KEYW PAYLOAD –COMPATIBILITY ANALYSIS

In support of the application for authority to operate the KeyW Payload, this clarifying information and compatibility assessment is submitted in the docket of the proceeding.[1] As demonstrated herein, the various intermittent uplink transmissions to the KeyW Payload from a single earth located in Tucson, Arizona will operate without causing material potential for harmful interference into co-frequency satellite receivers.

I. DISCUSSION

KeyW will operate a single gateway earth station located in Tucson, Arizona ("Tucson gateway") with the KeyW Payload. The Tucson gateway will operate with a variety of emissions from 1.25 MHz to 50 MHz wide in the 9200-10550 MHz (Earth-to-space) band to communicate with and test the antenna performance of the KeyW Payload. This emission and frequency flexibility should allow KeyW to avoid full overlap with other satellites that may operate in the band.[2]

KeyW has identified seven notified ITU filings have uplinks in the 9200-10550 MHz band and have the potential to be affected.[3] KeyW anticipates most of its tests will be run within the 9.8-9.9 GHz band. PAZ R (which we understand is associated with the Spanish PAZ satellite) appears to be the only satellite that could be affected by earth station uplink transmission in this band. As a result, the PAZ R satellite network was chosen for the analysis. Generally, however, this analysis would yield similar results if using one of the other ITU filings.

As discussed below, extensive simulations to assess the potential interference impact of uplink transmissions from the Tucson earth station establish that there is a *de minimis* potential for harmful interference.

A. Description of Simulations

The KeyW Payload will operate the Tucson gateway at a 10° minimum elevation angle. The analysis assesses the potential for in-line events between KeyW and the PAZ R satellite system based on the orbital characteristics of each satellite (both in sun-synchronous orbits or "SSOs"):

- KeyW: 550-km altitude, 97.6° inclination, sun-synchronous; and
- PAZ R: 510-km altitude, 97.4° inclination, sun-synchronous.

Relative position statistics were collected for 8,640,001 samples with a randomized right ascension/mean anomaly per step. The simulation assumed satellite orbits were strapped and

---

[1] *See* 47 C.F.R. § 1.65; Application of Spire Global, Inc., IBFS File No. SAT-MOD-20200603-00065 (filed June 3, 2020).

[2] KeyW will operate a similar range of downlink emissions consistent with the PFD limits applicable in the band in connection with KeyW Payload communications and antenna testing. *See, e.g.,* BlackSky Global LLC, File No. SAT-MOD-20190802-00070 (granted May 27, 2020).

[3] *See* Appendix 1.

thus maintained fixed relative plane separation (*i.e.*, sun-synchronous orbits precessed at the same rate). A separate simulation run assumed no strapping and examined 10x the number of relative position samples. The data below includes both runs.

These analyses simulated the orbits of the KeyW Payload and the PAZ R satellite and examined a percentage of time where both the KeyW and PAZ R satellites would be visible simultaneously from the Tucson gateway and the β (beta) angle (the topocentric separation angle between satellite from a point on the Earth) between the satellites. In doing so, the analysis examines the absolute worst-case scenario (*i.e.*, where the RAAN separation = 0°), as well as other differences in RAAN, as it affects percentages of time for mutual visibility and β angles.

The assessment makes several assumptions designed to provide worst-case results even though the circumstances are unlikely to occur. First, it assumes that PAZ R will always be imaging/ receiving synthetic aperture radar ("SAR") data when it is in view of the Tucson gateway.[4] Second, it assumes that the KeyW earth station uplink will be operational 100% of the time when the KeyW Payload is in view of the Tucson gateway, which is far in excess of the time necessary to conduct KeyW's testing and demonstration mission.[5] Third, it assumes that both satellites are operating co-frequency.[6] Finally, the assessment assumes full frequency overlap and thus maximum interference potential into the PAZ R satellite receiver.[7]

These assumptions are quite conservative and significantly overstate the percentages of time that harmful interference could potentially occur. As highlighted below, when more realistic assumptions are made the potential for interference would be *de minimis*.

II. Simulation Results

This assessment examines a percentage of time window where both the KeyW and PAZ R space stations are simultaneously visible from the Tucson gateway, as well as predicted β angle statistics between the satellites. Based on its orbital parameters and a minimum 10° elevation angle, PAZ R is visible from the Tucson earth station 1.179% of the time. The KeyW Payload will be visible from the Tucson gateway 1.305% of the time. Both satellites are visible from the Tucson site 0.0867% of the time.

---

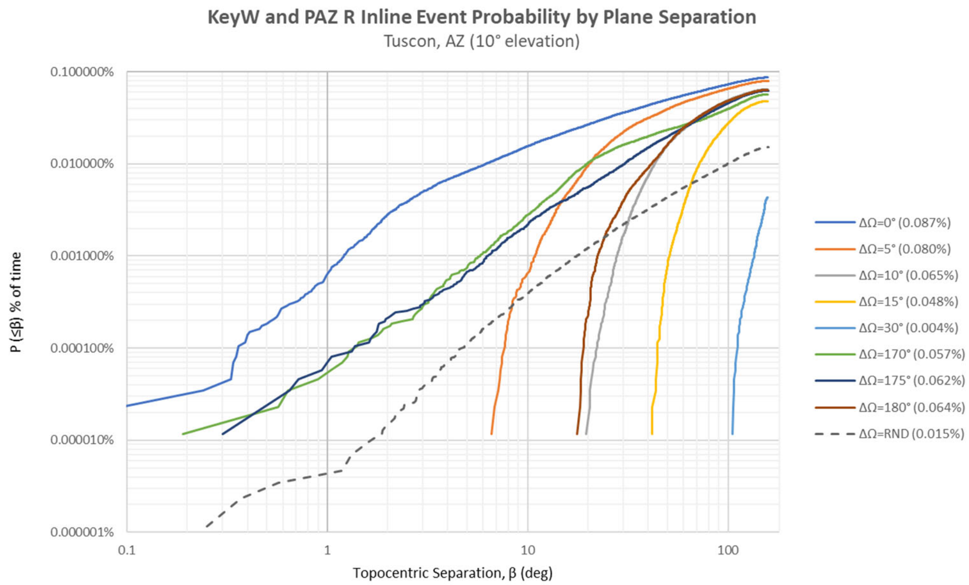
[4] A SAR transmits and receives reflected transmissions in the same frequency band to create radar-based images of the geographic area that is the subject of observation.

[5] The duty cycle of KeyW uplink transmissions is 10% and it need not operate such uplinks 100% of the time to satisfy its planned antenna testing and validation mission.

[6] If each are only operating co-frequency in the subject bands for a fraction of time, then the calculations would be further reduced. In other words, if neither satellite or only one satellite is operating during the window of time both are in view of the Tucson gateway, then there is no potential for interference during such periods.

[7] If there is only partial frequency overlap, either because of center frequency differences or differences in emission bandwidth, then only a portion of the earth station uplink transmit power would affect the wanted PAZ R receive emission.

ΔΩ	P(KeyW&PAZ R)
0	0.0867%
5	0.0796%
10	0.0647%
15	0.0481%
30	0.0043%
60	0.0000%
90	0.0000%
170	0.0569%
175	0.0624%
180	0.0637%
RND	0.0152%



As the difference in RAAN (RAAN ΔΩ) varies, so too does the probability for mutual visibility. As can be seen in the below chart, when there is a RAAN ΔΩ of 0, there is the highest chance for mutual visibility of 0.0867% of the time. Then, as the RAAN ΔΩ increased up to between 60° to 90° and beyond, the percentage of time of mutual visibility did not register at four decimal places but increases again as the RAAN ΔΩ increases toward 180°. When random RAAN ΔΩs were used in the simulation (essential representing an average), the satellites were mutually visible 0.0152% of the time.

Because the relative RAAN of the two orbits is not currently known, the simulation took into account a range of RAAN ΔΩs between the two satellites in order to identify worst-case statistics, as demonstrated by the blue curve reflecting a RAAN ΔΩ of 0° in the above graph. These curves illustrate the percentage of time that various topocentric angles will be experienced between the two systems.

Note that the plotted percentages of time are associated with β angles. Although for the worst-case RAAN ΔΩ of 0° when the satellites will be mutually visible in for 0.0867% of the time, they will have a β angle of 100° for 0.07% of the time and a β angle reduces to 10° for only 0.016% of the time. (Thus, for 99.084% of the time the satellites will be separated by 10° or more.) Other specific RAAN ΔΩs and the random RAAN ΔΩ generally have far smaller percentages of time with larger β angles. Small percentages of time and larger β angles are important when actual radiofrequency interference considerations are incorporated into the assessment.

A. Potential Harmful Interference Assessment

The Tucson gateway earth station transmits with a maximum RF power of 2W (1.58 dBW) from a 1.5m antenna. For the purposes of this interference analysis, the PAZ R antenna sidelobe mask is assumed to be governed by 29 – 25 * log10(θ). Three cases are considered: (i) when PAZ R is imaging (and thus receiving) a location far away from the Tucson gateway; (ii) PAZ R is imaging an area near the Tucson gateway; and (iii) PAZ R is imaging the Tucson gateway. In the first two cases, ΔT/T of 6% (*rather than actual harmful interference*) is considered and, in the third case, ΔT/T of 100% is considered.

	KeyW Uplink into PAZ_R		
	Not Imaging Tucson	Imaging Near Tucson	Imaging Tuscon
TX Antenna Pattern	X - 25 * log10(θ)	X - 25 * log10(θ)	X - 25 * log10(θ)
X -Value	29	29	29
Frequency	9.7	9.7	9.7
RF Density (dBW/MHz)	-15	-15	-15
Orbit Altitude (min)	510	510	510
Elevation angle (deg)	40	40	40
Slant range (km)	755.5	755.5	755.5
Free Space Loss	169.7	169.7	169.7
Boltzman	-228.6	-228.6	-228.6
System Noise Temp	527	527	527
Ref BW (MHz)	1	1	1
Noise Floor dBW/MHz	-141.4	-141.4	-141.4
I/N	-12.20	-12.20	0.00
Interference Density Allowe	-153.58	-153.58	-141.38
Rx Antenna Gain	0.00	20.00	46.50
Interference Density / MHz	-184.71	-164.71	-138.25
Allowed TX Antenna Gain	31.12	11.12	-3.13
Beta Angle (no other isolatio	0.82	5.19	19.29
Gain (check)	31.12	11.12	-3.13
% Delta_T/T	6.0	6.0	100.0

i. Results when PAZ R is imaging far away from the Tucson Gateway

In the case where PAZ R is imaging far away from the Tucson gateway, the PAZ R payload has 0 dBi directivity toward Tucson. A topocentric separation angle of at least 0.82° ensures that the interference from KeyW does not raise the noise floor by 6%. From the worst-case blue curve in the simulation results (RAAN ΔΩ of 0°), this would happen less than 0.0005% of the time (and assuming both systems operate 100% of the time).

ii. Results when PAZ R is imaging an area near the Tucson Gateway

In the case where PAZ R is imaging an area near the Tucson gateway, the PAZ R payload is receiving interference into a 20 dBi sidelobe. The topocentric separation angle required to keep this interference from raising the noise floor by more than 6% is 5.19°. From the worst-case blue curve in the simulation results, this would only happen slightly less than 0.01% of the time (assuming both systems operate 100% of the time).

iii. Results when PAZ R is imaging the Tucson Gateway

In the unlikely worst case where PAZ R is imaging the Tucson gateway, the PAZ R payload is receiving interference at a peak antenna gain of 46.5 dBi. In this extremely rare case, a minimum topocentric angle of 19.29° would be necessary to keep the interference from raising the noise floor by more than 100%. However, even this implausible scenario would only happen less than 0.03% of the time when the PAZ R is tasked to image the Tucson gateway (assuming both systems operate 100% of the time).

B. Further Considerations

A number of other issues act to significantly reduce the absolute worst-case percentages of time and potential interference figures calculated above. For example, the KeyW uplink waveform has a duty cycle of 10% and the PAZ R payload emission only has a duty cycle of ~3%. Therefore, the probability of raising the noise floor by 6% or by 100% while PAZ R is imaging the Tucson gateway must be reduced by the product of these two duty cycles or .003. Thus, the *absolute worst-case scenario of RAAN ΔΩ of 0° PAZ R is imaging the Tucson gateway would result in a percentage of time of potential interference of .00009% or less than one minute per* year *(assuming both systems operate 100% of the time)*.

However, these figures must be further reduced by the percentage of time each satellite is operational while simultaneously in view. KeyW anticipates an operating period of no more than 42.6% of time the KeyW Payload is visible, and the percentage of time that the PAZ R satellite may be operational while visible from Tucson should be a far smaller value. This is particularly true given that the SAR requires substantial power and can only operate a fraction of the time (on the order of approximately 10%) to enable onboard battery recharge.

Further, the assessment assumed full frequency overlap of signals, which may not be the case given the frequency and emission ranges that could be utilized by both satellites. As additional mitigation, SAR payloads like that of PAZ R use chirp waveforms and the received signal is mixed with the transmitted signal, which provides some interference rejection unless the transmit and receive signals are the same. Finally, information sharing and, as appropriate, formal coordination can resolve potential interference issues.

Avoiding harmful interference into PAZ R is straightforward time and frequency avoidance. And in the extremely unlikely event that harmful interreference does occur, KeyW will cease transmissions until all interference issues are resolved.

II. CONCLUSION

As the assessment conducted by KeyW demonstrates, even in the worst-case scenario, the potential for interference from uplink transmissions of the Tucson gateway into a satellite receiver is *de minimis*. The worst-case PAZ R operations may only be affected by harmful interference levels only if it is actually imaging the Tucson gateway, when the Tucson gateway is transmitting, and when they are both operating in the same band.

Even in such circumstances, and not factoring in unknown variable such as RAAN ΔΩ and the percentage of time the PAZ R satellite may be imaging the Tucson gateway site (which KeyW understands to be extraordinarily unlikely), the potential for harmful interference could be no more than 0.000038 percent of the time – and will likely be far less. Given such *de minimis* potential for interference, the Commission can authorize the KeyW Payload to communicate with its uplink gateway earth station in Tucson, Arizona on a non-interference, non-protected basis.

Appendix 1

NOTIFIED ITU SATELLITE NETWORK FILINGS

Space Network List Online

list of non-geostationary satellites in non-planned services

operating in frequency range from 9200 MHz to 10550 MHz
receiving beams

ADM/ORG	SATELLITE NAME	NOTIF.REASON	BR IFIC	FREQUENCIES
RUS	METEOR-3M	N	2652	view
KOR	KOMPSAT-5	N	2789	view
D	TERRASAR	N	2857	view
E	PAZ_R	N	2877	view
J	ASNARO-2	N	2887	view
KOR	KOMPSAT-6	N	2900	view
FIN	ICEYE-POC	N	2901	view