

Exhibit C - Interference Study

Interference and Electromagnetic Compatibility Study

The experimental Swarm satellite network, which includes 2 satellites and 3 US earth stations,¹ employs the 137-138 MHz band for space-to-earth links and the 148-150.05 MHz band for earth-to-space links, consistent with the US and International Table of Frequency Allocations. To demonstrate compliance with an experimental system's obligation to operate on a non-interference basis with other authorized operators in the bands, this report provides a three-part electromagnetic compatibility study with the existing authorized users. Specifically, the report includes: 1) a study of compatibility with terrestrial services, 2) a study of compatibility with other satellite systems, and 3) a study of compatibility with radio astronomy services.

Statement for Terrestrial Compatibility

ITU Radio Regulations impose power flux density (PFD) limits that trigger coordination for certain terrestrial (fixed and mobile) systems in the 137-138 MHz band.² In summary, the PFD threshold that triggers coordination with terrestrial services is $-125 \text{ dBW/m}^2/4\text{kHz}$.

Figure 1 shows a plot of the expected PFD at Earth's surface for all angles of arrival at the operational orbit altitude of 475 km. As shown in Figure 1, the power flux density (PFD) at the Earth's surface produced by the Swarm satellites will not exceed $-129 \text{ dB(W/m}^2)$ in any 4 kHz band at any angle of arrival, which is under the threshold for coordination with both terrestrial services and therefore does not trigger a coordination requirement.

¹ The satellites for which an authorization is sought will transmit only when within line of sight of three US earth stations, one in Los Altos, CA, one in Atlanta, GA, and one in Draper, UT, when commanded by the ground station. No other earth stations will transmit to the satellite.

² ITU RR Appendix 5, Annex 1, article 1.1.1.

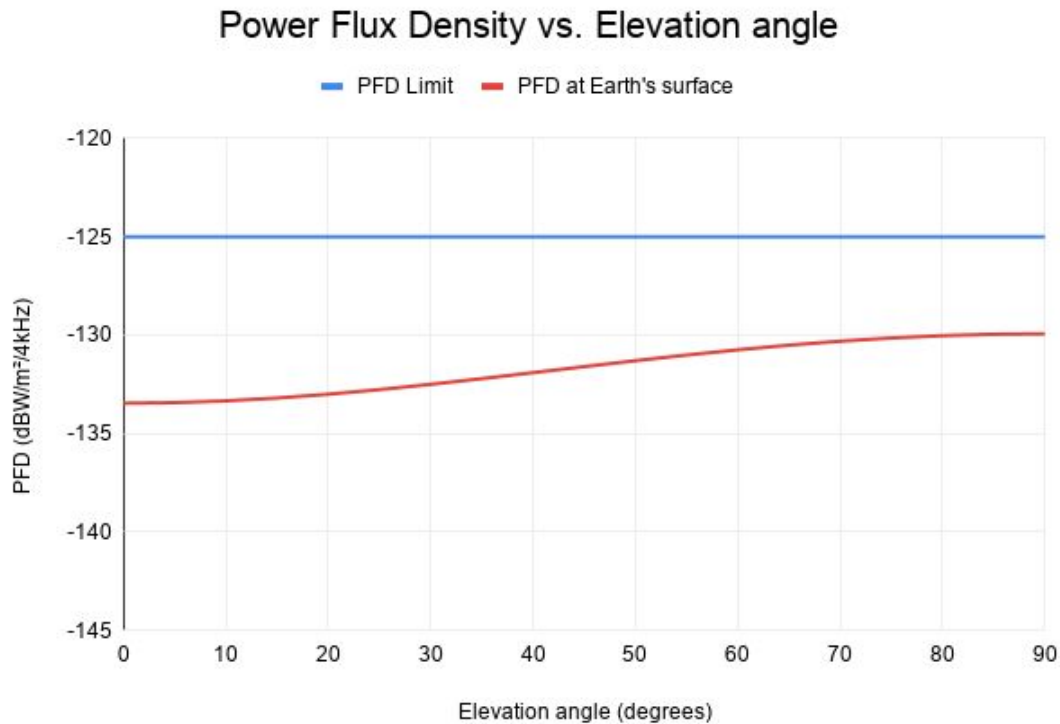


Figure 1. PFD at Earth's surface produced by a satellite transmission.

Statement of Satellite Service System Compatibility

For this experimental deployment, Swarm proposes to operate on the 137.880-138.000 MHz band in the space-to-Earth direction and on the 148.300-148.420 MHz band in the Earth-to-space direction (accommodating four channels in each of the uplink and downlink directions, see accompanying Exhibit A: Narrative for additional details).

From the ITU Space Network Systems Online (SNS), a list of satellite systems using the 137-138 MHz band was collected and shown in Table 1. For each satellite system, the table indicates the administrative jurisdiction, service areas, frequency overlaps, and ultimately a disposition for a coordination requirement. Most satellites have either no frequency overlap with Swarm satellites, have no area coverage overlap, or have no apparent earth stations in the USA. In addition, a search of the FCC IBFS for the 137-138 MHz band show that only Orbcomm is licensed for a space system using these space services links within the United States. In summary, only Orbcomm Satellites and NOAA N require some form of coordination for operations in the USA. Swarm will seek consent from both the NTIA and Orbcomm regarding those systems.

The Interference Protection Criteria (IPC) for meteorological satellites³ in the 137-138 MHz band

³ ITU R-REC-SA.1027-5, Table 1, Sharing Criteria at 137-138 MHz. Interfering signal power (dBW) should not exceed -136 dBW per 150 kHz more than 0.0063% of the time.

is -136 dBW per 150 kHz. This IPC is applicable for the NOAA N and NOAA KLM satellites. There is no frequency overlap with NOAA KLM and therefore no interference is expected. The NOAA N earth stations may have an isotropic gain as high as 10 dBi⁴ and in this case the signal power from a Swarm satellite into a NOAA N ground receiver could reach -124.3 dBW, exceeding the IPC. This however will be a rare situation where a Swarm satellite is transmitting at the same time the NOAA N earth station is pointed in the direction of the Swarm satellite (given a 10 dBi antenna has some directionality).

In fact, potential interference conjunctions above the -136 dBW/150 kHz IPC is estimated to occur less than 0.00090% of the time, which meets the IPC limit of less than 0.0063% of the time (as specified by the previously referenced ITU recommendation). This is estimated as follows:⁵ The Swarm transmissions will occur less than 0.17% of the time daily. The NOAA N satellite may transmit up to 3.3% of the time daily in the same area. A 10 dBi earth station antenna has a 6 dB beamwidth of approximately 72 degrees, which is about 16% sky coverage. This results in a potential interference conjunction exceeding -136 dBW into the earth station receiver no more than 0.00090% of the time. Therefore the experimental Swarm satellite system meets the IPC for NOAA N and coordination should not actually be required. Note that this estimate assumes the worst-case scenario in which the satellites share a similar orbit and equatorial crossing time and anything otherwise would yield a smaller conjunction percentage.

There are several other satellite systems shown in the tables below deserving additional attention: EBSAT-LEO-1, EBSAT-LEO-1B, IMDC, MNSAT, SI-SAT-BILIKIKI, and NSL-1. In each of these cases there is potential frequency overlap and the USA is a designated coverage area in the ITU notices. However, none of these systems have launched yet, and no US licenses or applications were submitted to the FCC as of November 2018. The EBSAT-LEO-1 and -1B systems are planned Mobile Satellite Service constellations by Thales Alenia Space filed through the French administration. The IMDC system is a single satellite by the company Innovative Solutions In Space in the Netherlands. It appears there will only be an earth station in the Netherlands. The MNSAT system is a planned Mobile Satellite Service constellation filed through the Australian administration. The SI-SAT-BILIKIKI system is a planned large Mobile Satellite Service constellation by Pangea Networks LLC. Pangea Networks is a US-based company but filed their satellite system notification through the Solomon Islands administration. The NSL-1 system is a planned constellation by NSLComm, filed through Israel. For each of these systems, the status of the launch authorization licensing and construction progress of the systems is unknown by Swarm, and the systems have no space system licensing within the United States. As such, no coordination is required with these systems.

Two additional satellite systems listed in the tables below deserving additional discussion are KELYPSIS and HOL-MG-A006. The KELYPSIS system is a planned constellation by Kepler Communications with an ITU filing through Canada. Kepler filed for US market access (IBFS File No. SAT-PDR-20161115-00114), but only requested access to the 10.7-12.7 GHz and 14-14.5 GHz frequency bands in the United States. No request was made to the Commission for access to frequencies in the 148-150.05 MHz band, so coordination with Kepler will not be required. The HOL-MG-A006 system

⁴ The ITU SNS for NOAA N shows receive antenna type ND with up to 10 dBi isotropic gain.

⁵ Swarm transmissions: 2 second duration * 36 contacts * 2 satellites / 86400 seconds/day = 0.17%,
NOAA transmissions: 12 minute duration * 4 contacts * 1 satellite / 1440 minutes/day = 3.3%,
NOAA earth station antenna sky coverage: $\text{PI} \cdot (72 \text{ deg beamwidth} / 2)^2 / \text{PI} \cdot (90 \text{ deg})^2 = 16\%$

is a planned constellation by Hiber (formerly Magnitude Space), licensed by the Netherlands. Hiber filed for US market access (IBFS File No. SAT-PDR-20180910-00069), but only requested access to the 399.9-401 MHz bands. No request was made to the Commission for access to frequencies in the 148-149.9 MHz band, so coordination with Hiber will not be required.

In these tables, red-colored boxes indicate frequency overlap between the respective system in the row and the Swarm satellite. Green rows indicate some level of coordination or additional consideration is required for the system.

Table 1: List of Satellite Systems in the ITU SNS, transmitting 137-138 MHz

Satellite	Country	Service Area	Maximum Frequency	Coordination requirement	Notes
AGILE	Italy	XVE Kenya ES	138	None	Equatorial NGSO, no orbital access to USA.
ATS-5	USA	GEO NC ES	137.365	None	GEO, no frequency overlap
EBSAT-LEO-1	France	XAA (world)	138	None	Not launched yet No US license/stations
EBSAT-LEO-1 B	France	XAA	138	None	Not launched yet No US license/stations
EUTELSAT-48 E	France	GEO Belgium ES	137.230	None	GEO, no frequency overlap
IMDC	Nether lands	XAA, Netherland ES	137.9-138 E-S, S-E	None	Not launched yet? No US license/stations Innovative Solutions In Space
IMP-J	USA	AK, NC ES	137.995	None	Inactive, 1970's
LEOTELCOM-1	USA	XAX (world)	137.325	Orbcomm Consent	No frequency overlap
LEOTELCOM-2	USA	XAX	137.928	Orbcomm Consent	To be coordinated with Orbcomm
LEOTELCOM-5	USA	XAA	137.655	Orbcomm Consent	No frequency overlap
MCSCS	China	XAA	137.525	None	No frequency overlap
METEOR-3M	Russia	XAA	137.975	None	Deactivated March 2006
METOP	France	XAA	137.1	None	No frequency overlap
MNSAT	Australia	AUS, NZ, CAN, USA	138	None	Not launched yet No US license/stations
NOAA N	USA	XAA	137.932	NTIA consent IPC met	To be coordinated w/ NTIA IPC met
NOAA-KLM	USA	XAA	137.793	None	No frequency overlap
RS-D2	India	IND (India)	137.550	None	No area or frequency overlap
SAUDISAT-1C	Saudi Arabia	ARS (Saudi Arabia)	137.525	None	No area or frequency overlap
SAUDISAT-2	Saudi Arabia	ARS	137.513	None	No area or frequency overlap
SEO BHASKARA-1	India	IND	137.990	None	No area overlap, 1980's
SEO BHASKARA-2	India	IND	137.990	None	No area overlap, 1980's

SI-SAT-BILIKIK I (300 satellites)	Solomon Island	XAA	137-138 (1 MHz)	None	Not launched yet No US license/stations Pangea Networks
SROSS-1	India	IND	137.690	None	No area or frequency overlap, 1990's

Table 2: List of Satellite Systems in the ITU SNS, transmitting 148-150.05 MHz

Satellite	Country	Service Area	Freq. Overlap (closest freq. shown)	Coordination requirement	Notes
AGILE	Italy	XVE space-to- space link	149.0 (2 MHz)	None	Equatorial NGSO, no orbital access to USA
ATS-5	USA	GEO NC ES	148.26 (30 kHz)	None	No frequency overlap
CASSIOPE-1A	Canada	XAA	150.005	None	No frequency overlap
EBSAT-LEO-1	France	XAA	148-150.05	None	Not launched yet? No US license/stations
EBSAT-LEO-1B	France	XAA	148.150.05	None	Not launched yet? No US license/stations
GOES West	USA	GEO Wallops VA	148.545	None	No frequency overlap
HOL-MG-A006	Nether lands	XAA	148-149.9	None	Not launched yet? Magnitude Space (Hiber). Filed for US market access (IBFS File No. SAT-PDR- 20180910-00069), but only requested access to 399.9-401 MHz bands. No area overlap for 148-149.9 MHz band.
IMP-J	USA	AK, NC ES	148.98 (30 kHz)	None	No frequency overlap Inactive, 1970's
IPS	Nether lands	HOL	148.118	None	No area or frequency overlap
IRS-1B, 1E	India	India	149.522 (12 kHz)	None	No area or frequency overlap
KELYPsis	Canada	XAA	148-150.05	None	Kepler Communications, filed for US market access (IBFS File No. SAT- PDR-20161115-00114), but only requested access to 10.7-12.7 GHz and 14-14.5 GHz frequency bands. No area overlap for 148-150.05 MHz band.
KITSAT-3	Korea	Korea	148.025,148.9 (20 kHz)	None	No area or frequency overlap
LEOTELCOM-1	USA	XAX	148-150.05	Orbcomm	To be coordinated with

				Consent	Orbcomm
LEOTELCOM-2	USA	XAX	148-148.905	Orbcomm Consent	To be coordinated with Orbcomm
LEOTELCOM-3	USA	XAX	149.81-149.9	None	No frequency overlap
LEOTELCOM-5	USA	XAA	148-150.05	Orbcomm Consent	To be coordinated with Orbcomm
LUOJIA-1A	China	CHN	148.35-148.4	None	No area overlap
LUX-NGSO -1/2/3	Luxemb ourg	XAA	149.0-151.0	None	No frequency overlap
MCSCS	China	XAA	149.025 (44 kHz)	None	No frequency overlap No US stations
MNSAT	Australia	XAA	148-150.05	None	Not launched yet No US license/stations
NSL-1	Israel	XAA	148-149.9	None	Not launched yet No US license/stations
QS-1	China	CHN	...148.025	None	No area or frequency overlap
RS-D2	India	IND (India)	...148.265	None	No area or frequency overlap Inactive, 1980's
SAMSON-2	Israel	ISR	148.8...	None	No area or frequency overlap
S4P	Swiss	HOL, SUI	148.2635 -148.5865	None	No area overlap
SAUDISAT-1C	Saudi Arabia	ARS (Saudi Arabia)	149.025 (44 kHz)	None	No area or frequency overlap
SAUDISAT-4, -5, -6	Saudi Arabia	ARS	148.035, 148.085, 149.035 (30 kHz)	None	No area or frequency overlap
SEO BHASKARA-1	India	IND	...148.265, 148.595...	None	No area or frequency overlap Inactive, 1980's
SEO BHASKARA-2	India	IND	...148.265, 148.595...	None	No area or frequency overlap Inactive, 1980's
SIMBA	Belgium	HOL	...148.118	None	No area or frequency overlap
SI-SAT-BILIKIK I	Solomon Island	XAA	149.025 (100 kHz)	None	No frequency overlap No US license/stations
SROSS-1,-3	India	IND	149.272...	None	No area or frequency overlap
TELEOS-1	SNG	SNG	148.6875...	None	No area or frequency overlap
TSYKADA	Russia	XAA	149.903...	None	No frequency overlap
YOUTHSAT	India	XAX	149.995...	None	No frequency overlap

Radio Astronomy Service Protection

Pursuant to the ITU Radio Regulations 5.208A, Swarm's satellites meet the ITU recommendations⁶ to avoid interference with the nearby Radio Astronomy Service (RAS) band

⁶ ITU Radio Regulations, Resolution 739 (Rev. WRC-15) and Recommendation ITU-R M.1583.

(150.05-153 MHz). The satellites transmit only in the 137-138 MHz band and out of band emissions are minimized by digital modulation techniques and filtering with at least 100 dB spectral roll-off at 150 MHz resulting in a power flux density (PFD) at Earth's surface not exceeding $-265 \text{ dB(W/(m}^2 \cdot \text{Hz))}$, thereby meeting the RAS protection criteria of $-259 \text{ dB(W/(m}^2 \cdot \text{Hz))}$.⁷

The experimental ground stations share the same frequency and out of band suppression characteristics. Ground stations will be positioned at a distance or otherwise obstructed such to prevent line-of-sight observations by a Radio Astronomy site using the 150.05-153 MHz band⁸ and resulting in a signal attenuation that meets the RAS interference protection criteria. In addition, the frequency of transmissions from the Swarm earth stations is much less than 2% of the time⁹ which also meets the RAS protection criteria.¹⁰

Conclusion

The experimental satellites and US earth stations pose no risk of creating harmful interference with any known system with the exception of Orbcomm. As represented above, Swarm satellite transmissions are compliant with the frequency allocation tables and meet PFD-based protection criteria for terrestrial systems and RAS as well as meteorological satellite systems. Swarm will seek specific consent from Orbcomm to mitigate any potential for interference with their system.¹¹

⁷ As specified in ITU-R M.1583, the protection criteria is $-238 \text{ dB(W/m}^2)$ in a 2.95 MHz reference bandwidth and as recommended in ITU-R RA.769-2 Table 1, the threshold for harmful interference is $-259 \text{ dB(W/(m}^2 \cdot \text{Hz))}$ at a center frequency of 151.525 MHz.

⁸ Recommendation ITU-R RA.769-1 specifies "above about 40 MHz sharing may be practicable with services in which the transmitters are not in direct line-of-sight of the observatories".

⁹ Transmissions from any of the three ground stations will occur approximately 0.56% of the time. This accounts for each of the three ground stations transmitting a maximum of 80 times per day, with experimental transmissions that are approximately 2 seconds in length.

¹⁰ ITU RR 2016, Resolution 739, article g, and ITU-R RA.1513-2, article 2.

¹¹ On October 16, 2018, Swarm contacted Orbcomm, the only mobile satellite service provider licensed to conduct commercial operations in the United States in the 137-138 and 148-150.05 MHz bands, to initiate coordination to prevent interference with Orbcomm's system. Coordination between Swarm and Orbcomm remains ongoing. Swarm appreciates that operations in the proposed VHF frequencies must occur on a sufferance basis, and Swarm cannot create interference and must accept interference from other authorized users. Should the Commission act prior to the conclusion of discussions with Orbcomm, Swarm will accept a condition on its grant of experimental authority that requires successful coordination prior to the initiation of communications.