dB. Variation around these numbers of plus or minus 5 dB was observed. Basement penetration loss was on the order of 20 to 30 dB greater than for that of the first floor. Diffraction (shadowing) loss around buildings varied greatly: 1 to 46 dB.

In [3] measurements of losses at 5.9 GHz into residential buildings averaged 16 dB. Variation of 7 dB around this value was observed. Penetration losses through deciduous trees (beeches and maples) varied between 4 and 16 dB. Basement penetration loss was on the order of 6 to 10 dB. This relatively low loss was probably because the basements were only slightly below ground. In [4] measurements at 5.2 GHz indicated a building penetration loss of 12 dB with standard deviation of 5 dB.

Overall if line-of-sight paths through windows are avoided, building penetration losses of at least 10 dB seem reasonably conservative. Other environmental effects seem too variable to be reliable.

Consideration could be given to the **terrain** between the transmitter and receiver. As noted in [5], the transmission loss difference between line-of-sight and non-line-of-sight can be considerable: 20 to 30 dB at the transition point between line-of-sight and non-line-of-sight. However, each situation is highly dependent upon local building, foliage and terrain characteristics. Generalizations are not apparent. However we can make some deductions for simplistic situations.

If the transmitter is in the boresight of the receive antenna but constrained to be no closer to the receive antenna than its far field zone, the transmitter may be 18.5 dB more powerful. If the radial distance is increased further, the transmitter power limitation is further reduced by 20 Log (boresight distance / far field distance). If the transmitter is ten times the far field distance from the receive antenna, the transmitter power may be increased to 18.5 plus 20 dB for a total of 38.5 dB.

If we constrain the transmitter to be to the side of the receive antenna boresight, additional relaxation is possible, due to FCC rules [6] that require suppression of the power received by the antenna at specified angles away from the boresight..

Conclusion

The power limitations on an unconstrained transmitter are rather significant. Some mitigating factors are available. However, whether or not they are adequate depends upon the anticipated service. Unconstrained we would expect the practical acceptable range of transmitter power P_t (dBm) to be on the order of -60 to -80 dBm. There are various factors that could allow these values to be increased roughly 10 to 20 dB with optimistic assumptions. Still, a transmitter power P_t (dBm) on the order of -40 to -60 dBm using a low gain transmit antenna does not seem to be particularly useful. For practical transmit power levels, some form of frequency management will be necessary to allow the transmitter to be placed in the vicinity of the receive antenna.

References:

[1] Kizer, G., *Digital Microwave Communication*. Hoboken: Wiley and Sons, 2013

[2] Loew, L. H., Lo, Y., Laflin, M. G. and Pol, E. E., *Building Penetration Measurements From Low-height Base Stations At 912, 1920, and 5990 MHz*, NTIA Report 95-325. Boulder: National Telecommunications and Information Administration, Institute for Telecommunications Sciences, September 1995.

[3] Furgin, G., Rappaport, T. S. and Xu, H., “Measurements and Models for Radio Path Loss and Penetration Loss In and Around Homes and Trees at 5.85 GHz”, *IEEE Transactions on Communications*, pp. 1484-1495, November 1998.

[4] ITU-R Report P.2346-0, *Compilation of Measurement Data Relating to Building Entry Loss*. Geneva: International Telecommunication Union, Radiocommunication Sector, May, 2015.

[5] ITU-R Recommendation P.1411-9, *Propagation data and prediction methods for the planning of short-range outdoor radiocommunication systems and radio local area networks in the frequency range 300 MHz to 100 GHz*. Geneva: International Telecommunication Union, Radiocommunication Sector, June 2017.

[6] FCC Rules, CFR Title 47, Chapter I, Subchapter D, Part 101 (Fixed Microwave Services), Subpart C, §101.115 (Directional Antennas) (b) (2) Antenna Standards, September 13, 2017.