ADS-B via Iridium NEXT satellites

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Abstract - **Iridium NEXT will replace Iridium's current satellite constellation, ensuring continuity of the first generation of global mobile satellite services. Iridium NEXT constellation will consist of 66 cross-linked, LEO satellites in six orbital planes intersecting over the North and South Poles. Each Iridium Next satellite will integrate a secondary payload. This paper is based on the feasibility study to embark a dedicated ADS-B secondary payload, on board half or all satellites.**

Keywords: ADS-B communication, IRIDIUM NEXT, ATM Satcom .

I. INTRODUCTION

The constellation deployment will be completed between beginning 2015 up to mid 2017, when the Iridium NEXT constellation will be fully operational. Iridium NEXT is designed to accommodate secondary payloads and provisions according to specific constraints in terms of volume, consumption, dissipation and electrical interfaces.

The system here presented is based on the acquisition by the Satellite of the ADS-B aircraft signals, namely the 1090 Mode S Extended Squitter, without any change on the aircraft equipment.

II. SYSTEM REQUIREMENTS

Today, the existing ADS-B traffic receiver type AS680-GS (see figure below) perform the ground reception (de-garbling) of the ADS-B signal.

Figure 1. ADS-B ground receiver Thales ATM type AS680-GS

In order to cancel interference induced by other 1090 ES signal (TCAS, response to Mode S radar request, …), it appears as necessary to perform the initial ADS-B reception from the payload. This induces to "spatialise" the ADS_B receiver functions.

The "Spatialisation" of the ADS-B receiver function implies a trade-off analysis between Payload and GES (Ground Earth Station):

- ❑ Trade-off have to be performed in order to determine the best distribution of ADS-B receiver functions @ the payload architecture,
- ❑ Satellite => GES data link.

The Iridium NEXT Constellation is constituted by 66 satellites at 780 Km altitude, in 6 orbit planes of 11 spacecraft each, with 86.4° inclination.

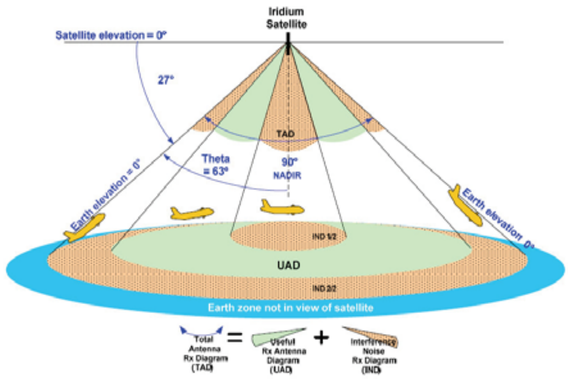

Figure 2. ADS-B conical coverage definition, up to 63° off-nadir (TAS-F source).

The baseline link budget hypotheses require for the on board satellite antenna a gain ranging from 2dBi (@ 0° elevation, i.e. the edge of coverage) to -3dBi (@ 63° elevation, i.e. Nadir direction towards the Earth center).

III. MISSION ANALYSIS

First step of the study consisted in the definition of mission and system requirements. Then the mission analysis has been carried on, by simulating the trajectories of both Iridium NEXT satellites and aeronautical users. A set of representative scenarios has been predefined for the mission analysis. In particular,

- Four constellation configurations have been envisaged, in order to explore the possibility to embark the ADS-B payload on board the IRIDIUM satellites:
  - Full Constellation: considering all 66 satellites;

- Half Constellation: two different sub-sets of the IRIDIUM constellation have been simulated with the ADS-B payload on 33 satellites:
  - N1 (All six IRIDIUM planes have satellites equipped with ADS-B payload unit);
  - N2 (Plane A, E and C satellites are equipped with the ADS-B payload unit).
- For each of these IRIDIUM configurations, four different aeronautical routes have been analyzed (Fig. 3) in order to cover the most important and critical situations for the European Civil Aviation Fleet:
  - the North Atlantic Route (Case A),
  - the South America to/from Europe Atlantic Route (Case B),
  - the Europe to/from South of Africa Route (Case C)
  - The Europe to/from Far East via Remote North Polar route (Case D).

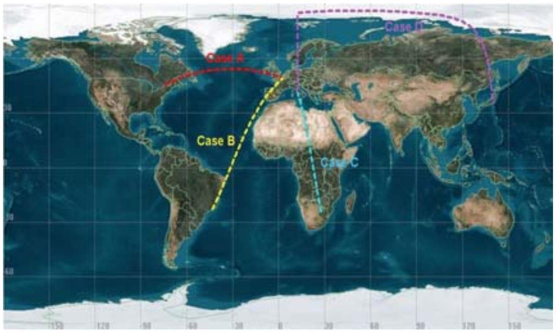

Figure 3. Selected Air routes to perform ADS-B mission analysis

The expected coverage to be developed by the ADS-B antenna on board to the Iridium satellite shall be a conical pattern type with a field of view up to 63° off- nadir max (Fig. 2). In order to verify if the on board satellite antenna can comply with the stringent link budget constraints and with the payload performance requirements in terms of aircraft-to-satellite loss of contact time (i.e. outages), three different options for satellite elevation angles (θ) have been simulated:

- Full coverage (0°≤θ≤63°),
- Medium coverage (13°≤θ≤63°),
- Reduced coverage (26°≤θ≤59°).

In addition, the performance in the four routes have been simulated against three timing constrains: the total Aircraft to Satellite Contact Time shall not be interrupted more than 15 minutes, 10 minutes or down to 1 minute. Clearly, the best performing IRIDIUM configuration is the FULL capability with all satellites equipped with an ADS-B payload, at the cost of having to equip 66 satellites with the ADS-B payload. Following table show the results for the IRIDIUM configuration N2 which presents the most promising performance with only half IRIDIUM constellation equipped with ADS-B payload in all three options for satellite elevation angle ranges.

TABLE I. HALF IRIDIUM CONSTELLATION N2 PERFORMANCE

		Case A	Case B	Case C	Case D
Full Coverage	Coverage Time [%]	99,5	81,62	83,35	99,99
	Visible Satellites	5	3	2	6
	Outages @1 minute	1	20	15	0
	Outages @10 minutes	0	3	5	0
	Outages @15 minutes	0	1	1	0
		Case A	Case B	Case C	Case D
Med. Coverage	Coverage Time [%]	99,01	81,1	82,74	99,54
	Visible Satellites	5	3	2	6
	Outages @1 minute	0	3	4	0
	Outages @10 minutes	0	1	1	0
	Outages @15 minutes	0	1	1	0
		Case A	Case B	Case C	Case D
Red. Coverage	Coverage Time [%]	57,88	40,68	44,2	78,79
	Visible Satellites	2	1	1	3
	Outages @1 minute	35	38	35	41
	Outages @10 minutes	2	3	2	1
	Outages @15 minutes	2	3	2	1

Furthermore, in order to support the above results, the analysis has been extended worldwide. Two major results are presented in the following figures for N2 configuration (in case of medium coverage angles) in terms of:

- Coverage rate (i.e. the ration of time with at least one satellite in view);
- Maximum Revisit Time (i.e. the gap of time between any of two satellites in view).

In accordance with the performance obtained with the pre-selected Air Routes.

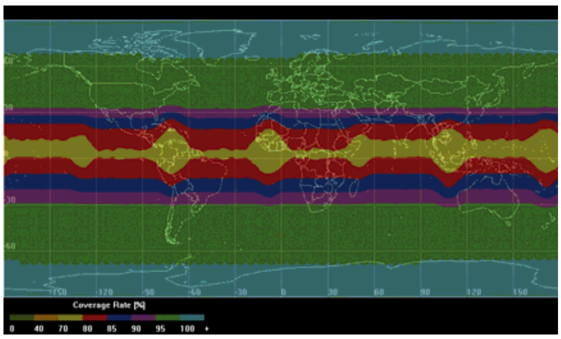

Figure 4. Coverage Rate with Half IRIDIUM constellation N2 for aircraft position worldwide (medium coverage)

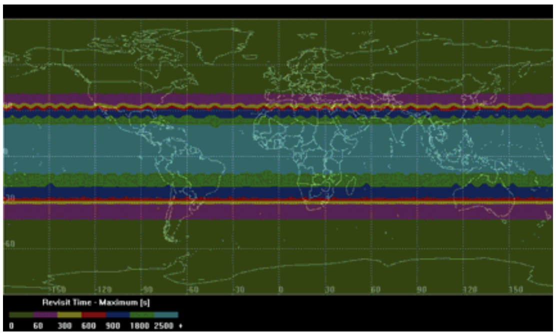

Figure 5. Maximum Revisit Time with Half IRIDIUM constellation N2 for aircraft position worldwide (medium coverage)

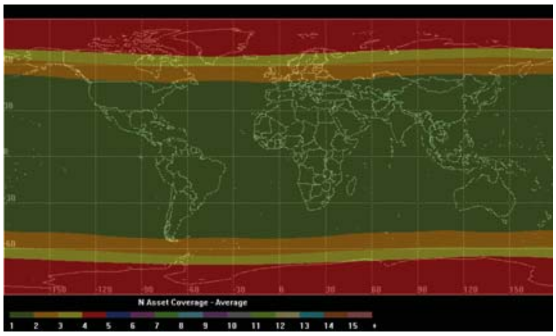

Figure 6. Selected Average number of Satellites simultaneously available over the coverage interval for IRIDIUM full constellation (Full coverage)

Final considerations on the three simulated IRIDIUM configurations are summarised hereafter:

- Full IRIDIUM constellation is the best performing configuration that has been analysed in this report. On the other hand the number of needed ADS-B payloads is maximised with evident cost issues.
- Half IRIDIUM constellation N2 is potentially the best performing half constellation configuration that has been analysed in this report.
- Half IRIDIUM constellation N1 performance results would lead to conclude that the benefits of this configuration are quite limited with respect N2 configuration also bearing in mind that at least six launches are needed to complete the ADS-B N1 configuration (as the 33 satellites occupy all the 6 IRIDIUM planes).

Now, for the selected IRIDIUM configurations, some additional considerations are provided to explore potential risk of saturation of the space receiver. For our purposes, the processing of ADS-B over high-density terrestrial area must be possible with Instantaneous Aircraft number over 1000 aircraft (this value has been considered as the maximum number of possible aircraft to be processed by one reception channel).

With the average number of simultaneously available satellites over the entire coverage interval for the set of ADS-B configurations (Figure 6 shows the result for N2 case), and by considering the estimated the PIAC[1] value (Peak Instantaneous Aircraft Count) over ECAC (European Civil Aviation Conference) Area in 2025 (i.e. 8119, taken as input from ANTARES Project), the risk of saturation of the reception channel is identified.

Additionally, by considering the possibility to have a multi-beam antenna design (at the cost of processing in parallel all received beams, i.e. one reception beam = one ADS-B processing channel), as described in following section, a substantial minimisation of the risk to overload the reception channel is introduced when tracking more than 1000 aircraft in the same beam.

Accordingly, following table summarises the results obtained by considering such a multi-beam antenna design for ADS-B payload, in terms of PIAC vs. Number of available satellites, for the three constellations in case of full and medium coverage.

TABLE II. MINIMISATION OF THE SATURATION RISK WITH A FOUR ELEMENT PHASED ARRAY ANTENNA (4 OR 8 BEAMS)

PIAC vs. Number of available satellites with 4 or 8 beam Phased array antenna		
IRIDIUM ADS-B configuration	***Full coverage (4/8 beams)***	***Medium coverage (4/8 beams)***
Full IRIDIUM constellation	1015/**508**	1015/**508**
Half IRIDIUM constellation N1	2030/**1015**	2030/**1015**
Half IRIDIUM constellation N2	2030/**1015**	2030/**1015**

IV. ANTENNA DESIGN

The following antenna typologies have been analyzed in full wave (3D EM CAD Model), with the aim to guarantee the link between Iridium S/C and any Aircraft captured in the conical field of view of the ADS-B antenna:

- Single element, i.e. Quadrihelix;
- 7-element array antenna.
- 4-element array antenna;

Accordingly, the antenna patterns have been shaped, as much as possible, in order to cover with the highest gain possible the required mission conical field of view, without overcoming the stringent requirement relative to the maximum volume allowable on the IRIDIUM satellite as shown in following Fig. 7.

1. PIAC estimation from ANTARES is available for four future potential scenarios: Scenario A (High Air Traffic Growth), B and C (Medium Growth), D (Low Growth). The PIAC value from Scenario A is used for the analysis in order to assess a worst case for saturation.

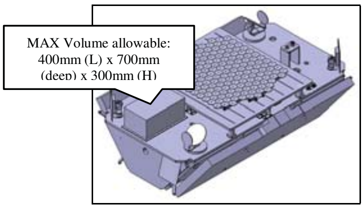

Figure 7. Iridium S/C, ADS-B antenna max volume allowable

A. Quadrihelix antenna

Three Quadrihelix antennas configurations (“A”, “B” and “C”) have been analyzed. The antennas have been accurately designed in order to achieve a shaped pattern (Fig. 8) with its maximum in side the medium coverage angle range. However, in order to achieve a reasonable gain for the mission, the antenna length is such that it violates the maximum allowable height of 300 mm.

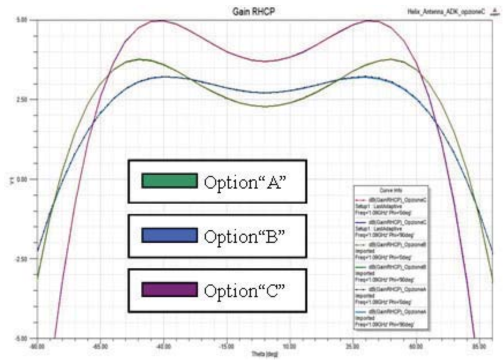

Figure 8. Antenna patterns relative to A, B, C quadrihelix antenna configurations

B. 7-element array antenna

6 elements run over the periphery of a circular ground plane with a diameter of 400mm while a 7th is located at the centre of the ground plane. For this antenna configuration, the crossed dipole antenna has resulted in being the best performer.

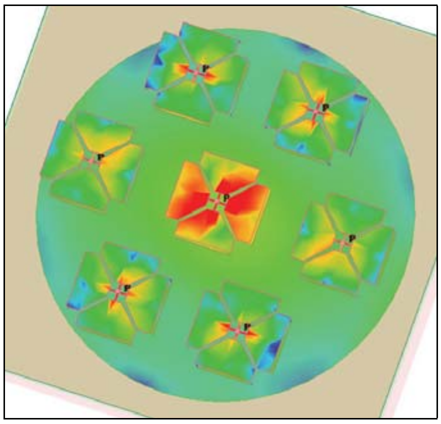

Figure 9. 7-element array antenna Full Wave Analysis

However, this solution is quite demanding in terms of mass, complexity and cost. A good compromise between cost and benefit would be the 4-element option, as described in the following sub-section.

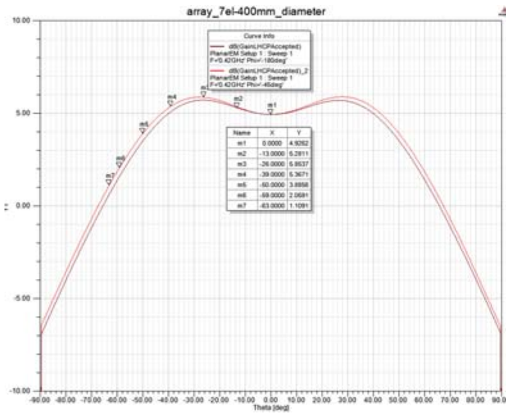

Figure 10. Crossed-dipoles 7-element array pattern

C. 4-element array antenna

A 4-element array with a ground plane of 400 mm of diameter has been designed with the aim to mitigate as much as possible the following important criticalities:

- mass;
- overall array losses;
- array complexity together with its beam forming network;
- use as much as possible of flown and proven technology in order to reduce the development cost;

Based on the above analysis, the preferred baseline configuration is the 4-element array with a circular ground plane with a diameter of 400 mm that does not exceed the stringent max allowable volume. The proposed antenna configuration allows a very efficient and compact feeding network with an expected overall loss less than 0.2 dB. In addition, the antenna allows the use of a flown and proven technology developed in the frame of previous domestic Space programs (Sicral, S1B). A full wave analysis is highlighted in the figure below with the antenna layout and the antenna surface currents generated by a dedicated set of elements excitations.

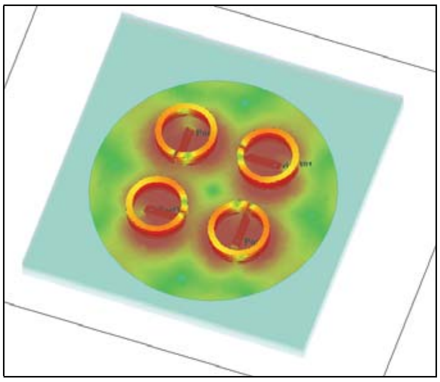

Figure 11. 4-element array antenna Full Wave Analysis

The achieved antenna pattern based on 4-element helix array is here there after shown.

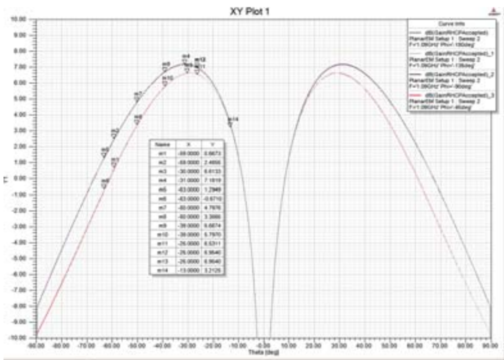

Figure 12. 4-element array pattern

As follows, a preliminary hypothesis of phased array has been also addressed with the aim to provide a suitable solution vs. the receiver saturation in case more than 1000 Aircraft are beating at the same time at the RX front end. In order to make the solution as simple as possible, the same 4 el. Array developed to generate the required conical pattern between 13° and 63° off Nadir has been used to characterize the phased array.

The proposed phased array shall be considered constituted in general by three main sections:

- Radiative section;
- Active section, in which the required MMIC LNA, Phase shifters and attenuators will be included;
- Power dividers in Alumina Substrate (Al_2O_3) / BFN.

The antenna dimensions without the active and beam forming sections are:

- Antenna diameter: 400 mm;
- Antenna height: 100 mm, BFN and Active Section not included.

Accordingly, two possible antenna configurations are envisaged:

1. *Config. 1*: One single input port, with a single steerable beam, activated via a dedicated Telemetry and Telecommand section;
2. *Config. 2*: N input ports, with N possible steerable beams sequentially activated by means of a dedicated switching matrix.

The intercepted area due to the crossing beam is required to evaluate the captured traffic aircraft capability vs. the receiver front end channel saturation. Two possible scenarios have been provided, respectively with 4 and 8 possible beams.

For both configurations (Fig. 13 and 14), following comments are applicable:

- In order to highlight the performance in steering of the proposed phased array, the crossing patterns area at -3, -6 and at -9 dB are shown.
- The reds circles in the graphs represent the off nadir conical coverage limits, respectively at 13° and 63°.
- The legends below describe the peak levels and the contour levels.

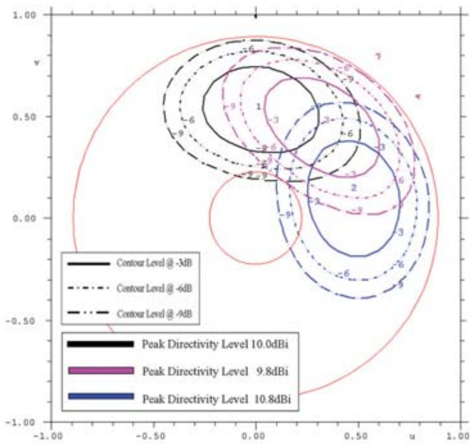

Figure 13. Phased array, configuration with 8 beams

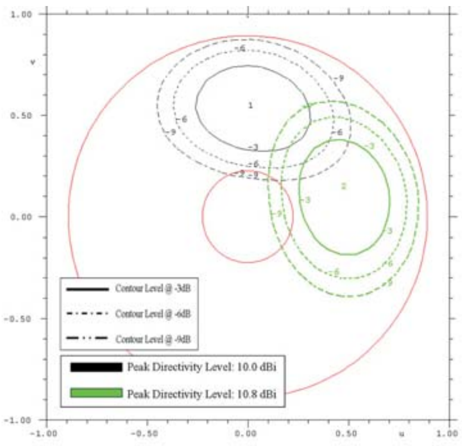

Figure 14. Phased array, configuration with 4 beams

V. CONCLUSIONS

ADS-B payload feasibility analysis on board the IRIDIUM next generation constellation has been assessed. Potential scenarios have been simulated and accordingly a preliminary payload design has been proposed. The overall resulting performance shows promising solutions that could be further investigated and refined both at mission and at payload level.

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