SATMEX 9 (RNSS)

TECHNICAL ANNEX

Technical Information to Supplement Schedule S

A.1 SCOPE

The purpose of this Technical Annex is to provide the Commission with the technical characteristics of the RNSS (Radio Navigation Satellite System) and related payload on the SATMEX 9 satellite that will be used to provide GPS WAAS (Wide Area Augmentation System) service to earth stations located in the United States. This Attachment contains additional information required by 47 C.F.R. §25.114 and other sections of Part 25 of the Commission's rules, 47 C.F.R. § 25.101 *et seq.,* that cannot be entered into the Schedule S submission.

A.2 GENERAL DESCRIPTION (§25.114(D)(1))

The SATMEX 9 satellite will operate at the 117° W.L. orbital location and will include a communications payload as well as the RNSS payload that is the subject of this request.[1]

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[1] The other communications payload on the SATMEX 9 satellite will operate in the extended Ku-band frequencies (13.75-14.0 GHz and 14.5-14.8 GHz uplink; 10.95-11.2 GHz and 11.45-11.7 GHz downlink). It operates with four separate national and regional beams providing coverage of Mexico, Central America, the Caribbean, and parts of South America. No U.S. market access is being requested for this communications payload.

The RNSS payload consists of two transparent repeaters that convert the C1 and C5 uplink signals to the L1 and L5 downlink signals, respectively. The precise center frequencies and bandwidths of these transmissions are provided in the Schedule S. The C-band earth stations that transmit the C1 and C5 uplink signals also receive the C-band telemetry downlink beacon, transmitted by the SATMEX 9 satellite, for purposes of antenna alignment and tracking. The detailed information provided in the Schedule S includes beam and emission data relevant to these signals only as they are the ones intended to be accessed by earth stations located in the United States.

The RNSS payload on the SATMEX 9 satellite will be operated by Satmex under the International Telecommunications Union ("ITU") network RAGGIANA-18 registered at the ITU by Papua New Guinea. Satmex will ensure that the transmissions to and from the RNSS payload on the SATMEX 9 satellite comply with the coordination agreements obtained by Papua New Guinea for the RAGGIANA-18 satellite network. Papua New Guinea will fulfill its obligations under Resolution 609 of the ITU Radio Regulations regarding the protection of aeronautical radionavigation service systems and will also be the nation registering the space object at the United Nations.

A.3 PREDICTED SPACE STATION ANTENNA GAIN CONTOURS (§25.114(D)(3))

The antenna gain contours for the beams associated with the RNSS payload and the telemetry downlink beacon on the SATMEX 9 satellite, as required by §25.114(c)(4)(vi)(A), are given in GXT format and embedded in the Schedule S. However, in the case of the L-band downlink beams ("L1GD" and "L5GD") the -2 dB relative gain contour does not intersect the Earth so no GXT file is provided, consistent with the Commission requirements in this regard.

A.4 TT&C

TT&C for the SATMEX 9 satellite will take place from a satellite control center and TT&C earth stations that are located in Mexico. Therefore, no additional information is being provided related to these TT&C links.

A.5 CESSATION OF EMISSIONS

All downlink transmissions can be turned on and off by ground telecommand, thereby causing cessation of emissions from the satellite, as required.

A.6 POWER FLUX DENSITY AT THE EARTH'S SURFACE

§25.208(a) contains Power Flux Density ("PFD") limits that apply in the 3650-4200 MHz band, which encompasses the downlink telemetry transmissions from the SATMEX 9 satellite. These PFD limits are as follows:

- -152 dB(W/m^2) in any 4 kHz band for angles of arrival between 0 and 5 degrees above the horizontal plane;
- -152+(δ-5)/2 dB(W/m^2) in any 4 kHz band for angles of arrival δ (in degrees) between 5 and 25 degrees above the horizontal plane; and
- -142 dB(W/m^2) in any 4 kHz band for angles of arrival between 25 and 90 degrees above the horizontal plane.

Compliance of the C-band telemetry downlink transmissions with the above FCC PFD limits is demonstrated below using a simple worst-case methodology. The maximum downlink EIRP of each of the two C-band telemetry downlink beacons of the SATMEX 9 satellite is 11.4 dBW. The shortest distance from the satellite to the Earth is 35,786 km, corresponding to a spreading loss of 162.1 dB. Therefore, the maximum possible PFD at the Earth's surface cannot exceed -150.7 dBW/m^2 for each telemetry downlink beacon (i.e., 11.4 - 162.1). As the reference bandwidth for the PFD limit in question is 4 kHz, the corresponding maximum PFD at an elevation angle of 90° measured in a 4 kHz band will not exceed -164.6 dBW/m^2, assuming a 100 kHz spreading bandwidth. This level is less than the -152 dBW/m^2/4kHz PFD limit value that applies at elevation angles of 5° and below. Therefore, compliance with the Commission's PFD limits is assured.

There are no PFD limits in the FCC rules or the ITU Radio Regulations relating to the L-band frequencies used for the L1 and L5 downlink transmissions. However, ICAO has specified for WAAS L1 downlink transmissions that the maximum received signal power at the output of a 0 dBi antenna located near the ground should not exceed -152.5 dBW.[2] The SATMEX 9 RNSS downlink is compliant with this ICAO requirement as demonstrated in Table A.6-1 below.

Table A.6-1 – Calculation of L1 Received Signal Power at Output of 0 dBi Antenna

Downlink frequency	MHz	1575.42
Peak satellite downlink EIRP	dBW	36.5
Spreading loss (minimum at nadir)	dBW	162.1
PFD at Earth's surface	dBW/m2	-125.6
Polarization mismatch	dB	-2.1
Effective gain of 0 dBi receive antenna	dBi	-2.1
Effective aperture of receive antenna	dB-m^2	-27.5
Received signal level	dBW	-153.1
ICAO received signal level limit	dBW	-152.5
Margin relative to ICAO limit	dB	0.56

2 See ICAO GNSS Standards and Recommended Practices (SARPs), included in Annex 10 to the Convention on International Civil Aviation, Section 3.7.3.4.4.3.2.2.

A.7 C-BAND TWO DEGREE COMPATIBILITY

Currently there are no satellites within two degrees of 117.0º W.L. authorized by the Commission for service to the United States operating in the C-band frequencies that overlap with those used for the C1 and C5 uplink transmissions to the SATMEX 9 RNSS payload, which are as follows:

- 6628.27 - 6650.27 MHz
- 6679.42 - 6701.42 MHz

Therefore, in order to demonstrate two-degree compatibility in these frequency ranges, the transmission parameters of the C-band uplinks of the SATMEX 9 RNSS payload have been assumed as both the wanted and victim carriers. Since the uplink input power densities for both the wanted and victim carriers are assumed to be identical, the uplink C/I is simply the difference between the on-axis gain and the off-axis gain of the C-band transmitting earth station antenna. The uplink C/I ratio is therefore calculated as follows:

$$(C/I)_{up} = G_{max} - (29-25*\log(\theta))$$

$$= 57.2 - (29-25*\log(2)) = 35.7 \text{ dB}$$

The calculated C/I ratio is large and clearly demonstrates two-degree compatibility. Note the above calculation did not take into account any advantage for topocentric-to-geocentric conversion.

A.8 ORBITAL DEBRIS MITIGATION PLAN

The spacecraft manufacturer for the SATMEX 9 satellite is Boeing Satellite Systems International, Inc. (“Boeing”). Satmex / Boeing will incorporate the material objectives of §25.114(d)(14) of the Commission’s Rules into the design of the satellite through the satellite’s Technical Specifications, Statement of Work and Test Plans. This will include provisions to review orbital debris mitigation as part of the ongoing design reviews for the SATMEX 9 satellite and to incorporate any related requirements, as appropriate, into its Test Plan, including a formal Failure Mode Verification Analysis ("FMVA") for orbital debris mitigation involving particularly the TT&C, propulsion and energy systems. During this process, some changes to the Orbital Debris Mitigation Plan may occur and Satmex will provide the Commission with updated information, as appropriate.

A.8.1 Spacecraft Hardware Design

Satmex confirms that the satellite will not undergo any release of debris during its operation. Furthermore, all separation and deployment mechanisms, and any other potential source of debris are expected to be retained by the spacecraft.

Satmex / Boeing will assess and limit the probability of the satellite becoming a source of debris by collisions with small debris or meteoroids of less than one gram in diameter that could cause loss of control and prevent post-mission disposal. Satmex / Boeing will take steps to limit the effects of such collisions through shielding, the placement of components, and the use of redundant systems.

Satmex / Boeing will incorporate a rugged TT&C system with regard to meteoroids smaller than 1 gram through redundancy, shielding and appropriate separation of components. The TT&C system will be equipped with near omni-directional antennas mounted on opposite sides of the spacecraft. These antennas are extremely rugged and capable of providing adequate coverage even if struck, bent or otherwise damaged by a small or medium sized particle. The omni-directional antennas, for both command and telemetry, will be sufficient to enable orbit raising. The command receivers and decoders and telemetry encoders and transmitters will be located within the satellite's Faraday cage which provides shielding and will be totally redundant and physically separated.

The propulsion subsystem will be designed such that it will not be separated from the spacecraft after de-orbit maneuvers. It will be protected from the effects of collisions with small debris through shielding. Moreover, propulsion subsystem components critical to disposal (e.g., propellant tanks) will be located deep inside the satellite, while other components, such as the thrusters, externally placed, are redundant to allow for de-orbit despite a collision with debris.

A.8.2 Minimizing Accidental Explosions

Satmex / Boeing will assess and limit the probability of accidental explosions during and after completion of mission operations. The satellite will be designed to ensure that debris generation will not result from the conversion of energy sources on board the satellite into energy that fragments the satellite. The propulsion subsystem pressure vessels will be designed with high safety margins. All tank pressures will be monitored by telemetry. Xenon is used as the fuel source for thruster and station-keeping operations on the SATMEX 9 satellite. Because Xenon is inert it requires far less end of life care and handling than bipropellant fuels. It is stored in tanks that are designed to leak before burst, and the residual pressure is low enough that there is no way to have a catastrophic leak event. There is therefore no need to leave valves open post de-orbit and shutdown. The batteries will be left in a permanent state of discharge.

A.8.3 Safe Flight Profiles

There are currently no operational geostationary satellites with station-keeping volumes that overlap with the proposed station-keeping volume of the SATMEX 9 satellite at 117.0° W.L. The closest satellite is SATMEX 8 at 116.8° W.L. The next closest satellites are the XM series in the vicinity of 115.2° W.L., the ANIK F3 satellite at 118.7° W.L. and the EchoStar and DIRECTV satellites in the 118.8° W.L. to 119.2° W.L. cluster.

There are also no FCC licensed satellites planned to be deployed, or proposals to the FCC for satellites to be deployed, to orbital positions where there would be overlapping station-keeping volumes with the proposed SATMEX 9 satellite at 117° W.L.

In addition, all satellite networks for which a request for coordination has been published by the ITU within ±0.15 degrees of 117.0° W.L. have also been reviewed. Excluding the US filed ones, and the RAGGIANA-18 network, the only other network filing is from Luxembourg for the LUX-G7-38C network at 117.0° W.L., and there is no indication from publicly available information that this satellite will be implemented.

Based on the preceding, it is concluded that physical coordination of the SATMEX 9 satellite with another party is not required at the present time.

A.8.4 Post Mission Disposal Plan

At the end of the operational life of the SATMEX 9 satellite, Satmex will maneuver the satellite to a disposal orbit with a minimum perigee of 300 km above the normal GSO operational orbit. This proposed disposal orbit altitude is based on the following calculation, as required in §25.283:

Total Solar Pressure Area "A" = 75 m^2
"M" = Dry Mass of Satellite = 1697 kg
"C_R" = Solar Pressure Radiation Coefficient = 1.33

Therefore, the Minimum Disposal Orbit Perigee Altitude:

= 36,021 km + 1000 x C_R x A/M
= 36,021 km + 1000 x 1.33 x 75/1697
= 36,079.78 km
= 293.8 km above GSO (35,786 km)

To provide margin, the nominal disposal orbit will be increased to 300 km. This will require 0.6 kg of Xenon propellant that will be reserved, taking account of all fuel measurement uncertainties, to perform the final orbit raising maneuvers.[3]

A.9 CROSS-POLAR ISOLATION OF THE SATELLITE ANTENNAS

§25.210(i)(1) of the Commission's rules requires that space station antennas in the Fixed-Satellite Service ("FSS") must be designed to provide a cross-polar isolation ("XPI") of at least 30 dB within the primary coverage area. This rule applies only to the C-band uplink of the SATMEX 9 RNSS payload as this operates in an FSS frequency allocation.

Section S7 of the associated Schedule S submission states that the specified minimum cross-polar isolation of the SATMEX 9 RNSS satellite C-band receive antenna is 23.3 dB. This is less than the 30 dB requirement stated in §25.210(i)(1). The shortfall in the XPI relative to §25.210(i)(1) will not be a problem for the SATMEX 9 RNSS mission or for any other users of the spectrum for the following reasons:

(i) The C1 and C5 uplinks to the SATMEX 9 RNSS payload operate only in a single polarization. Therefore, the XPI is of no consequence to the performance of the C1 and C5 uplinks.

(ii) As the XPI shortfall applies only to a satellite receive antenna there can be no possible impact in terms of increased cross-polar interference to any other user of the spectrum.

(iii) There is no realistic scenario where the XPI shortfall in the C-band receive antenna on the SATMEX 9 RNSS payload can result in increased interference to the SATMEX 9 RNSS mission. Interference protection of the C1 and C5 uplink signals from other

3 The small quantity of fuel required is accounted for by the fact that the SATMEX 9 satellite uses electric propulsion.

users of the spectrum will be based on the large angular discrimination achieved through the use of earth station antennas at least 13.1 meters in diameter.

Therefore, the shortfall in XPI for the C-band satellite receive antenna of the SATMEX 9 RNSS payload will have no impact on the interference to or from other networks and systems.

A.10 FREQUENCY RE-USE

§25.210(f) of the Commission's rules requires that space stations in the FSS employ full frequency re-use by either polarization or spatial discrimination. This rule applies only to the C-band uplink of the SATMEX 9 RNSS payload as this operates in an FSS frequency allocation.

This rule is intended to maximize the efficient use of the RF spectrum on a satellite so that it can maximize its throughput for communications purposes. The RNSS WAAS payload of the SATMEX 9 satellite is not a communications mission and instead serves a different, but equally important, purpose related to improved accuracy of GPS receivers in certain critical applications.

The WAAS mission requires the transmission of navigation related information in two separate 20 MHz bandwidth channels. These two channels (L1 and L5) are required to be separated in frequency in the L-band downlink and so it is most convenient and efficient to also separate them (C1 and C5) in the C-band uplink part of the transmission chain by using different RF channels for each, with both operating on the same sense of polarization. In fact, because of the use of large transmitting earth station antennas for the C1 and C5 uplink transmissions, the RNSS WAAS mission is actually very efficient in its use of the orbit-spectrum resource.

Finally, the C1 and C5 uplink transmissions operate outside of the most crowded portion of the C-band uplink spectrum, which is 5,925 to 6,425 MHz. The spectrum used by the C1 and C5 uplink transmissions is little used and so maximizing the pure spectral efficiency in this part of the C-band is not as important as if it were in the standard C-band spectrum.

A.11 DATA NOT ABLE TO BE INPUT TO SCHEDULE S SOFTWARE

It is not possible to input certain data into the Schedule S software, as explained below:

1. S11. Digital Modulation Parameters. Item (g) (CDMA Processing Gain) is 36 dB for Digital Mod. ID "D1" and 46 dB for Digital Mod. ID "D5". This field in the Schedule S will not accept these values.

CERTIFICATION OF PERSON RESPONSIBLE FOR PREPARING ENGINEERING INFORMATION

I hereby certify that I am the technically qualified person responsible for preparation of the engineering information contained in this application, that I am familiar with Part 25 of the Commission's rules, that I have either prepared or reviewed the engineering information submitted in this application and that it is complete and accurate to the best of my knowledge and belief.

/s/

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June 17, 2014

Regulatory Compliance Index

Rule Part	Location
25.114(c)(1) – (3)	Form 312, Main Form & Schedule S
25.114(c)(4)(i) – (vi)	Schedule S
25.114(c)(4)(vii)	Interim Waiver granted by the Commission[1]
25.114(c)(5) and (c)(7)	Schedule S
25.114(c)(8)	Schedule S and Technical Annex at A-3 – A-4
25.114(c)(9)	Technical Annex at A-2
24.114(c)(10)-(13)	Schedule S
25.114(d)(1)	Technical Annex at A-1 – A-2
25.114(d)(3)	Technical Annex at A-2 & Schedule S
25.114(d)(4)	Technical Annex at A-1 – A-2 & Schedule S
25.114(d)(5)	Technical Annex at A-3 & Schedule S
25.114(d)(6)	Legal Narrative at 8-9
25.114(d)(7)	Technical Annex at A-4 – A-5
25.114(d)(14)	Technical Annex at A-5 – A-8
25.131(j)	Waiver Requested; Legal Narrative at 20-21
25.137(a)(1)	Legal Narrative at 1
25.137(a)(2)	Legal Narrative at 9-13
25.137(c)	Legal Narrative at 15
25.137(d)(1)	Legal Narrative at 16-17
25.137(d)(4)	Legal Narrative at 17
25.140(b)(1) and (b)(2)	Technical Annex at A-4 – A-5
25.157 – 25.158	Waiver requested; Legal Narrative at 17-19
25.164 – 25.165	Legal Narrative at 16-17
25.202(e) and (f)	Schedule S
25.207	Technical Annex at A-2
25.208	Technical Annex at A-3 – A-4
25.210(f)	Waiver Requested; Legal Narrative at 21; Technical Annex at A-9
25.210(i)(1)	Waiver Requested at 21-22; Technical Annex at A-8
25.210(j)	Schedule S
25.283	Technical Annex at A-7 – A-8

[1] *See International Bureau Adopts Policy of Granting Interim Waiver of Certain Requirements for Space Station Applications*, DA 14-90 (rel. Jan. 28, 2014).