Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the Matter of	)	
	)	
Request by iRobot Corporation	)	ET Docket No. 15-30
For Waiver of Section 15.250(c)	)	
of the Commission's Rules	)	

REPLY COMMENTS OF IROBOT CORPORATION

iRobot Corporation ("iRobot"), through counsel, hereby replies to comments filed in the above-captioned proceeding.[1] iRobot seeks a waiver of Section 15.250(c) of the Federal Communications Commission's ("Commission" or "FCC") rules to obtain equipment certification for and market a Robotic Lawn Mower (RLM) system.[2] The record shows that grant of the waiver is consistent with the intent of the rule, and will make available a device that will reduce deaths and injuries related to lawn mowing, reduce emissions and noise pollution, and improve the quality of life for many consumers.[3]

As described herein in response to the comments filed by the National Radio Astronomy Observatory ("NRAO"), the iRobot system will adequately protect radio astronomy use of the 6650-6675.2 MHz band.[4] As a realistic matter, iRobot's proposed operations will have an

[1] *OET Seeks Comments on the iRobot Request for a Waiver*, Public Notice, ET Docket No. 15-30 (rel. Feb. 5, 2015).
[2] Request by iRobot Corporation for Waiver of Section 15.250(c) of the Commission's Rules, ET Docket No. 15-30 (filed Jan. 22, 2015) ("Waiver Request").
[3] Waiver Request at 1.
[4] Comments of the National Radio Astronomy Observatory, ET Docket No. 15-30 (filed March 6, 2015) ("NRAO Comments").

infinitesimal likelihood of impacting any radio astronomy measurements in the band. The public interest and Commission precedent support grant of the waiver.

DISCUSSION

Grant of the Waiver is in the Public Interest.

iRobot has requested that the Commission waive the Section 15.250(c) prohibition against the use of fixed outdoor infrastructure so that it may market a robotic lawn mower that employs beacons placed in the ground of residential lawns.[5] These beacons will be set out only during mowing season and, except for a brief set-up period, will only communicate with the robot.[6]

The underlying purpose of Section 15.250(c), which was adopted by the Commission out of an abundance of caution, is to prevent the creation of communications networks that could interfere with existing authorized services.[7] The record shows that the iRobot RLM system cannot form a wide area network, and no party challenges this fact. The placement of outdoor portable beacons during the mowing season does not come within the category of "fixed outdoor infrastructure" as contemplated by the Commission when it established Section 15.250(c). In practice, the effect of iRobot's operations will be no different from a compliant wideband device.[8]

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[5] Waiver Request at 3-4.
[6] *Id*.
[7] *In the Matter of Ultra-Wideband Transmission Systems*, Second Report and Order and Second Memorandum Opinion and Order, 19 FCC Rcd 24558, 24568-24571 (2004).
[8] As noted in the Waiver Request, after set-up the portable beacons will communicate only to the robot, while unique addressing will prevent transmitters from communicating with devices off the property. Waiver Request at 4. Moreover, "[c]ustomers will be instructed to remove the beacons at the close of the mowing season, which is necessary to prevent battery drain and protect the beacons from damage due to environmental elements." *Id*.

iRobot has detailed the many public health, safety and other benefits that will come with grant of the waiver. For example, robotic lawn mowers are safer for consumers to use, are better for the environment than gasoline mowers, and will assist the elderly and disabled as well as give consumers more free time.[9] Again, no party challenges these facts.

The iRobot RLMs Would Pose a Negligible Risk of Harmful Interference to Radio Astronomy.

The iRobot RLMs would adequately protect radio astronomy's use of the 6650-6675.2 MHz frequency band. The geographic location of the affected observatories, coupled with iRobot's commitment to market and label the devices for residential use only, will serve to protect radio astronomy. Further, as a Part 15 wideband system, Quiet Zone coordination would not be useful.

iRobot respects the work of the radio astronomy community and closely considered the impact of its system on all incumbents and users, including radio astronomy. As iRobot details herein, its calculations show that there is an exceedingly low practical risk that the iRobot RLM system would cause harmful interference to the NRAO's observations of the 6.66852 GHz spectral line of methanol, considering the propagation characteristics of terrain, foliage, and buildings and operational characteristics of the RLMs.

(a) iRobot RLMs will not be operating in close proximity to radio astronomy sites.

As a general matter, iRobot RLMs will not be operating in close proximity to radio astronomy sites. The iRobot RLM will be marketed for consumer use only, and iRobot has offered to place a notice in the user manual and on the robot that states:

[9] *See* Waiver Request at 1-2 and 6-7.

"Consumer use only; use must be limited to residential areas."[10] The NRAO observatories for the most part are not closely surrounded by residential areas, at least no residential areas with lawns. As NRAO has explained in other filings, "[m]any of the NRAO telescopes, but especially the Very Large Array (VLA) and the Robert C. Byrd Green Bank Telescope, are surrounded by large quantities of livestock grazing, penned, etc."[11] A review of the observatory locations on Google maps also shows that many are surrounded by desert or forests, not environments where residential lawn equipment is used.[12] For these reasons, it is exceedingly unlikely that an RLM designed for and limited to residential use would be used within the interference radius of an observatory.

(b) NRAO's exclusion zone is significantly overstated; calculations based on the correct interference levels, terrain blockage, ground attenuation and foliage demonstrate that no iRobot RLM will be operated within the harmful interference threshold.

Use of the correct interference level to calculate the potential radius of interference, without accounting at all for the significant additional reductions from terrain and foliage, proves that ten of the potential sites have no potential for harmful interference from the iRobot RLM systems. When terrain and foliage are considered, the calculations demonstrate that no iRobot

[10] Waiver Request at 8.
[11] *Office of Engineering and Technology Declares Multispectral Solutions, Inc. Request for a Waiver of Part 5 to be a "Permit-but-Disclose" Proceeding for Ex Parte Purposes*, ET Docket No. 06-025, Comments of the National Radio Astronomy Observatory at ¶ 5 (filed June 8, 2006); *see also Office of Engineering and Technology Declares Multispectral Solutions, Inc. Request for a Waiver of Part 5 to be a "Permit-but-Disclose" Proceeding for Ex Parte Purposes*, ET Docket No. 06-025, Comments of the National Spectrum Managers Association at 2 (filed June 12, 2006) (noting that the "Very Large Array facility in New Mexico is embedded within and surrounded by hundreds of thousands of acres of grazing land.").
[12] *See e.g.* Declaration of Heath Dube, attached, at Table 1 ("Declaration").

RLM will be operated within the harmful interference threshold of any of the three remaining sites.

NRAO calculates that an 89 km exclusion zone is necessary to protect radio telescopes from harmful interference. This radius is overstated. NRAO relies upon a detrimental interference level to RAS operations of -241 dBW/m²/Hz, which is the level for continuum measurements.[13] The particular concern stated by NRAO is interference to spectral-line observations of methanol for which the appropriate interference level is -228 dBW/m²/Hz.[14] The difference between these threshold levels significantly reduces the claimed radius of interference **to a maximum of 19.3 km**, before considering other factors.[15] Additionally, there is a different threshold for telescopes that operate as part of a large array. As explained in the attached Declaration, the ten NRAO observatories that are part of the Very Large Baseline Array ("VLBA") are actually subject to an interference threshold of -198 dBW/m^2/Hz, which reduces the radius of interference from an iRobot beacon **to only 610 meters with perfect line of sight**.[16] This distance only appears to contain residences at one VLBA site – North Liberty, Iowa, which is a heavily forested site.[17]

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[13] *See* ITU-R Recommendation RA 769-2 at Table 1.
[14] *See* ITU-R Recommendation RA 769-2 at Table 2. The National Academy of Sciences' Committee on Radio Frequencies has explained that –228 dBW$m^{-2}Hz^{-1}$ (interpolated from Table 2 of Recommendation ITU-R RA.769) is the required threshold level for spectral line observations in the 6525-6700 MHz band. *See Establishment of an Interference Temperature Metric to Quantify and Manage Interference and to Expand Available Unlicensed Operation in Certain Fixed, Mobile and Satellite Frequency Bands*, Comments of the National Academy of Sciences' Committee on Radio Frequencies, ET Docket No. 03-237, at 10 (filed April 5, 2004). iRobot notes that these comments omit the "m" portion of the unit measured, though they cite to the ITU table which has the proper unit of measurement.
[15] Declaration at ¶ 4.
[16] *See* Table 3 of ITU-R Recommendation RA 769-2.
[17] Declaration at ¶ 5. Simulations of terrain effects or calculations of the influence of foliage is unnecessary on the other nine VLBA sites, given the lack of residences within 610 m.

With regard to the two other (non VLBA) NRAO observatories with residences within the maximum interference zone – Arecibo and the Green Bank telescope – when terrain blockage is considered the interference radius is reduced considerably. To calculate true interference distances, iRobot has performed propagation simulations which are based on the Longley-Rice model and take real geography around the radio telescope sites into account.[18] iRobot beacons will be situated less than two feet off the ground, which makes ground effect attenuation a significant contributing factor to the co-existence of iRobot RLM systems within a relatively small distance of NRAO sites. Another important consideration is that iRobot's wideband technology by its nature spreads already low power transmissions over a large bandwidth of spectrum so that only a tiny fraction would impact the 6.66852 GHz line of observation.

Below is a summary of calculations for the thirteen NRAO sites that perform spectral measurements of methanol. This indicates that no iRobot RLM will be operated within the harmful interference threshold of any of these sites when terrain and foliage are considered. For ten of the thirteen sites, use of the correct interference level alone proves that there is no potential for harmful interference from the iRobot RLM systems. For the remaining three sites, further calculations and simulations accounting for terrain and foliage demonstrate that there is no potential for harmful interference from the iRobot RLM systems.[19]

[18] Declaration at ¶ ¶ 6-9.
[19] Using the ITU-R foliage loss model, iRobot calculates significant additional loss for wooded areas. For example, iRobot calculates an additional 44.6 dB of attenuation at 6700 MHz with only 100 m of foliage between a transmitter and receiver. Declaration at ¶ 7.

Table 1: Summary of necessary RLM beacon standoff distances to every methanol observing radio astronomy site to prevent interference. Yellow indicates residences located in the calculated interference radius; green indicates no residences within the calculated radius. Terrain was only simulated in the case of the Arecibo and Green Bank sites, due to the LOS ("Line of Sight") standoff calculations, and had a significant protective effect; both are also heavily wooded, as is the North Liberty, Iowa site.

Site	NRAO calculated necessary standoff (m) ---------- -241dBW/m^2/Hz	LOS necessary standoff (m) ---------- -198 dBW/m^2/Hz for VLBA sites ---------- -228 dBW/m^2/Hz for other sites	Necessary standoff including Terrain Loss (m)	Necessary standoff including Terrain and Foliage Loss (m)
1) VLBA – St Croix	89000	610		
2) VLBA – Hancock, NH	89000	610		
3) VLBA – North Liberty, IA	89000	610 Include Foliage	→	~100-200
4) VLBA – Fort Davis, TX	89000	610		
5) VLBA – Los Alamos, NM	89000	610		
6) VLBA – Pie Town, NM	89000	610		
7) VLBA – Kitt Peak, AZ	89000	610		
8) VLBA – Owens Valley, CA	89000	610		
9) VLBA – Brewster, WA	89000	610		
10) VLBA – Mauna Kea, HI	89000	610		
11) Arecibo, Puerto Rico	89000	19300 Include Terrain →	6840 Include Foliage →	~100-200
12) Green Bank, WV	89000	19300 Include Terrain →	6800 Include Foliage →	~100-200
13) Very Large Array NM	89000	19300		

iRobot's proposal is similar to what the FCC considered in the level probing radar ("LPR") proceeding, where the Commission examined the potential interference of LPR wideband device to radio astronomy and concluded that "the potential for interference caused by LPRs at that distance (one kilometer) would be infinitesimal, when also taking into account the variability of propagation characteristics due to terrain, weather and other factors."[20] The Commission also concluded that additional technical requirements, including required separation distances, were not required to protect radio astronomy. The same is true in this instance.

NRAO also asserts that the iRobot beacons constitute "fixed infrastructure transmitters" which would require coordination with the federal government for use within the National Radio Quiet Zone.[21] Section 1.924(a) of the Commission's rules requires that "applicants and licensees planning to construct and operate a new or modified station" within certain geographic locations surrounding the NRAO (*i.e.* the NRAO Quiet Zone) notify the NRAO of the proposed construction and operation so that NRAO has the opportunity to object to the proposed facility.[22] The Quiet Zone requirement does not extend to Part 15 wideband operations such as the iRobot RLM, which due to its extremely low power levels, does not require a license to operate.[23] The

[20] *Amendment of Part 15 of the Commission's Rules To Establish Regulations for Tank Level Probing Radars in the Frequency Band 77-81 GHz; Amendment of Part 15 of the Commission's Rules To Establish Regulations for Level Probing Radars and Tank Level Probing Radars in the Frequency Bands 5.925-7.250 GHz, 24.05-29.00 GHz and 75-85 GHz; Ohmart/VEGA Corp., Request for Waiver of Section 15.252 to Permit Marketing of Level Probing Radars in the 26 GHz Band*, Report and Order and Order, 29 FCC Rcd 761, 788 (2014). The Commission also concluded that "RAS receivers discriminate against off-beam signals and are pointed skyward, discriminating against reflected signals that would be reflected from the side or below." *Id*.
[21] NRAO Comments at ¶ 6.
[22] 47 C.F.R. § 1.924 (a).
[23] *See Review of Quiet Zones Application Procedures,* Notice of Proposed Rulemaking, 16 FCC Rcd 20690 (2001) ("Section 1.924 of our rules sets forth procedures regarding coordination of Wireless Telecommunications Services applications and operations within areas known as 'Quiet Zones.'").

combination of iRobot RLM signal levels and very low antenna heights would render coordination irrelevant.

iRobot RLMs will be able to operate without harmful interference to radio astronomy.

CONCLUSION

For the foregoing reasons, it is in the public interest for the Commission to grant expeditiously iRobot's Waiver Request.

Respectfully submitted,
IROBOT CORPORATION

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Before the
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In the Matter of	)	
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Request by iRobot Corporation	)	ET Docket No. 15-30
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DECLARATION OF HEATH DUBE

1. My name is Heath Dube. I am presently employed as a Principal Electrical Engineer at iRobot Corporation, a position I have held since 2011. In this capacity, I am primarily focused on Wi-Fi radio integration and antenna design, and I calculate link budgets and system operating margins for Wi-Fi radios and access points. I earned a B.S. in Physics with a minor in Applied Mathematics from the University of New Hampshire in 1998. In 2011, I earned a Master's of Science in Electrical Engineering from Worcester Polytechnic Institute, with concentrations in analog electronics and RF engineering.

2. I have reviewed the comments filed in this proceeding by the National Radio Astronomy Observatory ("NRAO").[1] NRAO expresses concern about the potential for harmful interference to the observations of the 6.66852 GHz spectral line of methanol performed at various NRAO observatories.[2]

3. NRAO calculates that a line of sight separation distance of 89 km is required to protect the NRAO facilities from interference by iRobot robotic lawn mower ("RLM") systems.[3] This large radius calculated by NRAO is overstated, both because of the interference level used in the calculations

[1] *Request by iRobot Corporation for Waiver of Section 15.250(c) of the Commission's Rules*, Comments of the National Radio Astronomy Observatory (filed March 6, 2015).
[2] *Id*. at ¶ ¶ 2 and 3.
[3] *Id*. at ¶ 5.

and the lack of modeling many factors, including foliage, buildings and most notably terrain. Radio astronomy sites are typically located so that terrain offers protection from unwanted radio signals. Therefore, a much more realistic estimate of safe operating distances for the iRobot RLM beacons can be made by using the stated interference level for spectral line observations and simulating the actual terrain surrounding radio astronomy sites, which I do here.

4. The stated interference level of -241 dBW/m^2/Hz used by NRAO applies to radio astronomy continuum measurements, shown in Table 1 of ITU-R Recommendation RA 769-2. However, NRAO is specifically concerned about interference to the spectral band measurement of methanol at 6.66852 GHz, which is addressed in Table 2 of the ITU-R Recommendation. Though the frequency of the spectral line of methanol is not specifically listed in Table 2, the interference threshold for observations of methanol has been stated previously by the National Academy of Sciences' Committee on Radio Frequencies (through interpolation of Table 2) as -228 dBW/m^2/Hz.[4] Employing this threshold alone significantly reduces the radius of interference to NRAO sites **to a maximum of 19.3 km**, before considering other factors.

5. The -228 dBW/m^2/Hz stated interference level is for individual antenna observations, such as those that occur (and are specifically listed by NRAO) at the Arecibo and Green Bank observatory sites. Ten of the thirteen NRAO sites are part of the Very Large Baseline Array ("VLBA"). The VLBA performs very large baseline interferometry ("VLBI"), which is subject to a completely different interference level, listed in Table 3 of ITU-R RA 769-2. This level is significantly different; through interpolation to the specific methanol frequency, it is -198 dBW/m^2/Hz. Calculating based on

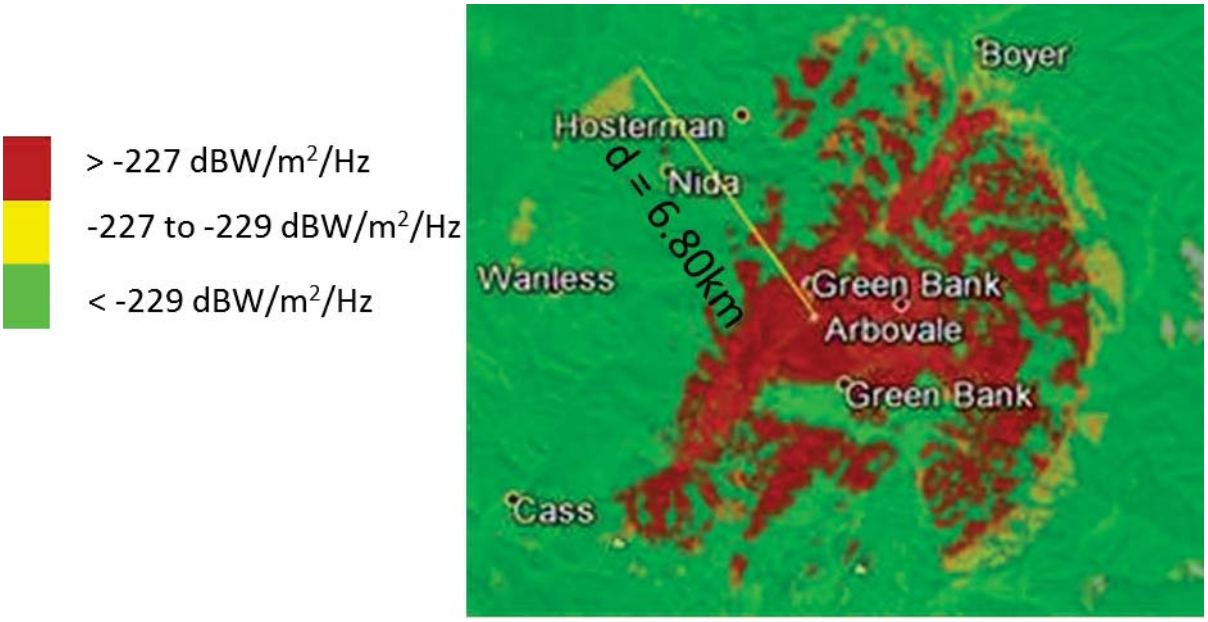
[4] *See Establishment of an Interference Temperature Metric to Quantify and Manage Interference and to Expand Available Unlicensed Operation in Certain Fixed, Mobile and Satellite Frequency Bands*, Comments of the National Academy of Sciences' Committee on Radio Frequencies, ET Docket No. 03-237, at 10 (filed April 5, 2004). I note that the filing appears to have a typo in the units stated in that it is missing the "m;" my calculations are based on the proper ITU units.

this interference level significantly reduces the radius of interference for an iRobot RLM beacon **to only 610 meters, assuming perfect line of sight**. Simulations of terrain effects or calculations of the influence of foliage are virtually unnecessary at this short distance; only one VLBA site (North Liberty, Iowa) has residences within 610 m (about 30 of them). However, the site is heavily forested, especially near these few homes, which will impede RF propagation from the iRobot beacons. A summary of the closest residences from these thirteen RAS sites estimated from Google Earth are included here to guide how far to analyze each site for interference:

Table 1: Distance from each of the thirteen radio astronomy sites to the nearest residence and description of the terrain surrounding the residence, estimated from Google Earth to guide simulation and conclusions regarding residential properties that could produce RAS interference from RLM beacons.

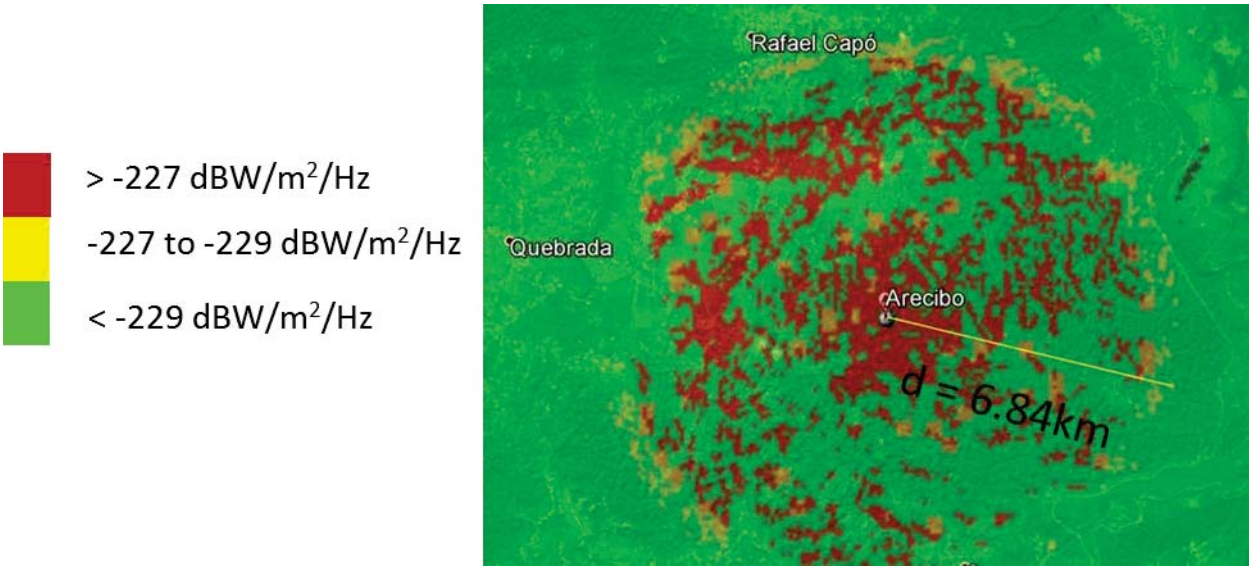
Site	Nearest Residence (est. via Google Earth)
1) VLBA – St Croix	780m (behind a ridge)
2) VLBA – Hancock, NH	1km (treed)
3) VLBA – North Liberty, IA	360m (treed)
4) VLBA – Fort Davis, TX	1.1km (no grass anywhere near here)
5) VLBA – Los Alamos, NM	3.8km
6) VLBA – Pie Town, NM	1km (no grass)
7) VLBA – Kitt Peak, AZ	15km (no grass)
8) VLBA – Owens Valley, CA	5.7km
9) VLBA – Brewster, WA	6.8km
10) VLBA – Mauna Kea, HI	>20km
11) Arecibo, Puerto Rico	1km (treed hills)
12) Green Bank, WV	1.5km
13) Very Large Array NM	>20km

6. To accurately predict the real-world range from two NRAO sites that have been identified with residences within the line of sight interference radius (Green Banks, WV and Arecibo, Puerto Rico), I utilized SPLAT!,[5] a readily available implementation of the Longley-Rice radio propagation model.[6] The industry-standard Longley-Rice model predicts attenuation of radio signals in the frequency range 20 MHz to 20 GHz, taking into account actual topography, diffraction and scatter. The figures generated herein are colored SPLAT! overlays on top of Google Earth maps. I assumed that the isotopically transmitting beacon is located at the top of the NRAO radiotelescope and measured until the flux density was at the specified interference level for a 6.7 GHz transmit signal. Heights of antennas were assumed to be 450 ft. for the Green Banks site and 365 ft. for Arecibo.



Simulation for Green Bank, WV radio astronomy site (38°25′59.24″N 79°50′23.41″W). Worst-case radius shown is 6.80 km using 450 ft. radio astronomy antenna height. Red color indicates greater than maximum interference level, yellow is equal to maximum interference level, and green is less than maximum interference level.

[5] SPLAT! Because the World Isn't Flat, http://www.qsl.net/kd2bd/splat.html.
[6] P. L. Rice, A. G. Longley, *et al.*, Transmission Loss Predictions for Tropospheric Communications Circuits (1965), *available at* https://ia902600.us.archive.org/22/items/transmissionloss1011rice/transmissionloss1011rice.pdf.



Simulation for Arecibo, Puerto Rico radio astronomy site (18°20′36.60″N 66°45′11.10″W). Worst-case radius shown is 6.84 km using 365 ft. radio astronomy antenna height. Red color indicates greater than maximum interference level, yellow is equal to maximum interference level, and green is less than maximum interference level.

7. It is important to note that these two sites are also heavily wooded. Utilizing the ITU-R model for foliage loss,[7] passing through a 100 m long wooded area would attenuate a 6.7 GHz signal by 44.6dB. In the specific case of an RLM beacon, a 104 m long wooded area would attenuate the transmit power of -131 dBW/Hz to below the -228 dBW/m^2/Hz detrimental interference level required for NRAO single site observatories.

8. The following table summarizes the worst case transmit distances that an iRobot RLM beacon would need to be located away from the NRAO sites to ensure no harmful interference. The radius for terrain simulated sites is highly bearing dependent but the largest distance simulated was taken; this was often at the top of unpopulated mountains. In summary, for the thirteen NRAO sites that perform spectral measurements of methanol, I have made the following standoff conclusions:

[7] Consultative Committee for International Radio Report, CCIR Report, "Influences of Terrain Irregularities and Vegetation on Troposphere Propagation," at 253-236 (1986).

Table 2: Summary of necessary RLM beacon standoff distances to every methanol observing radio astronomy site to prevent interference. Yellow indicates residences located in the calculated interference radius; green indicates no residences within the calculated radius. Terrain was only simulated in the case of the Arecibo and Green Bank sites, due to the LOS ("Line of Sight") standoff calculations, and had a significant protective effect; both are also heavily wooded, as is the North Liberty, Iowa site.

Site	NRAO calculated necessary standoff (m) ---------- -241dBW/m^2/Hz	LOS necessary standoff (m) ---------- -198 dBW/m^2/Hz for VLBA sites ---------- -228 dBW/m^2/Hz for other sites	Necessary standoff including Terrain Loss (m)	Necessary standoff including Terrain and Foliage Loss (m)
1) VLBA – St Croix	89000	610		
2) VLBA – Hancock, NH	89000	610		
3) VLBA – North Liberty, IA	89000	610 Include Foliage	→	~100-200
4) VLBA – Fort Davis, TX	89000	610		
5) VLBA – Los Alamos, NM	89000	610		
6) VLBA – Pie Town, NM	89000	610		
7) VLBA – Kitt Peak, AZ	89000	610		
8) VLBA – Owens Valley, CA	89000	610		
9) VLBA – Brewster, WA	89000	610		
10) VLBA – Mauna Kea, HI	89000	610		
11) Arecibo, Puerto Rico	89000	19300 Include Terrain →	6840 Include Foliage →	~100-200
12) Green Bank, WV	89000	19300 Include Terrain →	6800 Include Foliage →	~100-200
13) Very Large Array NM	89000	19300		

9. Though certainly conservative (the assumed height of the antennas are most likely overestimates, and interfering trees and structure/buildings are not accounted for), the terrain simulations alone show that terrain has a large effect on safe iRobot RLM transmit distance. Adding in the ITU-R model for foliage attenuation brings the interference distance down well below 1km.

I declare under penalty of perjury under the laws of the United States of America that the foregoing is true and correct to the best of my knowledge. Executed on March 25, 2015.

Heath Dube
Principal Electrical Engineer
iRobot Corporation