

ECHOES: The Feasibility of Space-based VHF Communications

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Abstract— Communication, Navigation and Surveillance (CNS) systems are key in the provision of safe and efficient air traffic management. Space-Based VHF (SB-VHF) concept provides an important step towards meeting the needs of the air transport sector, especially in remote and oceanic areas, without requiring changes to aircraft avionics, which is the main obstacle when implementing new solutions.

Space-Based VHF will use the Aeronautical Mobile- Satellite (R) Service (AMS(R)S) in the frequency band 117.975 – 137 MHz to provide an Air-Ground VHF Digital Link (VDL) and/or VHF Voice Communication from Low Earth Orbit Satellites.

The implementation of Space-Based VHF in combination with Space Based Surveillance (SB-SUR) will enhance the situational awareness of pilots and air traffic controllers in areas with limited coverage, improving safety levels and reducing risk factors. Space Based services could make it possible to reduce the separation minima between aircraft, improving the capacity and efficiency of aircraft management, and supporting aircrafts to fly on preferred routes thereby reducing flight times, fuel consumption and CO2 emissions.

ECHOES is a Digital Sky Demonstrator (DSD) project that aims to demonstrate the technical and operational feasibility of a satellite-based solution for VHF communications—both voice and datalink—combined with space-based Automatic Dependent Surveillance–Broadcast (ADS-B) for aviation under a realistic environment. For this, two satellites in Low Earth Orbit (LEO) have been designed and launched to provide the first step that will extend the reach of reliable CNS services to these underserved regions.

This paper focuses on the advantages of the Space-Based VHF and highlights some of the work performed by ECHOES in terms of technical feasibility as well as regulation and standardization. It makes a preliminary analysis based on the doppler shift expected by bringing an already existing ground-based system to space, and presents the results obtained by the project.

Keywords—CNS, VHF, LEO, ATM

I. INTRODUCTION

A traffic growth together with a lack of communication and surveillance coverage in oceanic and remote areas, severely affects air transport sectors in terms of capacity. In this sense, solutions that can be implemented with the minimum possible changes in infrastructure and regulations are ideal since they can be implemented globally in the shortest period of time.

ECHOES use cases validate that satellite-based VHF in combination with ADS-B can support reduced aircraft separation standards in remote areas, enabling more flexible and efficient flight trajectories. The demonstration is supported by a series of live exercises conducted across multiple FIRs in the South Atlantic corridor, including Canary Islands, Azores-Santa Maria, Dakar Oceanic, Cape Verde, and Brazil's Atlantic. The infrastructure developed during the project is used to exchange information with flights in the En-route phase in the dedicated airspaces. This infrastructure is composed of the following elements:

- **Ground Segment:** The equipment installed to address the exercises and its integration with the operational systems of the Air Navigation Service Provider (ANSP).
- **Space Segment:** Represented by the two demonstrator satellites developed in the framework of ECHOES, carrying the VHF and ADS-B payloads.

The demonstration has been carried out in two phases: first, the prototypes developed were matured and tested in a laboratory environment, while collecting and analyzing technical parameters for surveillance and communication services performance assessment. Finally, in the second phase, these prototypes were integrated into a LEO satellite and tested the end-to-end system. These exercises tested the performance of the satellite-based services under realistic conditions, using existing aircraft avionics and without requiring changes to pilot or controller procedures.

The project has reached a Technological Readiness Level 6 (TRL6) and aims to reach a TRL7, proving that the proposed satellite-based CNS is ready for further deployment. ECHOES also contribute to regulatory and standardization efforts by

providing empirical data to bodies such as ICAO, ITU, and EUROCAE.

By demonstrating that satellite-based VHF and ADS-B can deliver performance comparable to terrestrial systems, ECHOES positions itself as a transformative enabler for global ATM, particularly in regions where traditional infrastructure is not viable. It represents a “quickwin” solution that can be deployed rapidly, without requiring costly modifications to aircraft or ground systems, and with significant benefits for safety, capacity, and the environment

II. REGULATORY CONSIDERATIONS

A smooth integration with existing airborne equipment and terrestrial VHF systems for seamless communication requires regulatory amendments that address the interoperability with current equipment and align SB-VHF implementation across airspace regions, thus reducing technical disparities and establishing consistent service levels.

By providing technical and operational evidence to the international standardization and regulatory bodies, ECHOES project provides essential data to advance the regulatory pathway required to enable the future implementation of SB-VHF.

The first big achievement for the concept was the allocation of the frequencies to the Aeronautical Mobile Satellite (Route) Service (AMS(R)S) securing a portion of the frequency spectrum for the indicated service.

To appreciate the work behind this milestone, it is necessary to understand the correct order of international procedures to use a frequency assignment. The first step is the allocation of this service in the table of frequency allocation in article 5 of the Radio Regulations (RR) [1]. Without this allocation, the service cannot make use of the frequency.

ITU-R defines the conditions for use of the new allocation to the AMS(R)S without concluding/constraining on any future allotment or assignment of the frequencies. The ITU-R process to agree on a new allocation is mostly based on compatibility with other services using adjacent bands.

Under World Radiocommunication Conference (WRC-23) Agenda Item 1.7 and Resolution 428 (WRC-19), ITU had the task to define the relevant technical characteristics and to study the compatibilities between possible AMS(R)S systems within the band 117.975-137 MHz and existing primary services in-band and in adjacent bands. Once the new allocation is defined, ICAO conducts the subsequent stages on allotment or assignment of frequencies consistently with the conditions specified by ITU-R for the use of the new allocation.

After the approval of the allocation of the use of the AMS(R)S service at the WRC-23, ICAO then has the task to review and, as necessary, modify affected SARPs. To address this, the work is divided into two working groups:

1. Project-Team Space-Based VHF (PT-SBV), reporting to DCIWG ICAO panel, responsible for

reviewing and proposing the amendment to Annex 10, Volume III [2] for technical topics.

2. SB-VHF CG, reporting to FMSP responsible for reviewing and proposing the amendment to Annex 10, Volume V [3] for frequencies assignment procedure.

With the approval of these changes at the SARP level, other technical aspects are detailed at a second level. For example, review of VDL Mode 2 (VDLm2) parameters, protocols and testing procedures that will be included in document Doc.9776 [4], review of Doc. 9925 [5] and the criteria for AMS(R)S frequency allocation, compatible with the current AMS(R)S services, that will be included in ICAO Doc. 9718 [6].

In addition, the approval of SARPs modifications for technical and frequency assignment procedures to optimize the SB-VHF services must also address any related Operational topics.

III. COMPATIBILITY WITH CURRENT AVIONICS

The SB-VHF system will support VHF voice and datalink services without the need of introducing new avionics. This situation has been taken into account analyzing the implications of bringing VHF Data Radio (VDR) to space. With the objective of providing seamless communication and surveillance, ECHOES complies with the stringent regulations for each of the services, including ED-136 and ED-138 for voice service, ED-122 and ED-228B for data, and based on ED-129B for ADS-B.

The demonstration success criteria is defined by verifying that performance in terms of functionality, latency, expiration time, update probability, readability, and availability parameters to assess they are comparable to ground-based infrastructure.

On the other hand, ECHOES addresses one of the main challenges of the SB-VHF, which is the deviation from the central frequency of the signal received by the aircraft. The causes of this deviation are mainly due to the following contributions:

- Offset applied to the transmitted frequency (i.e. carrier offset)
- Oscillator stability
- Doppler frequency shift

This paper examines these sources of frequency deviation and proposes satellite radio-based solutions to ensure transparent operation of both VHF voice and data (VDLm2) airborne radios. The VHF frequency assumed for the subsequent calculations is 137 MHz.

A. Satellite Oscillator Stability

The instability of the onboard clock may cause an error in the frequency to be transmitted. As an order of magnitude, a frequency stability of ± 1 ppm is achievable for the onboard clock. This would result in a frequency error of up to 137 Hz.

B. Doppler Shift

Doppler frequency shift is caused by the relative velocity between transmitter and receiver. It is a deterministic process

that, if needed, would be possible to be compensated up to a certain point, as explained in following chapter. A geometrical model is depicted in Fig. 1 to calculate the maximum doppler experienced by the signal.

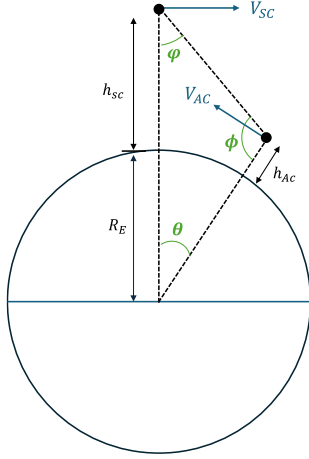


Figure 1. Geometrical model for the visibility of an aircraft from the spacecraft.

Where:

- V_{SC} and V_{AC} are the spacecraft and aircraft velocities, respectively.
- R_E is the earth radius considered to be 6371 km.
- h_{SC} and h_{AC} are the spacecraft and aircraft altitudes, respectively.
- φ is the semi view-angle of the VHF antenna.
- θ is the earth centered angle of the limit of visibility for the spacecraft.
- ϕ is the angle between the aircraft position vector with respect to earth and the spacecraft position vector with respect to the aircraft.

Note that velocities indicated in Fig. 1 are the projection on the plane defined by the aircraft, the satellite and the center of the Earth, as the velocity component out of the plane has no contribution to the Doppler shift. Assuming zero flight path angle of the aircraft, the elevation of the spacecraft (e) over the aircraft horizon, can be computed as follows:

$$e = \frac{\pi}{2} - \sin^{-1} \left(\frac{(R_E + h_{SC}) \sin \varphi}{R_E + h_{AC}} \right) \quad (1)$$

Then, the relative velocity projected onto the line of sight is expressed in (2).

$$\Delta V = V_{SC} \sin \varphi + V_{AC} \cos e \quad (2)$$

Finally, the frequency shift (Δf) is proportional to the relative velocity as expressed in (3).

$$\Delta f = \frac{\Delta V}{c} f_0 \quad (3)$$

Where c is the speed of light and f_0 is the center frequency of the transmitted signal. Considering a circular orbit at 650 km,

an aircraft flying at 10 km and a field of view of the antenna of 62° , the expected doppler shift is provided in Table I.

TABLE I. EXPECTED DOPPLER SHIFT

Case	ΔV [m/s]	Δf [Hz]	Delta w.r.t. stationary [Hz]
Stationary aircraft	6653	3040	0
Aircraft at 300 m/s	6944	3173	133
Aircraft at 778 m/s	7409	3385	345

It can be noticed that most of the contribution to the doppler effect is caused by the satellite velocity which is much higher than the aircraft cruise velocity.

Fig. 2 shows the expected doppler shift observed when the satellite flies right over the aircraft, over a full visibility interval. Note that the time axis has been shifted to consider zero as the time that the spacecraft overflies right above the aircraft. The figure shows a comparison of five different aircraft, one stationary to observe purely the satellite contribution and the other four travelling to each of the cardinal points (North, East, West and South). The satellite is travelling North.

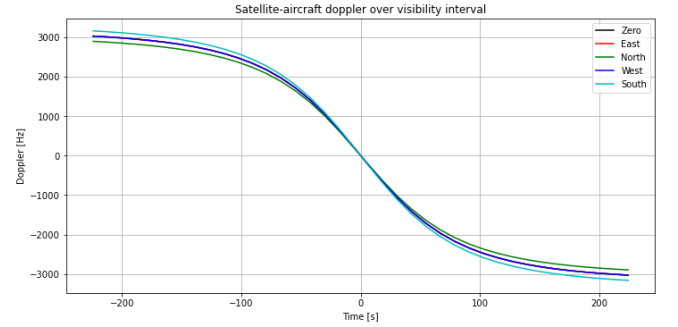


Figure 2. Comparison of the expected doppler effect for an overhead pass with different aircraft orientations.

In Fig. 2, it is possible to observe that the maximum shift experienced by each aircraft is different. The aircraft travelling towards the East and West do not have a contribution to the doppler effect as the velocity is perpendicular to the satellite-aircraft direction, therefore it is like the stationary aircraft case. The maximum doppler shift is experienced by the aircraft heading South since the speeds add up, obtaining the following results for the visibility opportunity simulated:

TABLE II. MAXIMUM EXPECTED DOPPLER FOR AN OVERHEAD PASS

Maximum doppler shift [Hz]	Satellite contribution [Hz]	Aircraft contribution [Hz]
3158.65	3026	132.6

As this is dynamic, the line-of-sight relative velocity of the satellite to aircraft is not constant and this induces a doppler rate which can be observed in Fig. 3.

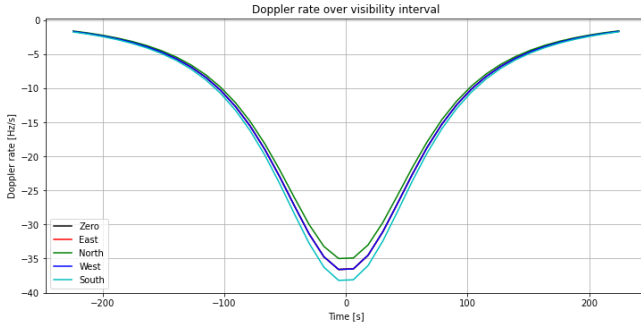


Figure 3. Doppler rate experienced in an overhead pass for different aircraft orientations.

The doppler rate is maximum when the satellite is above the aircraft and the worst-case results are shown in Table III.

TABLE III. MAXIMUM EXPECTED DOPPLER RATE FOR AN OVERHEAD PASS

Minimum doppler rate [Hz/s]	Maximum doppler rate [Hz/s]	Satellite contribution [Hz/s]	Aircraft contribution [Hz/s]
± 1.7	± 38.2	± 36.59	± 1.6

Previous figures help understand the evolution of the doppler shift with time over an overhead pass of the spacecraft. The following figure provide a snapshot of the doppler experienced by any aircraft flying to the south located under the coverage of the satellite at a given instant.

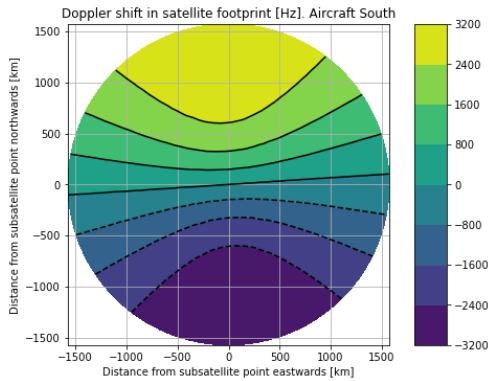


Figure 4. Doppler experienced over the footprint of the spacecraft.

It is possible to observe that there is not a big difference between each of the cases. For each one, the biggest variation appears in the vertical axis (north/south relative position) while the horizontal axis (east-west relative position) has a lower effect.

The biggest doppler rate over the footprint is experienced when the aircraft is in the sub-satellite point with a maximum rate lower than -40 Hz/s while the maximum rate experienced in the visibility limits is lower than 15 Hz/s, being almost null in the north-south limits.

C. Doppler compensation uncertainties

Another source for the frequency shift can be caused by the doppler compensation itself. The doppler effect can be compensated by shifting the center frequency of the VHF spacecraft radio so the frequency reaching the aircraft is within the airborne radio specifications. However, the compensation cannot be exact, and the following potential residual errors can be estimated:

1) *Effect of the delay to apply the compensation:* In case Doppler pre-compensation is applied at transmission, the efficiency of the correction is highly dependent on the time elapsed from the instant where the position and velocity of the satellite and the aircraft are computed to the moment the signal is transmitted. The frequency shift due to this effect is maximum when the aircraft is below the satellite, but it is reduced as the subsatellite point moves away from the aircraft, as seen before. It can be estimated with previous results of Fig. 3 that the minimum processing delay is -1.7 Hz/s and the maximum -38.20 Hz/s.

2) *Position knowledge error:* The relative position and velocity of the satellite and the aircraft is known with a certain accuracy. GPS sensor has a typical error in the order of magnitude of 10 m for the position and 0.005 m/s for the velocity. In case ADS-B is used, the availability of data is typically distributed every 4 seconds which could introduce an error in position knowledge around 1 km. Typical total errors are below 6 Hz.

IV. DOPPLER SHIFT PRE-COMPENSATION MECHANISMS

As anticipated in the previous chapter, it is possible to compensate at the satellite, so the aircraft receives the central frequency. The pre-compensation mechanisms can be studied differentiating by services, since they must comply with different standards.

1) VDL Mode 2:

According to standards (i.e. ED-29C [7], ICAO Annex 10, Vol III [2]) the maximum frequency error allowed for the airborne radios to receive the message is ± 967 Hz. It must be guaranteed that the frequency transmitted by the satellite radio could accommodate with those specified limits so that the existing aircraft equipment can receive the satellite transmissions as if it were operating in a terrestrial scenario.

As seen in previous calculations the expected frequency error is about ± 3.2 kHz so a pre-compensation mechanism must be therefore implemented. The pre-compensation mechanism selected can be based on the type of communication to be supported.

a) Unicast:

In this case the VDLm2 data packets are sent in burst of frames to a specific aircraft. Based on the expected Doppler shift on the destination aircraft, the burst is transmitted with an offset to compensate for the Doppler shift, so the frequency at reception corresponds to the center frequency of the channel.

Even though the unicast pre-compensation is performed for a specific transmission, aircraft situated in nearby regions will

also receive the same transmission. For the particular case of VDLm2 service, with a frequency margin of ± 910 Hz, Fig. 5 shows the region that satisfies the condition.

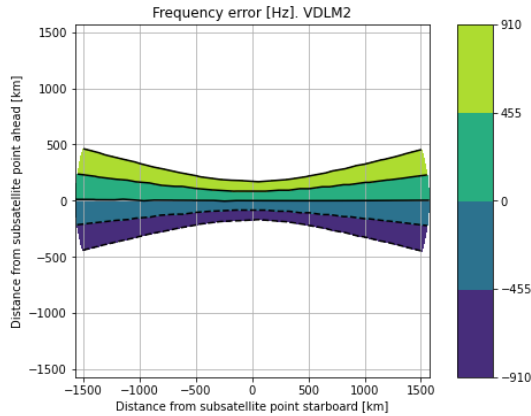


Figure 5. Region of the footprint of the satellite coverage that satisfies a frequency offset within ± 910 MHz

All of the aircraft inside this region will be able to receive and cope with the message.

b) Broadcast:

For broadcast operations the messages are directed to all aircraft in coverage, and it is assumed that an aircraft can handle the reception of the same message twice, as is the case for Ground Station Information Frames (GSIF).

The concept to compensate for the Doppler effect is to transmit the same message several times with different frequency offsets to guarantee that the frequency received by the aircraft is within the frequency capture range.

The minimum number of retransmissions to guarantee all aircraft in coverage catch the message can be computed as the maximum error frequency seen by the receiver divided twice the doppler shift error allowed. The traffic generated by such approach would remain low so it should not affect the channel occupation.

Fig. 6 is an example of broadcast pre-compensation dividing the coverage into four regions, each having a different frequency offset to fulfil a ± 910 Hz maximum frequency shift specification. This will leave some margin for other sources of frequency shift that cannot be compensated, as explained previously.

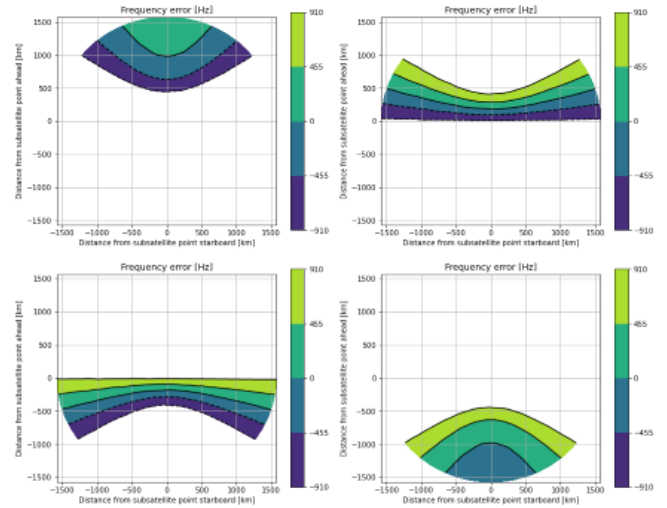


Figure 6. Broadcast pre-compensation mechanism consisting on four offset frequencies.

The VDLm2 system is based on a CSMA (Carrier Sense Multiple Access) scheme that consists basically in sensing whether the channel for transmission is busy or not, and transmission occurs in the event the channel is idle. As it has been explained in previous sections, the Doppler shift caused by the satellite movement can introduce an offset in the carrier that is higher than the VDR frequency capture range. As the Doppler shift depends on specific aircraft location, a Doppler pre-compensation approach will be able to guarantee the correct reception by the airborne radio from the satellite transmissions (see Fig. 6). On the other hand, aircraft far away in other regions may not be able to receive the pre-compensated satellite transmission correctly. For those aircraft in other regions, even if their CSMA cannot detect the channel as busy and decided to transmit, their transmissions are unlikely to affect the reception in the aircraft in the region receiving with the correct pre-compensation due to the long distance.

Note in terrestrial networks the situation is equivalent, aircraft located in places that are far from each other will not listen among them due to terrestrial coverage limits.

2) Voice Service:

According to ICAO Annex 10, Vol III, Part 2 [2], the capabilities of the airborne radios at reception of VHF Voice signals over 25 kHz channel are:

- Effective acceptance bandwidth with offset carrier: ± 8000 Hz
- Effective acceptance bandwidth without offset carrier: ± 6850 Hz

It must be guaranteed that the frequency received by the airborne radio is within those specified limits for the system to work with existing aircraft equipment.

From the results of the previous sections, it can be observed that the communications from the satellite to aircraft in the voice 25 kHz case, does not need pre-compensation for doppler shift

since the worst-case scenario still satisfies the specification with enough margin.

In the case the solution is scaled to a constellation of satellites to provide global coverage, the voice service presents another challenge. Voice service establishes communication for a longer period of time than VDL Mode 2 and it cannot be guaranteed that one single spacecraft is in visibility of the aircraft for the whole duration of the call. Therefore, the system will not only have to handle the frequency shift, but it also must handle communications handovers from one spacecraft to the next one in order to provide continuity of the service.

There is some uncertainty about the exact moment that one aircraft exits from the visibility of one specific spacecraft, which makes the handover challenging. The solution to this is already implemented for ground stations when a single ground station cannot transmit to the complete region. It is called CLIMAX and it consists of transmitting the signal from multiple ground stations with an offset carrier frequency, while staying within the channel width (25kHz), and the receptor chooses the best one to receive the message.

During ECHOES, a theoretical analysis was carried out confirming the possibility of considering climax as one possible solution to the overlapping regions for voice service to manage spacecraft handovers.

V. CURRENT AIRBORNE RADIOS

After the previous theoretical analysis that established the reference, different airborne radios currently in use by the aircraft were analyzed to assess the potential real impact of the satellite channel doppler on the radio. For each of the services the following measurements were taken:

A. Data Link Tests

The VHF-2100 radio, manufactured by Collins Aerospace, is one of the most commonly installed on board aircraft. As seen in Fig. 7 it supports doppler shifts due to the satellite movement, previously calculated to be around 3.2 kHz, when the input power at the aircraft is greater than -98 dBm.

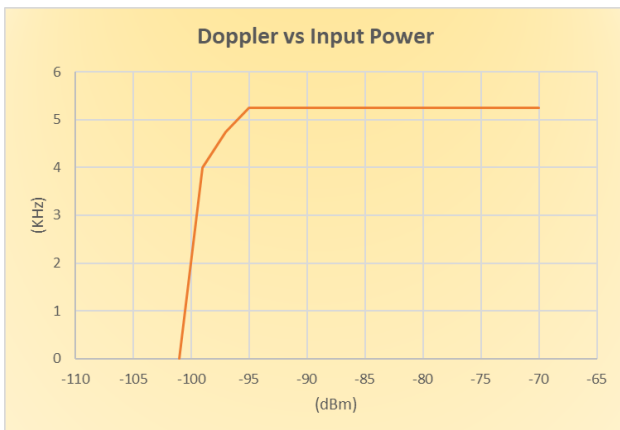


Figure 7. Doppler shift supported by Collins VHF-2100 radio.

The radio behavior was found to be the same when introducing a dynamic doppler effect simulating a satellite overflight.

B. Voice Tests

Fig. 8 gives a comparative overview of the capabilities of three different VHF radios. Note that it has been included 8 kHz channel even though this paper focuses on 25 kHz spacing.

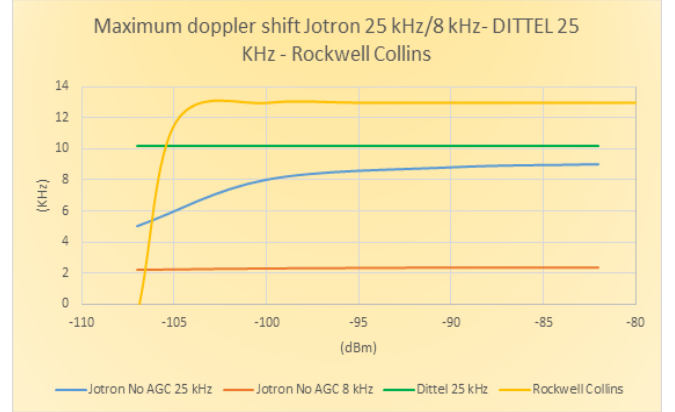


Figure 8. Doppler shift supported by three different VHF radios.

The radios considered in this paper have shown to support doppler shifts higher than the maximum doppler shift expected due to the satellite movement.

Regarding the performances, according to ICAO SARPs the Signal to Noise and Distortion (SINAD) should be greater than 10 dB and Total Harmonic Distortion (THD) lower than 5%. Fig. 9 and Fig. 10 show that the behavior of the demodulated audio when doppler is applied is within the specified limits.

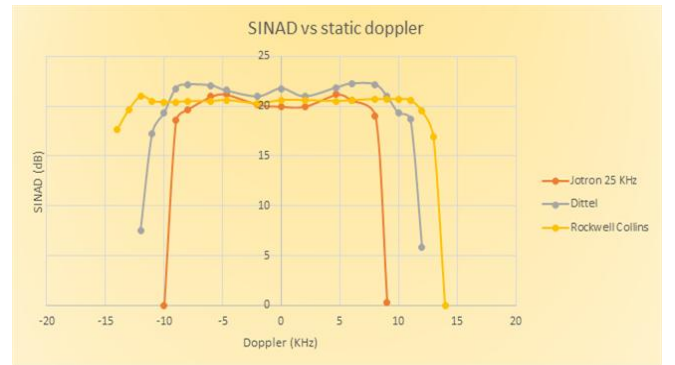


Figure 9. SINAD comparison after introducing doppler shift.

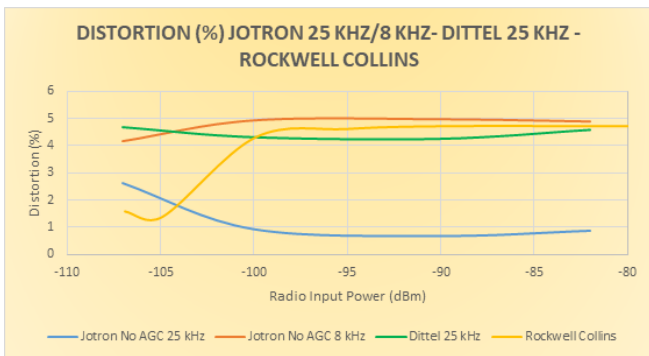


Figure 10. Expected distortion for different power inputs over the airborne radios.

As in the case of data radio, tests show that voice radio behavior is not affected by dynamic doppler shift and the performances of the audio demodulated when doppler is applied remain above the specified values by ICAO SARPs.

VI. ECHOES LIVE DEMONSTRATION

To be able to establish seamless communication with the aircraft, ECHOES' demonstrator satellites apply a pre-compensation to cope with the Doppler effect based on previous analysis. ECHOES demo exercises take place over the South Atlantic Ocean, including the participation of the corresponding ANSPs as shown in the following figure.

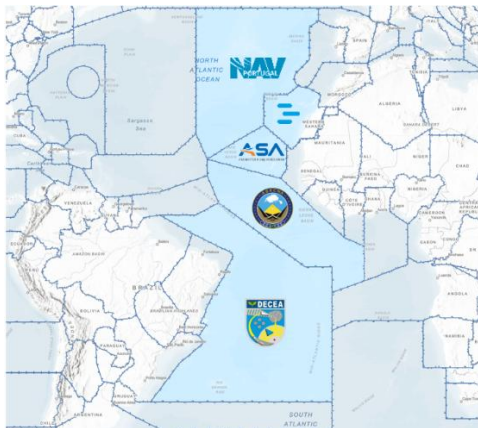


Figure 11. ECHOES participating ANSP and their FIR.

The following exercises were performed with opportunity traffics in cruise phase over the mentioned area:

- Satellite-based ADS-B proof of concept and to provide inputs to the results.
- Satellite-based VHF voice communications and measurement analysis of the performances.
- Satellite-based VHF data use for ATN data communications (CPDLC) and measurement analysis of the performances.
- Satellite-based VHF data use for FANS data communications (CPDLC and ADS-C) and measurement analysis of the performances.

- Satellite-based VHF to exchange AOC communications.

It is worth mentioning that no operational instructions were given to the pilots as the objective was to assess functionality and technical performance.

The exercises started in June 2025 and will extend until the end of the same year. Six different airlines were involved in the trials, making it possible to gather more data for the results analysis. The main outputs up to date are positive, confirming the feasibility of the space-based VHF concept for future ATM and environmental improvement over oceanic and remote airspace.

During the ADS-B exercises, the system successfully captured and relayed messages to the ground infrastructure, enabling flight monitoring in controlled airspace beyond terrestrial radar coverage and allowing a first-level performance assessment. In the voice exercises, ATC controllers from several ANSPs noted that the voice quality over SB-VHF was significantly better than HF (current technology), with trials showing positive results and delays already below ED-137 specifications. The ATN data exercises demonstrated successful two-way message exchange between aircraft avionics and ATN ground systems through the ECHOES satellite, with delays consistent with ED-228B parameters; the same outcome was confirmed during the FANS data exercises.

Finally, in the AOC data exercises, messages were successfully transmitted through the ECHOES platform using the ground infrastructure, confirming the system's capability to handle and correctly route such messages through the CSP's internal network. Additionally, AOC position requests were successfully received by aircraft, and the corresponding location messages were correctly returned to the AOC via the ECHOES platform.

These results have been used to validate the following use cases:

1) Initial assessment of separation minima reduction for increased airspace capacity in Oceanic regions:

Using the results explained above, compliance was interpreted in PBCS terms, mapping to the separation minima. ECHOES provides sufficient technical evidence to support a reduction to Sub-20NM longitudinal separation in the assessed oceanic sectors under PBCS, without degrading safety, provided demo-level communications and surveillance performance is sustained. Moreover, it also supports <10 NM extrapolating the results of the two satellites to a full constellation, in defined sectors based on the availability of instant voice communications.

2) Permanent contrails prevention on the South Atlantic corridor:

ECHOES demonstrates the feasibility of integrating contrail prediction into real time operational framework as it provides the communications and surveillance enablers needed to execute permanent contrail formation predictability and would enable

contrail-aware tactical manoeuvres in oceanic and remote airspace.

3) *VHF AOC message transmission for flights analysis, fleet management and ADS-B as source for GADSS:*

Based on the demonstration evidence, AOC message exchange over SB-VHF data and SB-ADS-B distribution via ECHOES are technically supported in oceanic and remote areas, enabling airline applications for flight analysis, fleet management, and supporting GADSS normal aircraft tracking for both AOC and ANSP.

4) *Initial assessment of utilisation of User Preferred Routes (UPR) in oceanic regions:*

ECHOES provides technical evidence to support the future utilization of UPR in principle in the assessed oceanic sectors, given that the demonstrated communication and surveillance performance is sustained operationally and that required ATC procedures and tooling are in place.

Fast Time Simulation (FTS) indicates that a separation minima of 10NM is needed to accommodate the maximum number of aircraft in their optimal flight level (user preferred route).

5) *Use of satellite-based VHF voice communication and satellite based ADSB as a means of contingency/delegation:*

ECHOES has performed numerous cross-FIR delegation exercises where the aircraft and the controller are not in the same FIR. The use of SB-VHF voice and SB-ADS-B via ECHOES supports contingency operations and planned sector delegation in oceanic and remote airspace, provided that the measured communication and surveillance performance is sustained operationally and that the necessary inter-ANSP agreements and procedures are in place. The finding is suitable for targeted operational application and for standardization and regulatory follow-up.

VII. CONCLUSIONS

This paper introduced the ECHOES project and its importance paving the way for the space-based VHF concept. Although some of the challenges affecting space-based communications were found, ECHOES work in the technical and regulatory sides has provided a solid foundation for the future operational implementation, demonstrating its feasibility. This technology will not only enable to increase the airspace capacity and safety in oceanic and remote areas, but it will greatly contribute to ATM in terms of cost-efficiency and environmental impact.

An important feature of the initiative is the fact of interoperability with already existing ground-based infrastructure, making no changes to onboard radios. This is a key aspect allowing rapid time-to-market and seamless communications to pilots, enlarging today's coverage to remote and polar areas.

The most restrictive service is the VDLm2 due to the specifications of the hardware requirements. Two different pre-compensation mechanisms were presented as solutions for the

frequency Doppler shift regarding the type of communication (i.e. unicast, broadcast).

On the other hand, it was shown that VHF voice over 25 kHz channel counts with enough margin so that no Doppler pre-compensation would be needed to guarantee communications. Also, the problem was presented with having multiple spacecraft covering the same region for this service, which results in the reduction of service performance. The solution proposed is based on the already in use CLIMAX approach, consisting in transmitting with different offset carrier from satellites at different orbital planes. The offset should be selected to guarantee that the separation between different transmissions is such that no overlap would be produced and ensuring fulfilment of the specifications at same time.

Next, the results of tests for some of the most used radios onboard aircraft at laboratory were presented. Obtaining positive results indicates that the radios are able to withstand the expected frequency shift due to the space-based communications even if no compensation is applied.

Finally, the outcomes of the ECHOES live trials under an operational scenario were presented. These results positively confirm the feasibility of applying reduced aircraft separation standards in oceanic airspace, enabling more flexible and efficient flight trajectories. The validation was justified by assessing five different use cases supported by the results of the ECHOES demonstration.

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