ICAO SAM/CAR/NAM Regional Preparatory Group Workshop for the ITU World Radiocommunication Conference 2023 (WRC-23)
21 – 22 February 2022

ENAIRE Indra EUROCONTROL SITA FOR AIRCRAFT

Space Based VHF Studies

VOICE project: outcomes of technical studies and test/validations

ICAO-FSMP-workshop
22/2/2022

Contents

Introduction.

- The objective of this presentation is to present the results of the technical studies and laboratory tests performed by VOICE project in support of the SB-CNS concept.
- ICAO FMSP and PT-T members are invited to:
  - take note regarding the activities that are performed and are planned in the future under the umbrella of this project.
  - discuss and agree about the response to ITU-R 5B considering all potential services voice and data provided in the whole or parts of the whole band.
  - receive a feedback about next actions proposed in this paper.

Contents

VOICE Project – Validation approach

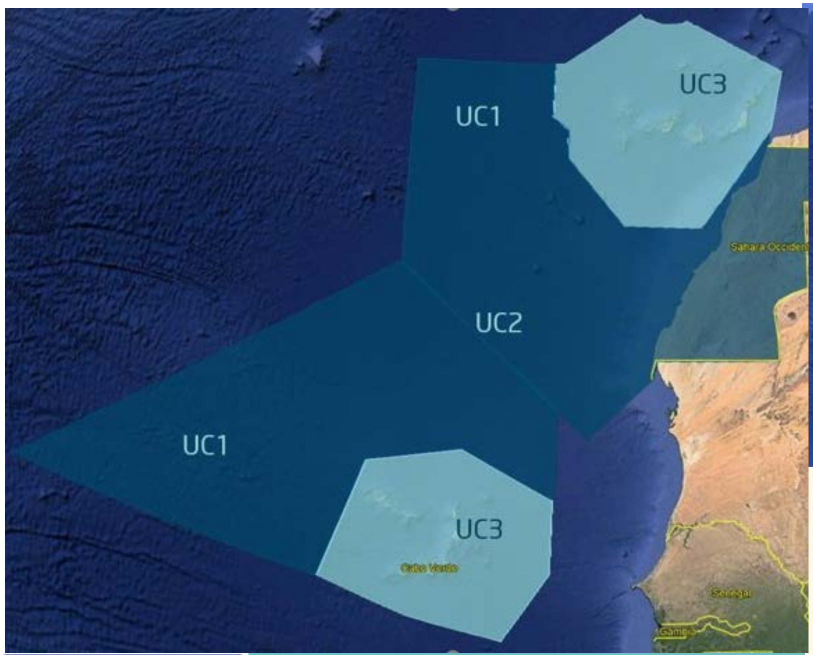
- **Objective:**
  - Evaluate the feasibility of Space based VHF communications in oceanic and remote airspaces in order to provide VHF voice and Data services and ensure the possibility to provide complementary and continuous coverage for VHF voice and Data services from Continental to oceanic Airspaces.
- **Validation approach:**
  - Aircrafts in the area of interest of the exercise will be asked to communicate using pre-assigned frequencies (1 for VHF voice and 1 for Data) in areas where normally no VHF coverage is available.
  - Communication with ATCO from Canarias and SAL FIRs will be stablished using assigned VHF frequencies.
  - No operational instructions will be given during this demonstration.
- **Technical aspects:**
  - VHF frequencies for VHF voice and data has been selected considering that they are not repeated in the affected envelope of the possible satellite positions used for Tx.
  - Transmitted power in Satellite is dynamically configurable based on satellite position (LAT-LONG) and based in command and control orders, in order to ensure that there´s no impact outside the exercise envelope.
  - Satellite is configured in Rx mode as default, and will switch to Tx mode only when commanded by the system and with the power levels in order to ensure there´s no impact outside the exercise envelope.

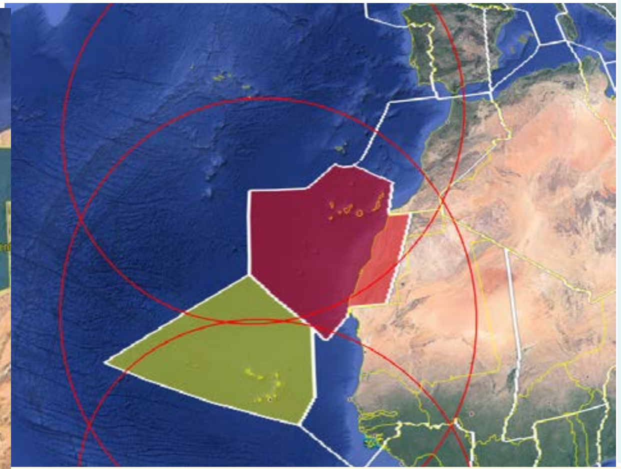
VOICE Project – End to End Test

VOICE

Reduced separations and improved efficiency based on Vhf cOmmunICations over LEO satEllites

indra GOMSPACE SESAR JOINT UNDERTAKING ENAIRE EUROCONTROL





Objectives

The main objective of this project is to perform a proof of concept for this technology in real environment by end 2022.

- Demonstrate that use of VHF comms with LEO satellites is successful and does not interfere with existing installations.
- Provide real data for approval of use of VHF in LEO satellites in the next WRC2023

Consortium partners

- **Indra (consortium leader)**
  - Subcontractors: SITA, INTA, UPM
- **Enaire**
  - LTP: CRIDA, ASA-Cape Verde
- **GomSpace**
  - GomSpace A/S
  - GomSpace Lux
- **Eurocontrol**

Advisory Board

Air Europa	IATA
AESA	JOTRON

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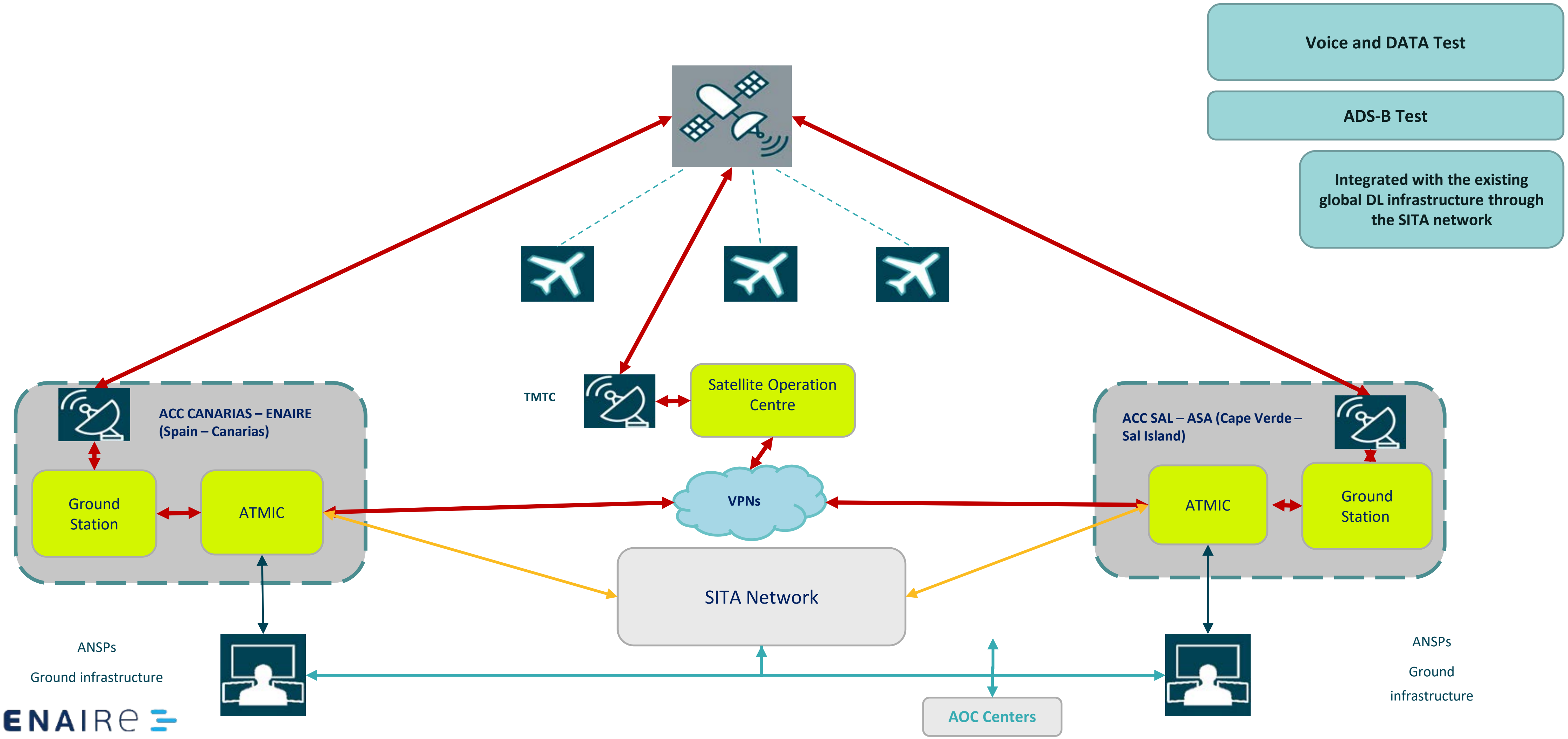
indra ENAIRE SITA FOR AIRCRAFT EUROCONTROL

VOICE Project – Infrastructure

VOICE

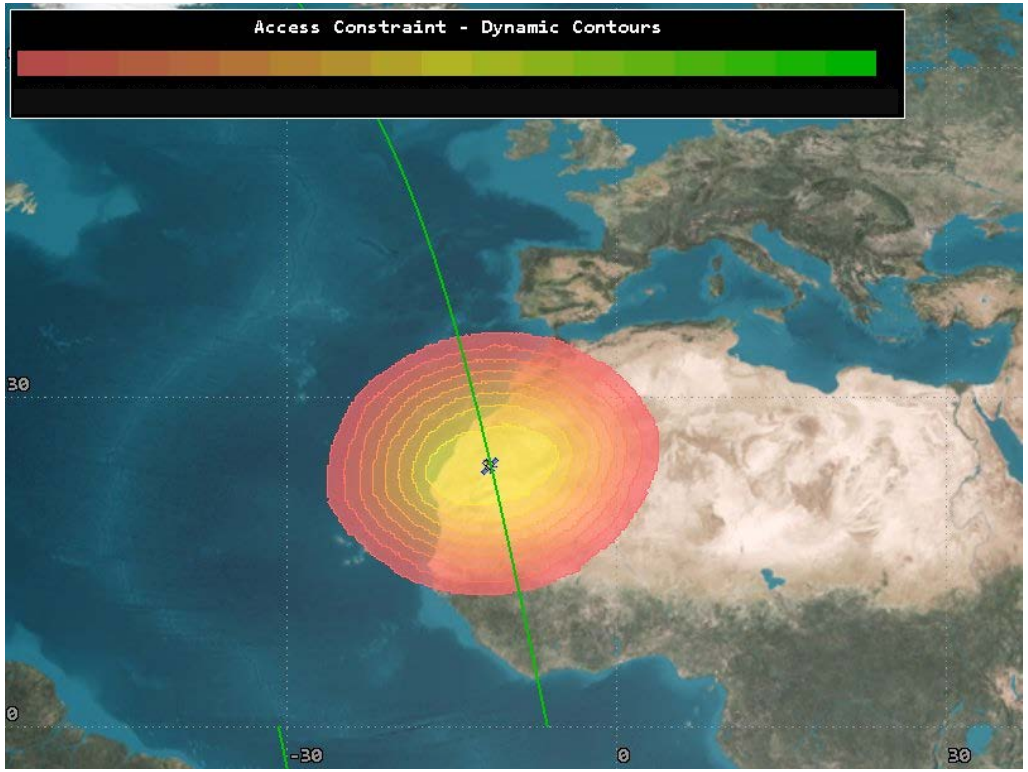
VHF – Data and Voice - System Definition for VOICE project



VOICE Project – Theoretical Coverage

Orbit Type: Sun-Synchronous 550 km

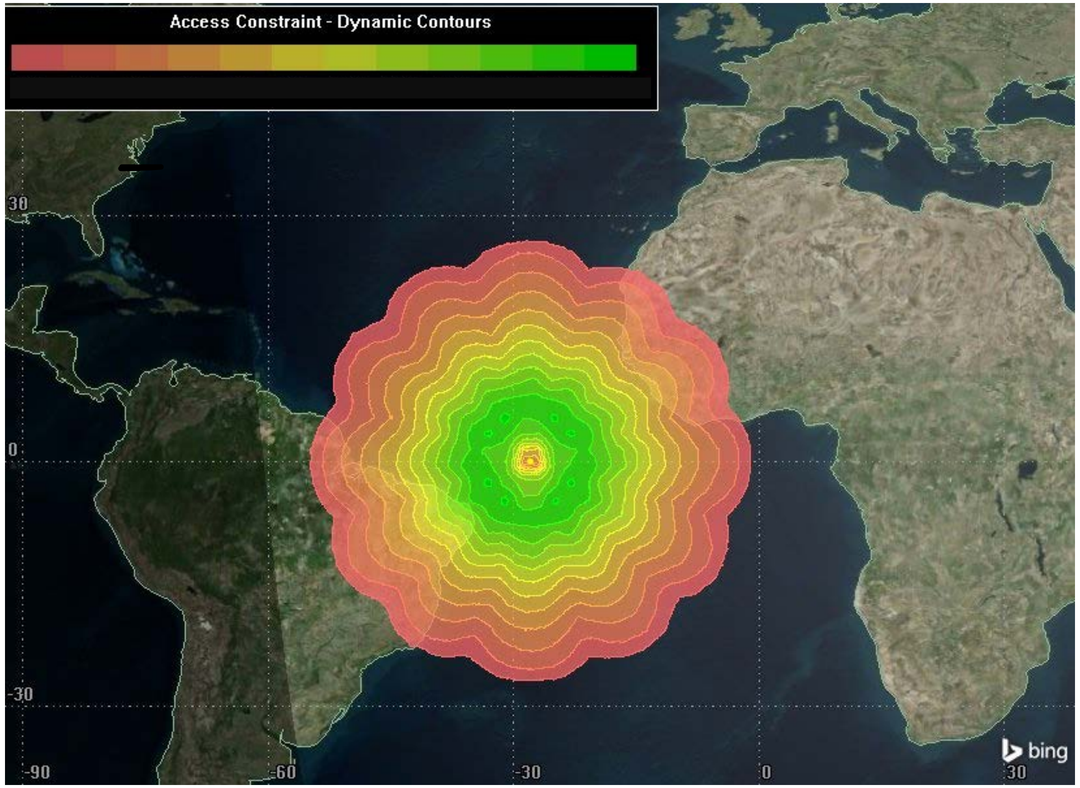
VHF Antenna Type: Isoflux Nadir pointing
VHF Tx Coverage (configurable): Maximum 1500 km



VHF link budget for Data and Voice Satellite to Aircraft

(PFD, Scintillation, Doppler, Faraday, Antenna ….)

ADS-B Antenna type patch

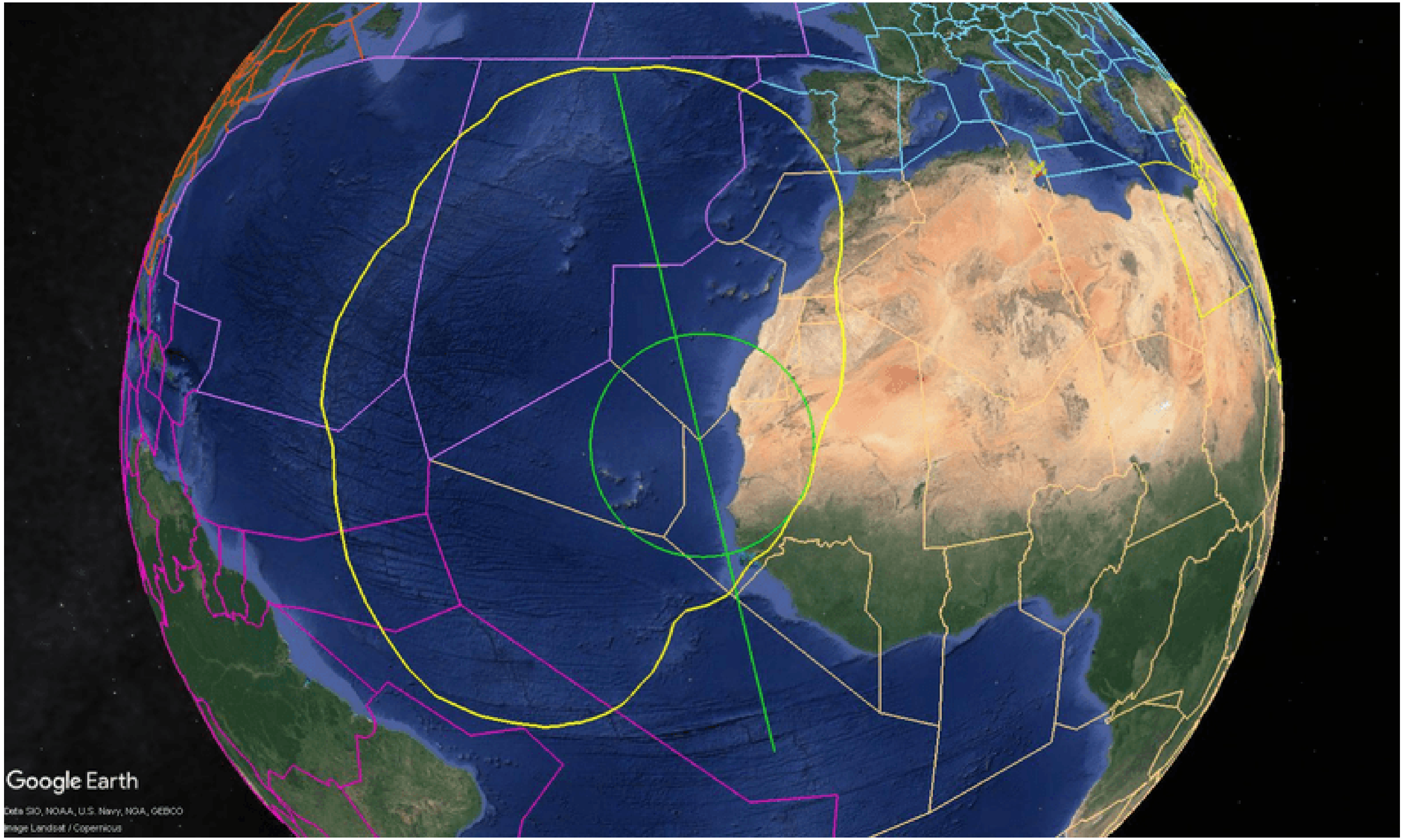


ADS-B - Aircraft to Satellite (Rx) Coverage

(S/N, Detectability, Antenna ….)

VOICE Project – Technical Test

VOICE



N-S passes marked in red.

S-N passes marked in green

Satellite Footprint is dynamically configurable based on satellite position (LAT-LONG) and based in command and control orders, in order to ensure that there´s no impact outside the exercise envelope.

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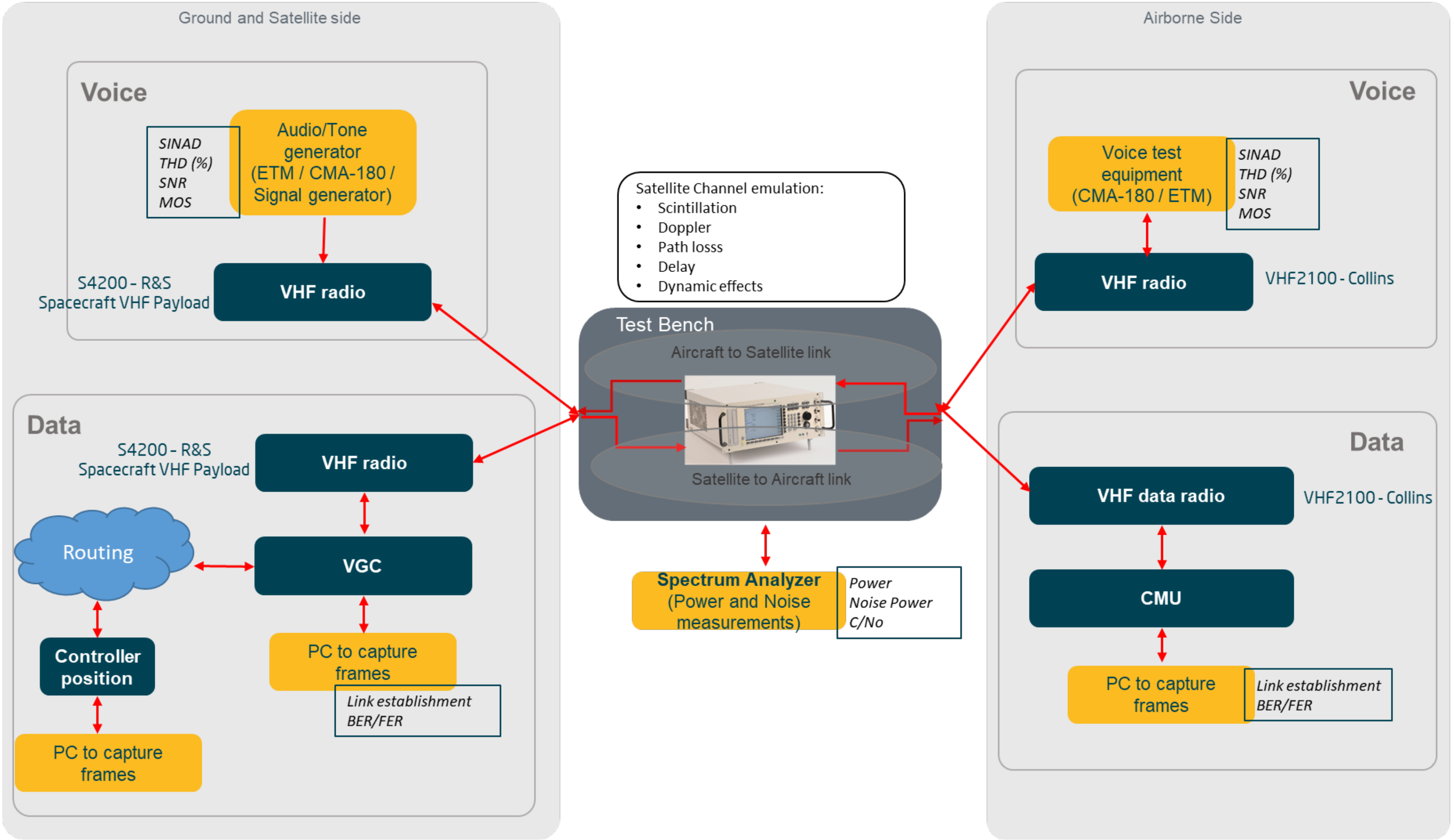
Test Bench for global communications



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Signal propagation - impact on VHF link

- **Objective:** Evaluate impact of higher satellite channel propagation attenuation and scintillation effect to verify PFDs and SNRs for VHF Voice and VHF Data links requested in ICAO SARPS.
- **Studies / Analysis:**
  - Analysis considering variable propagation conditions, scintillation and the typical aircraft antennas characteristics and by taking into account the relevant ITU-R Recommendations/Reports for these studies
- **Tests / Measurement:**
  - Laboratory Test environment
    - Composed of commercial VHF equipment (both airborne from Collins and ground sides) deployed in ENAIRE test facilities.
    - Satellite Channel Emulator to introduce representative attenuation patterns and scintillation effect.
    - Scintillation emulated based on ITU-R models and generated through computed time series.
  - SESAR VOICE project to carry out flight tests with a LEO satellite.

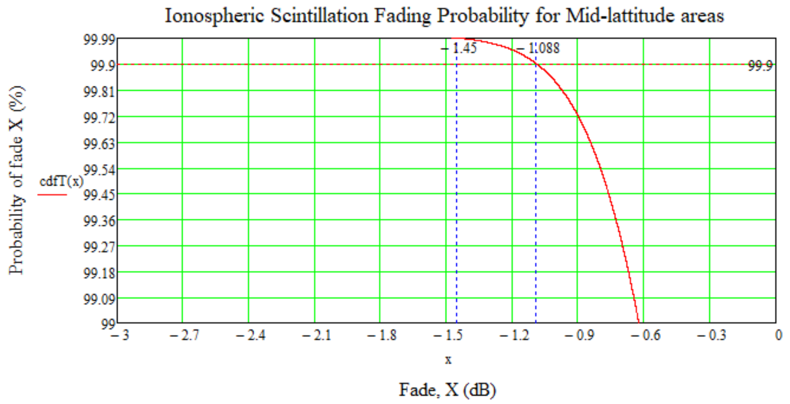
Signal propagation -Impact of satellite channel propagation on VHF links. Scintillation Analysis

ITU 5B group Inputs

- <u>**Document 5B/112-E – ITU-R WP 3L**</u>
  - <u>**link to ITU-R P.531-14:**</u> Ionospheric propagation data and prediction methods required for the design of satellite networks and systems.

- <u>**Annex 29 to Document 5B/355-E:**</u>
  - "…. Depending on satellite system design trade-offs, **it may be of interest not to dimension the satellite system to account for the worst-case propagation loss**, which is transient and highly dependent to time, weather and location, and to compensate with appropriate measures (like appropriate flight planning) over the concerned regions when affected. "
  - "…Based on these considerations, it is proposed to retain in this report the assumptions corresponding to the low and medium levels of scintillation losses, i.e. 1 dB and 5 dB respectively, and to establish link budgets under both of these assumptions."

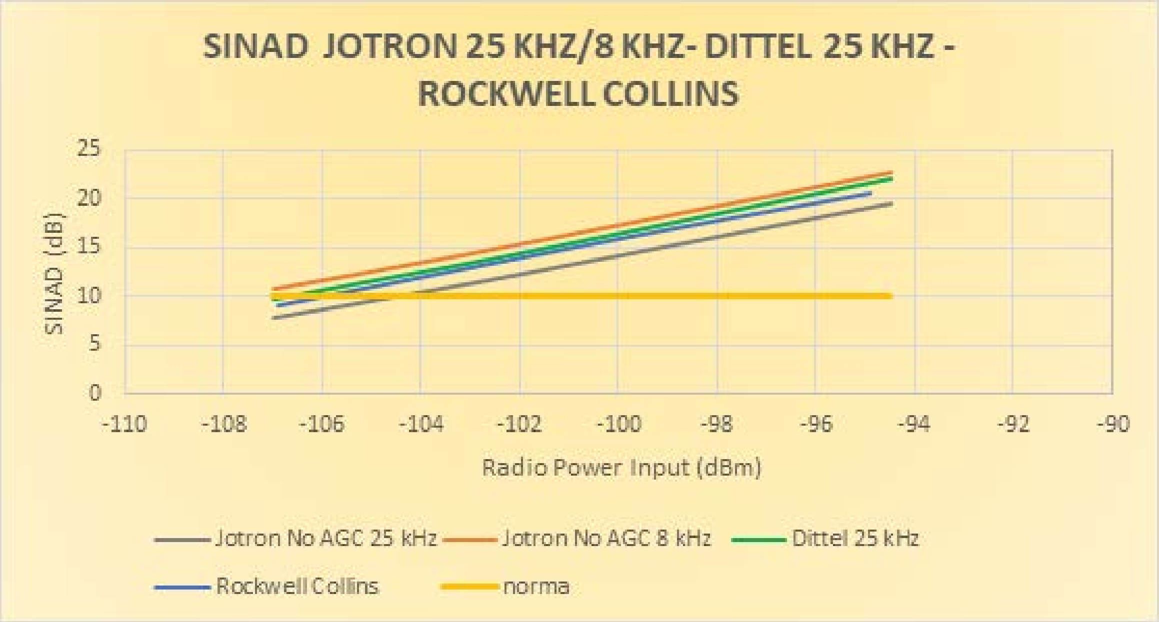
- <u>**Document 5B/372-E – WP 3L**</u>
  - "… The value of 1 dB seems to be appropriate for middle latitude regions…".

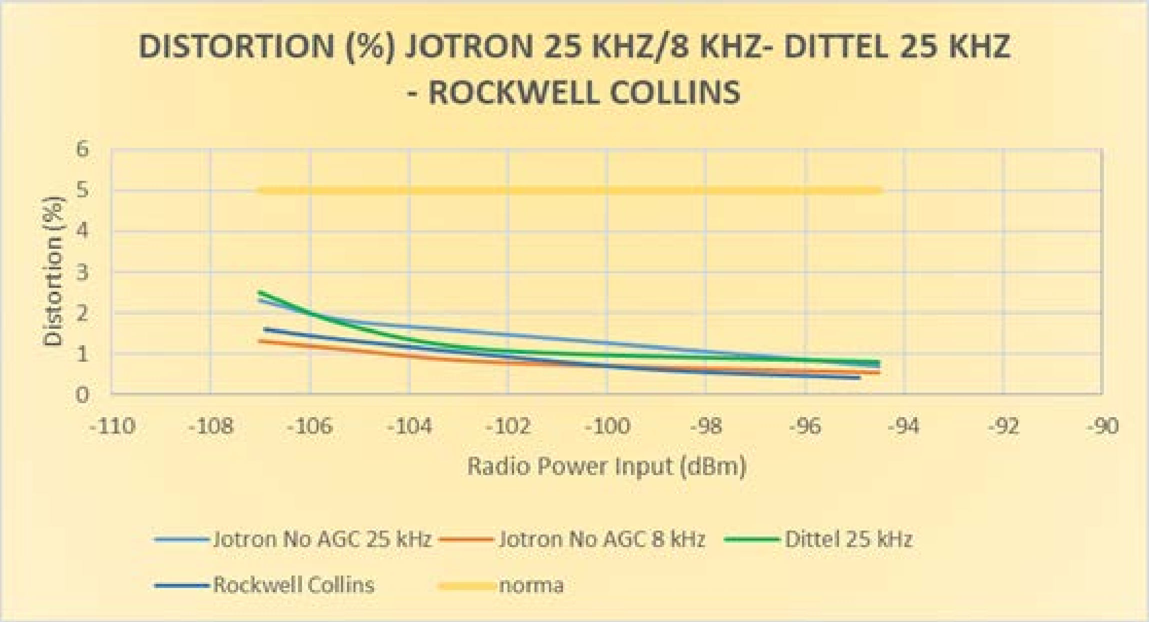


<u>Outcomes:</u>

- Using Nakagami formulation we can mathematically model the event can be mathematically modeled by a distribution function for middle latitudes areas considering existing scintillation bibliography and statistical data around 138MHz. Therefore, as was discussed with ITU-R Working Party 3L and according to Nakagami model, **1 dB of fading effect for 99,9% of cases in middle latitudes is considered**.

Signal propagation - Impact of satellite channel propagation on VHF links. Voice Calibration Tests: C/No and sensitivity

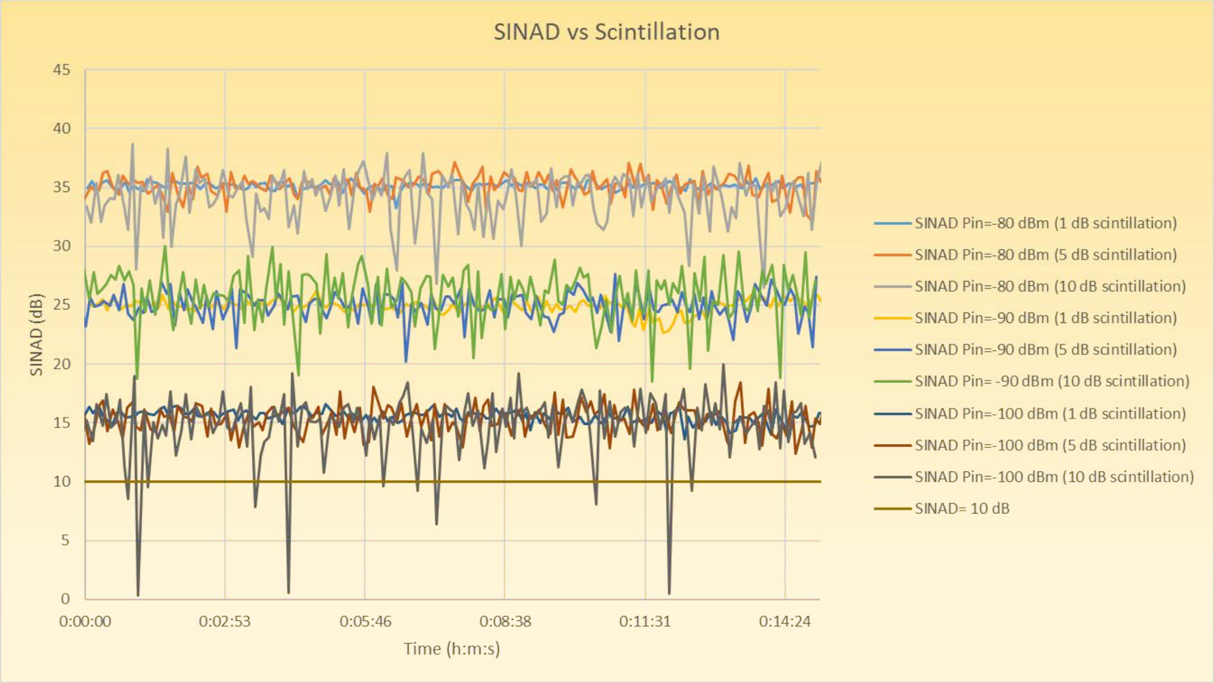


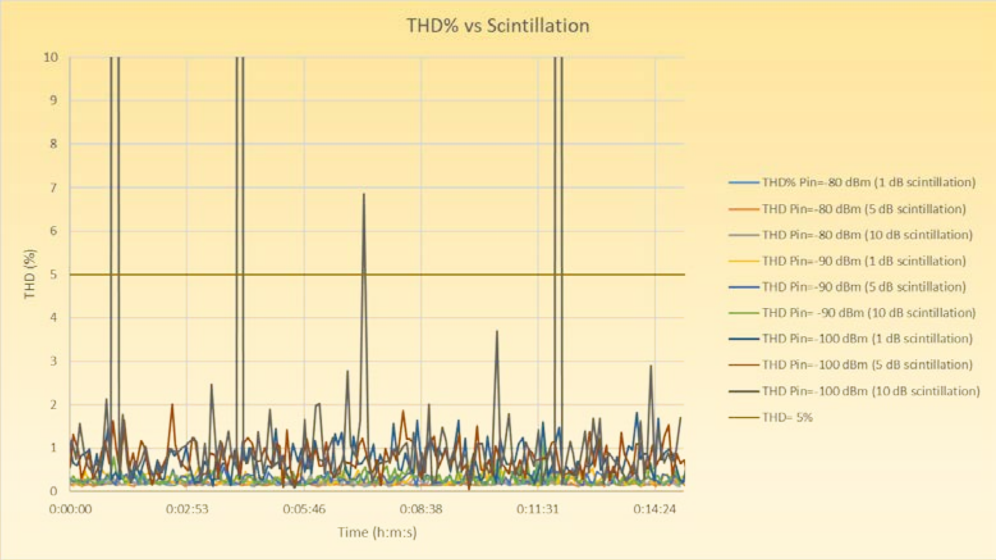


- Calibration based on power levels from Link budget computation. Reference results to compare with the ones when satellite channel effects are introduced.
- **Performance of demodulated audio is above the values specified** in ICAO SARPS (SINAD >10 dB and THD<5%) for the expected range of input powers.

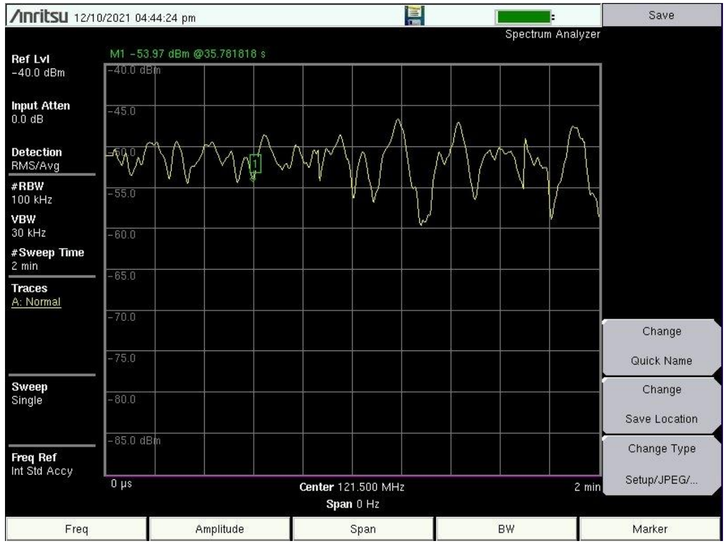
SINAD: Signal-to-noise and distortion ratio

Signal propagation - Impact of satellite channel propagation on VHF links. Voice Tests: Scintillation



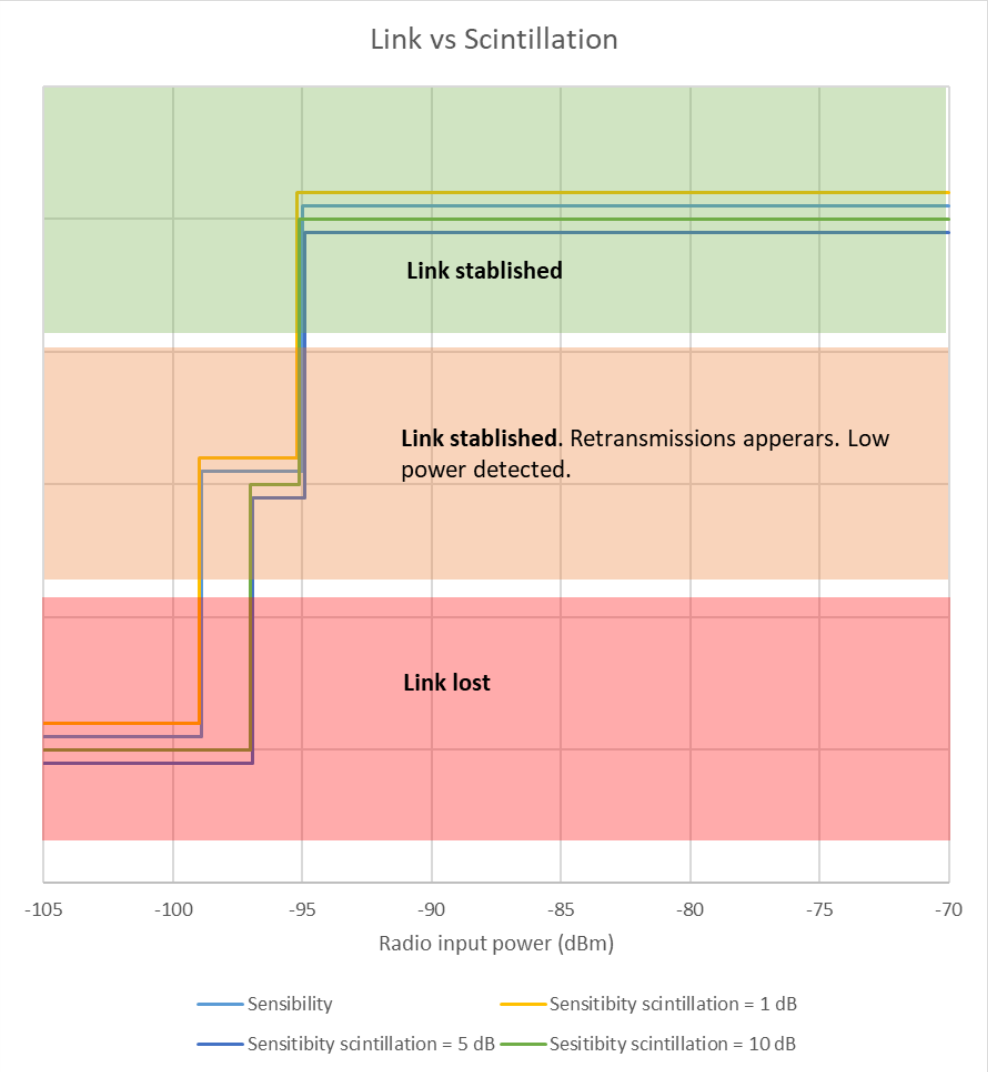


- Tests of 3 scintillation time series with different attenuations (1 dB middle latitudes, 5 dB high latitudes) and 10 dB (equatorial)
- **SINAD and THD% are over values specified** in ICAO SARPS (SINAD >10 dB and THD<5%) when scintillation is applied, except a few instants for the 10 dB scintillation case.



SINAD: Signal-to-noise and distortion ratio

Signal propagation - Impact of satellite channel propagation on VHF links. Preliminary DATA link Tests: sensitivity & Scintillation



- Calibration was done with power level from Link budget computation. **Data link was established until a power level of –99 dBm**.
- VDLM2 retransmissions avoid some scintillation effects minimizing its effects in the link behaviour.
- No degradation is observed for 1 dB scintillation case with respect no scintillation. For 5 dB and 10 dB cases, there is no degradation for inputs levels higher than -97 dBm.

Contents

Doppler effect on VHF link

- **<u>Objective</u>:** Evaluate the impact of the satellite Doppler effect in airborne VHF radios, taking into account currently defined ICAO SARPS specification for carrier frequency acquisition range. To be assessed for VHF Voice and VHF Data (focus on VDLm2).

- **<u>Studies / Analysis</u>:**
  - Computation of the aggregated frequency offset over the Satellite footprint with the main contribution of the Satellite Doppler shift.
  - Study of the impact on VHF Data reception and assess the necessity of a pre-compensation mechanism.
  - Study of the impact on VHF Voice reception for 25 kHz channel.

- **<u>Tests / Measurement</u>:**
  - Laboratory Test environment
    - Composed of commercial VHF equipment (both airborne and ground sides) deployed in ENAIRE test facilities.
    - Representative satellite Doppler effect profiles introduced in the VHF links by a Satellite Channel Emulator.
    - Evaluate the maximum Doppler shift tolerated, both for voice and data that a commercial airborne VHF radio.
  - SESAR VOICE project to carry out flight tests with a LEO satellite.

Doppler effect on VHF link – Analysis Spacecraft -> Aircraft Doppler effect

- **VDL Mode 2 Standards Specifications**
- **ED-92C** Minimum Operational performance standard for **an airborne VDL Mode-2 system** operating in the frequency range 118-136.975 MHz

2.2.1.2.7 Frequency Capture Range

The receiver willbe capable of acquiring and maintaining a lock to the desired signal tuned to any selected channel at or above the sensitivity level (Section 2.2.1.2) with the maximum permitted signal frequency offset defined below.

The receiver will achieve the error rate requirement (Section 2.2.1.2) when the desired signal at the reference signal level (Section 2.2.1.2) is subject to a frequency offset of ± 967 Hz at the room temperature.

NOTE: *This value is composed of the maximum transmitter frequency error at 136.975 MHz (± 685 Hz) and the maximum Doppler shift (± 282 Hz).*

- **VHF Voice Standards Specifications**
- **Annex 10:** Volume III Communications Systems Part II – Voice Communication Systems
- Effective **acceptance bandwidth for 25 kHz** channel spacing (including Doppler shift)

2.3.2.3 *Effective acceptance bandwidth for 100 kHz, 50 kHz and 25 kHz channel spacing receiving installations.* When tuned to a channel designated in Volume V as having a width of 25 kHz, 50 kHz or 100 kHz, the receiving function shall ensure an effective acceptance bandwidth as follows:

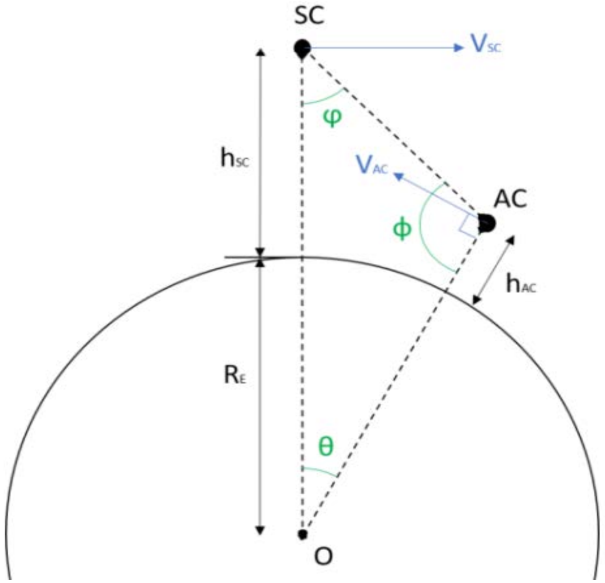
a) in areas where offset carrier systems are employed, the receiving function shall provide an adequate audio output when the signal specified at 2.3.2.2 has a carrier frequency within 8 kHz of the assigned frequency;

b) in areas where offset carrier systems are not employed, the receiving function shall provide an adequate audio output when the signal specified at 2.3.2.2 has a carrier frequency of plus or minus 0.005 per cent of the assigned frequency.

	VDLM2 (Hz)	Voice 25 kHz offset carrier	Voice 25 kHz no offset carrier
Frequency stability [ppm]	±5	±30	±5
Frequency stability [Hz]	±685	±4110	±685
Acceptance bandwidth [ppm]	**±7**	**±58**	**±50**
Acceptance bandwidth [Hz]	**±967**	**±8000**	**±6850**

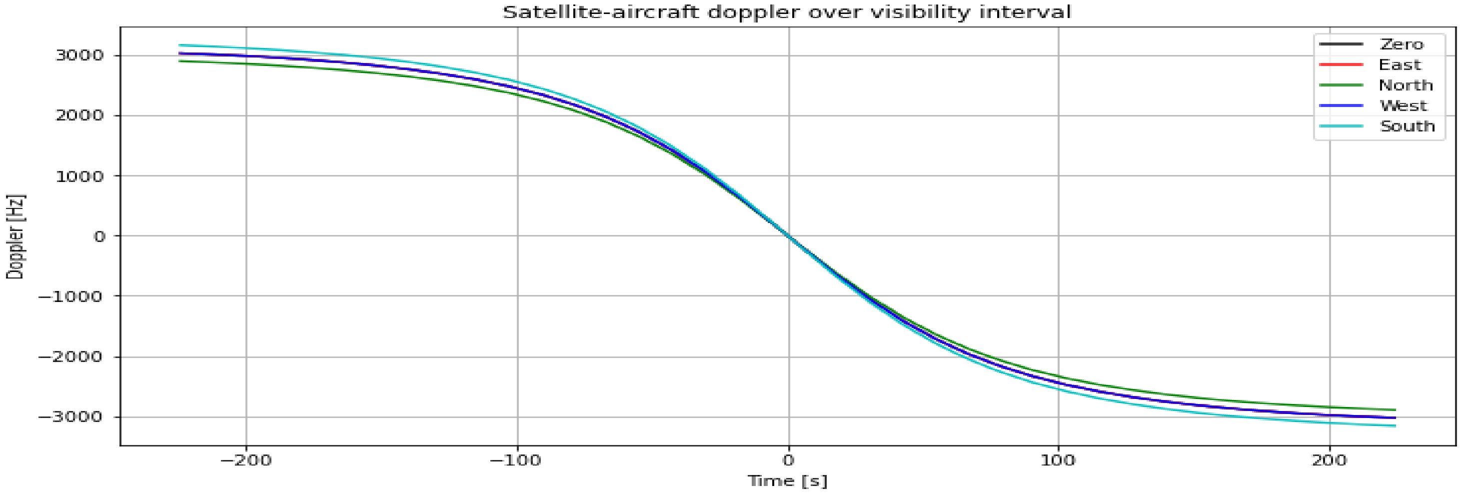
Doppler effect on VHF link- Analysis Spacecraft -> Aircraft Doppler effect

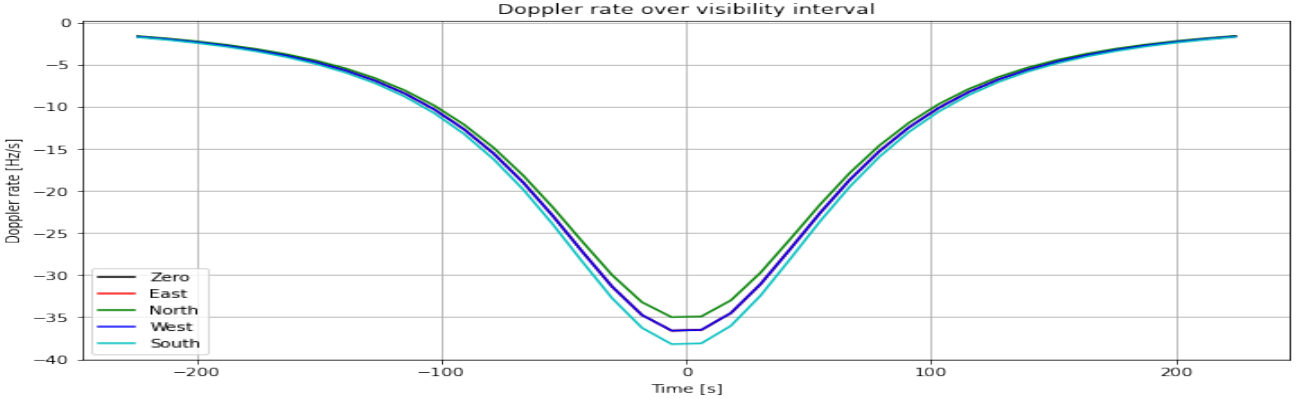
- **Frequency error budget computation**
- Maximum expected shift ±3.2 kHz
- Maximum Doppler shift experienced with a direct overflight
- Doppler shift attenuated as maximum spacecraft elevation decreases
- Clock relativistic effect is negligible
- Possibility to pre-compensate the Doppler shift based on known spacecraft-aircraft position/velocity (uncertainties in the computation of around 60 Hz)



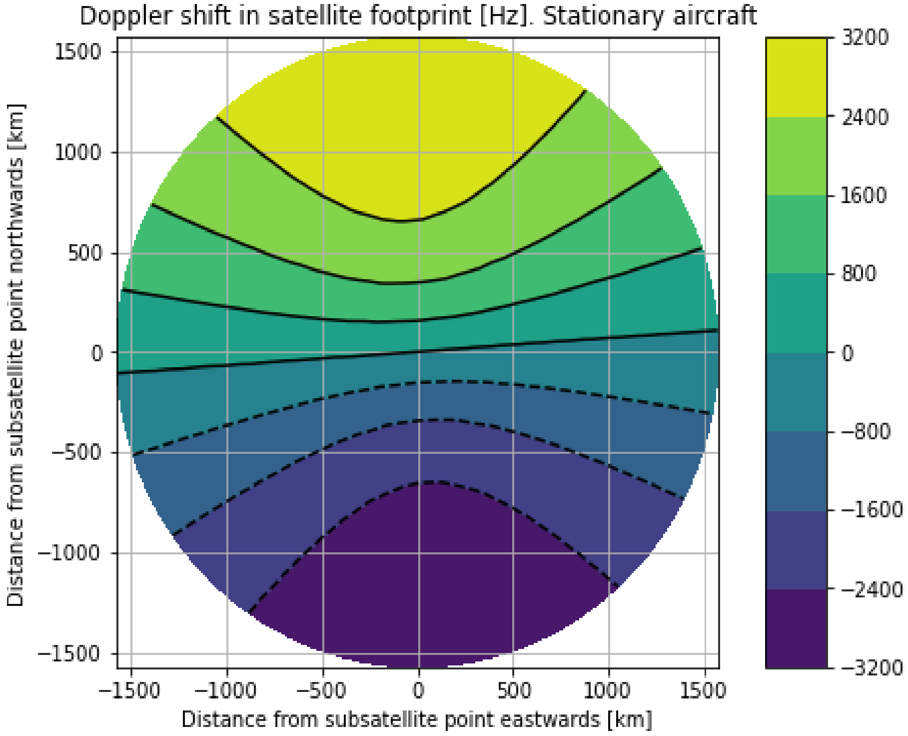
	Frequency error [Hz]	Comments
Spacecraft oscillator	±15	
Spacecraft-aircraft velocity	±3170	It can be estimated
Aircraft oscillator	±685	Not to be considered
Uncertainty in aircraft & spacecraft position / velocity	±60	

Doppler effect on VHF link- Analysis Spacecraft -> Aircraft
Doppler effect



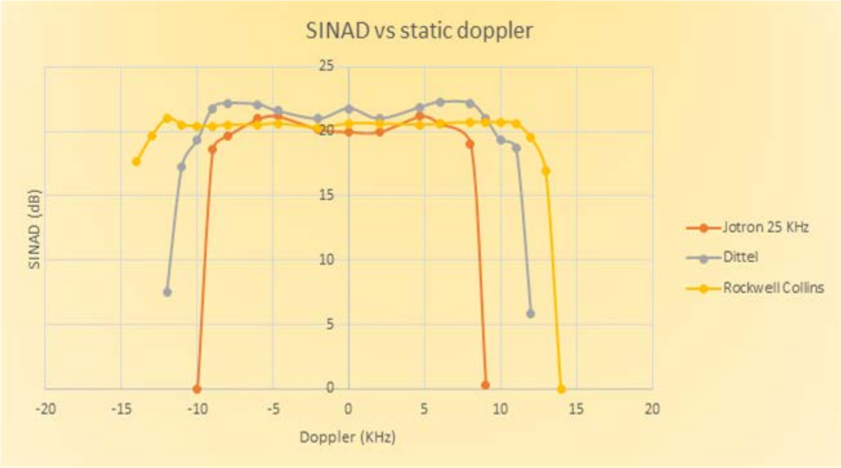


Doppler shift and Doppler rate experienced by an aircraft as function of time in a spacecraft overflight when flying from North to South



Doppler shift experienced by an aircraft in the footprint

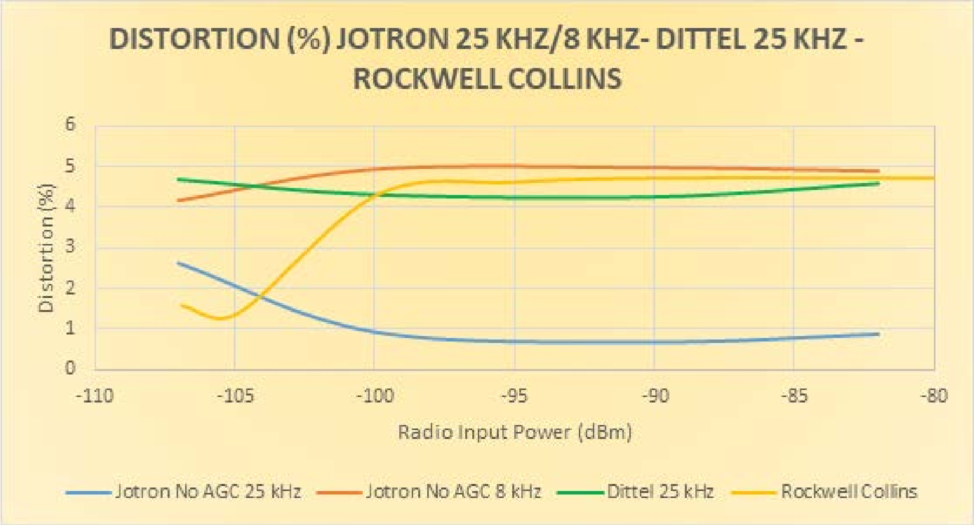
Doppler effect on VHF link- Impact of satellite channel Doppler on VHF links. VHF Voice Tests: Static Doppler



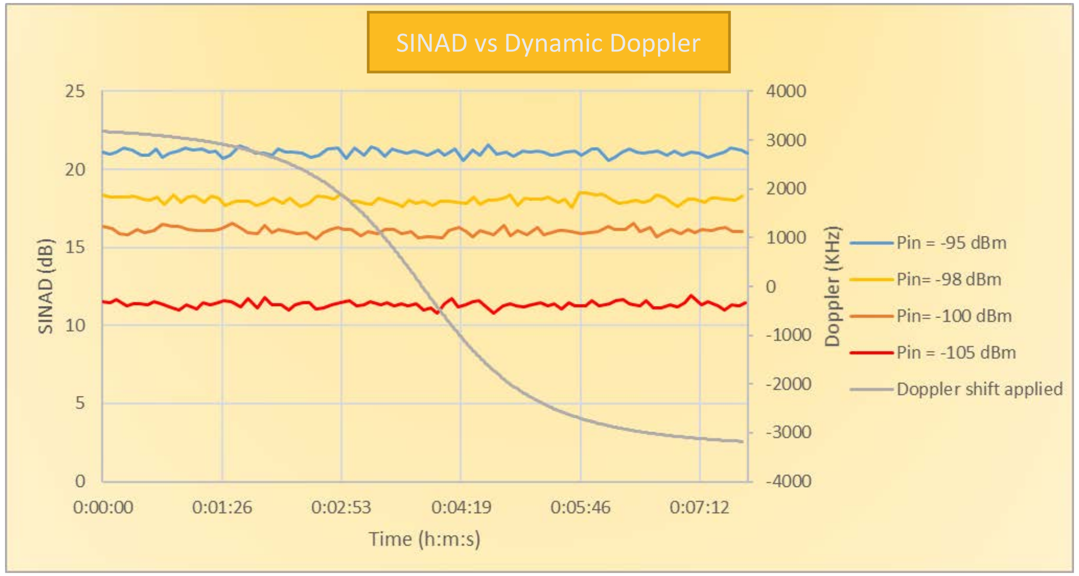
SINAD vs Doppler for fix radio input power

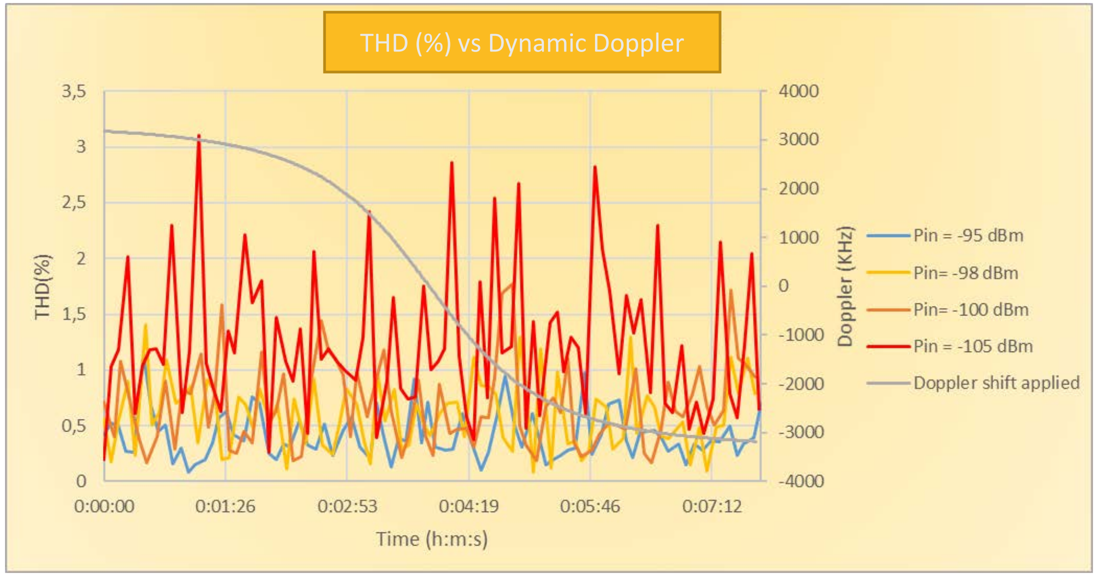
- In the radio tested, **25 KHz channels support Doppler shifts higher than the maximum Doppler shift expected** due to satellite movement (3.2 kHz).
- The behavior of the **audio demodulated when Doppler is applied is within the limits specified** in ICAO SARPS (SINAD >10 dB and THD<5%).

Maximum Doppler shift for a SINAD> 10 dB and THD<5%



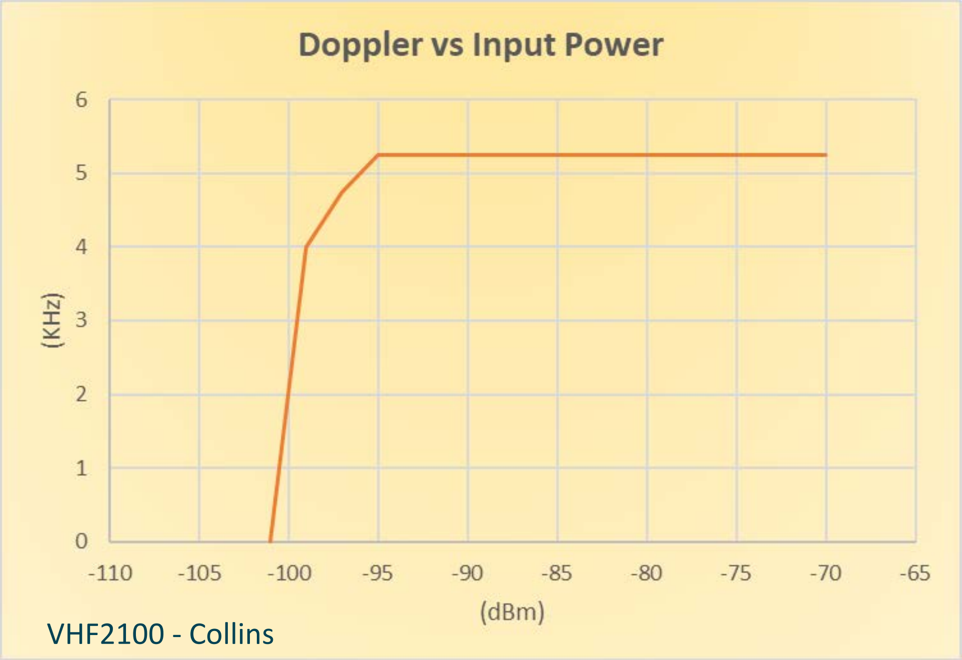
Doppler effect on VHF link- Impact of satellite channel Doppler on VHF radio. VHF Voice Tests: Dynamic Doppler





- Radio behaviour is not affected by dynamic Doppler shift.
- The performance of the audio demodulate when Doppler is applied is above the values specified in ICAO SARPS (SINAD >10 dB and THD<5%)

Doppler effect on VHF link - Impact of satellite channel Doppler on VHF radio. Data Link Tests: Doppler



- Airborne Radio tested **(Collins VHF2100) supports Doppler shifts** due to satellite movement (3.2 kHz) that produces a **maximum frequency offset higher** than specified (ED-92C: 967 Hz).
- The Airborne radio behavior is the same when introducing dynamic Doppler effect (one satellite overflight)
- This Airborne radio is one of the most commonly installed on board aircraft

Contents

Spectrum compatibility

- **Objective:** Study the compatibility between the space-based VHF system and systems operating inside the band 117.975-137MHz, below the band <117.975MHz and above the band >137MHz. The considered channels will be both, 25 kHz channels with AM Voice Signal and D8PSK Data Signal. The interference levels at different bands will be studied at aircraft and ground levels transmitting VHF carriers and measuring in band and out of band interference levels. Power Flux Density (PFD) and absolute value (dBW) on ground will be the key parameters involved.

- **Studies / Analysis:**
  - Analysis of ITU-R regulations affecting the harmful interference protection and determine the required level of protection to be implemented if required.
  - Analyze interference over adjacent channels coming from spectrum shift due to satellite Doppler.

- **Tests / Measurement:**
  - Test in the lab transmitter spectrum mask behavior using a real VHF amplifier.

Spectrum compatibility – Below 117.975MHz

Compatibility of Unwanted AMS(R)S Out-Of-Band and spurious emissions below 117.975 MHz to be ensured by ICAO Frequency management

ITU-R Draft Report for AI 1.7, paragraph 7.3: "… ICAO has outlined that there is also no need to perform a comprehensive compatibility study within ITU-R between the AMS(R)S and aeronautical radionavigation services. The same frequency planning and coordination works on-going within ICAO will be performed to ensure compatibility between AMS(R)S and aeronautical radionavigation services."

Spectrum compatibility – In band 117.975MHz-137 MHz

According to the summary in ITU-R Draft Report for AI 1.7 of ITU-R WP5B November meeting:

- Section 9.1 for in the frequency band 117.975-136 MHz and Section 9.2 for in the frequency band 136-137 MHz :

“Protection of in-band systems operating under AM(R)S and AM(OR)S, and of adjacent band systems below 117.975 MHz under ARNS would be resolved through conventional frequency planning exercise, involving the relevant aeronautical authorities including ICAO, and assigning frequencies to the satellite system over interested regions in a manner that ensures compatibility between ground and satellite facilities.”

Spectrum compatibility above 137MHz

Based on the summary in Draft Report for AI 1.7 of ITU-R WP5B November meeting:

- Section 9.1 for operating of the space-based VHF system in the frequency band 117.975-136 MHz:

"Protection of adjacent-band systems operating above 137 MHz in the Mobile satellite service (space-to-Earth), Space operation service (space-to-Earth), Space research service (space-to-Earth), and Meteorological satellite service (space-to-Earth) would be ensured, thanks to the 1 MHz guard band in 136-137 MHz."

- Section 9.2 for operation of the space-based VHF system in the frequency band 136-137 MHz:

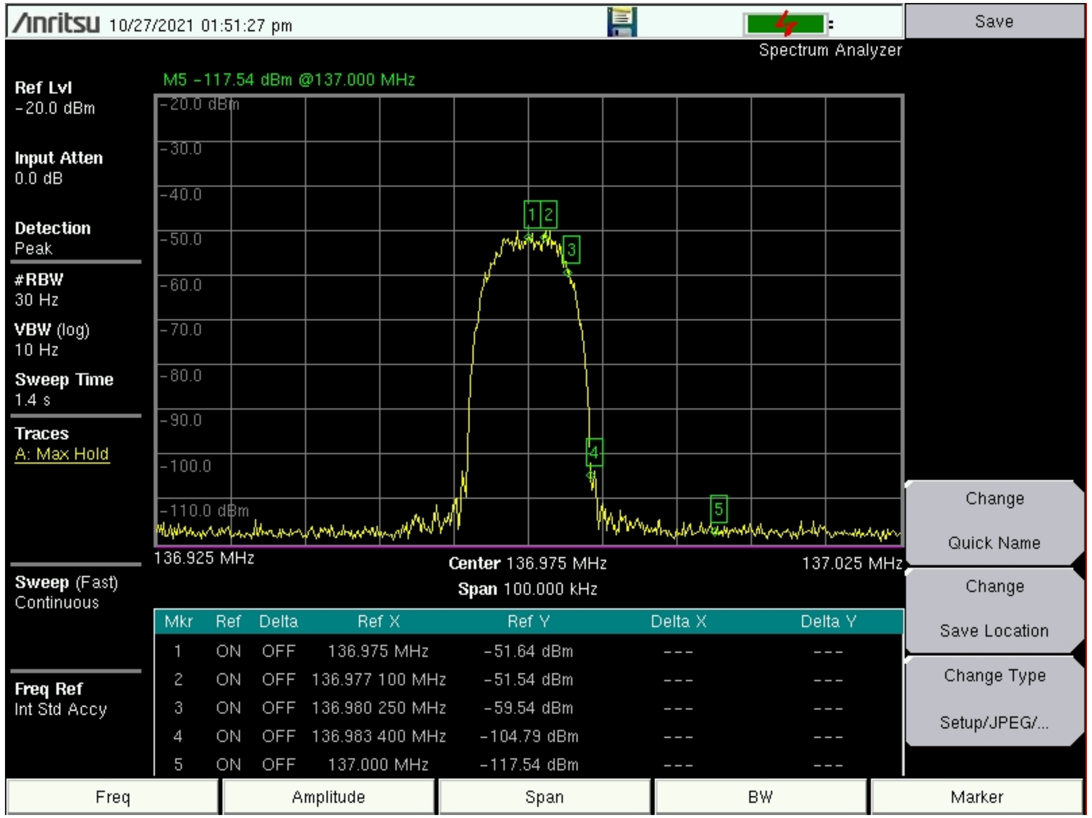
"Protection of adjacent-band systems operating above 137 MHz in the Mobile satellite service (space-to-Earth), Space operation service (space-to-Earth), Space research service (space-to-Earth), and Meteorological satellite service (space-to-Earth) would be ensured by a spectrum roll-off in order to achieve a maximum emission above 137 MHz not more than -156.3 dB(W/(m^2 · 14 kHz)) or the equivalent -197.7 dB(W/(m^2 · Hz))."

Spectrum compatibility above 137MHz

Actual VHF radio measurements on a VHF D8PSK frequency modulation 10,5Ksymbols/s

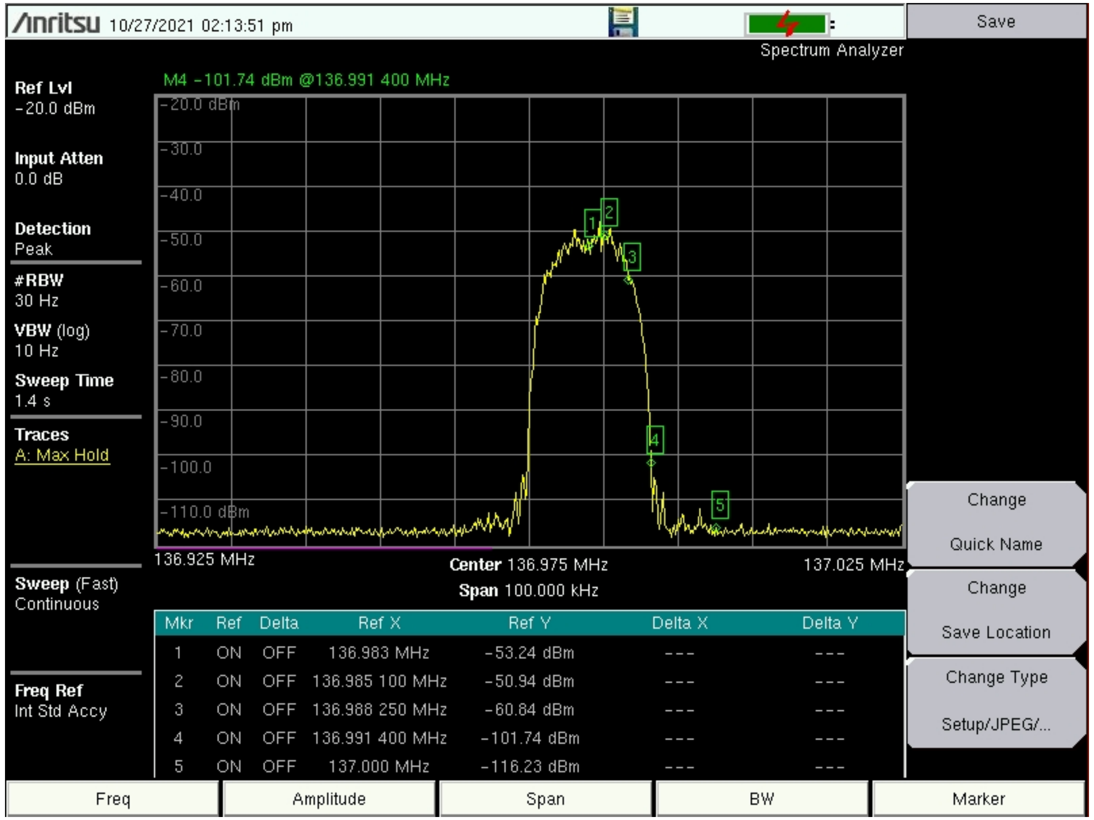
Without Doppler

- @136.975MHz
- Out of Band power < -60dBc spurious



With Worst case Doppler

- @136.975MHz+8KHz Doppler shift
- Out of Band power < -60dBc spurious



Out of Band (OoB) power at 137 MHz is attenuated higher than 60 dB from the In band AMS(R)S signal

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7. **Compatibility to use VDL-Mode 2 from Space**
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9. Questions and Answers

Compatibility to use VDL-Mode 2 from Space

- **Objective:** analysis of compatibility for the operation of space-based stations in the 136 – 137 MHz frequency band with ground stations.

- **Studies / Analysis:**
  - Analysis of the compatibility of the use of the VHF datalink from satellite system.
  - Identification of any technical and operational constraint and their impact on the satellite services.

- **Tests / Measurement:**
  - SESAR VOICE Very Large Demonstration activity: an operational infrastructure will be deployed in the Gran Canary Island between the ENAIRE ATC system, the SITA network and initial assets (Ground Segment and first satellite).
  - VOICE project aims to demonstrate that, with the use of Satellite based VHF systems providing Voice and Datalink ATS, traffic in remote and oceanic airspace can be handled as in a continental, and current aircraft separation could be reduced without compromising safety.

Compatibility to use VDL-Mode 2 from Space

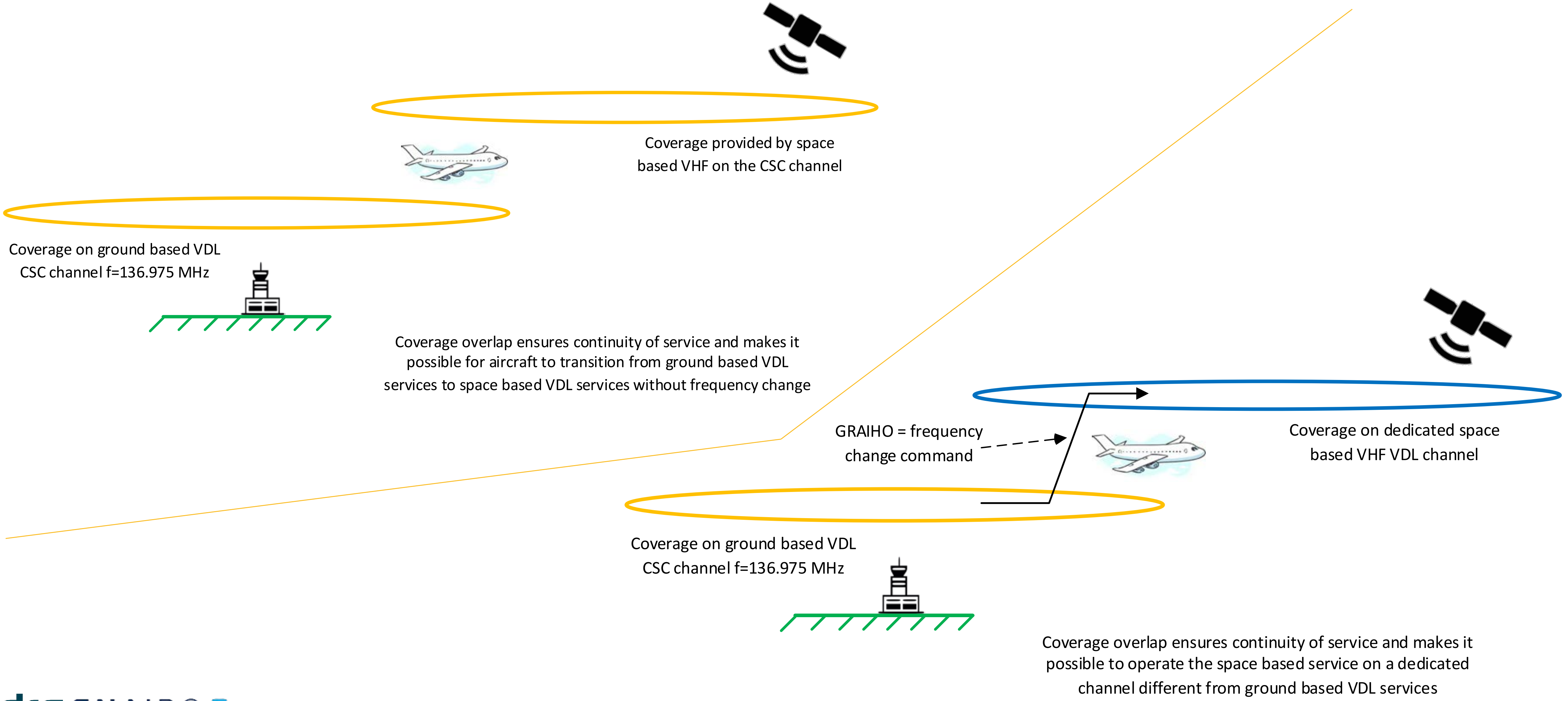
Operation of space-based VDLm2 system

- The satellite system is similar to the ground station in term of behaviour :
    - CSMA protocol
    - D8PSK modulation
    - CVME to assign to the radio a dedicated channel as specified by ICAO
    - The ground stations and the space-based VHF system will be visible each other. As a result, this will avoid the issue of the hidden transmitters in the event that they use the same channel (CSC)

- To assess the impact of unwanted emissions of the space-based VHF system onto the ground-based radio operating in the adjacent channel

- Satellite coverage over oceanic and remote areas:
    - Satellite is complementary component to the ground-based VDL network
    - Channel to be assigned by ICAO
    - Other specific channels to be considered depending on the traffic
    - Minimum overlaps with ground stations operating close to the coastline to ensure continuity of service
    - Seamlessly transition from a ground station to the satellite component
    - No impact on ground stations

Compatibility to use VDL-Mode 2 from Space



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Technical Summary

VHF Voice. Initial results show that:

- actual aircraft radios exhibit performances as specified in ICAO for the Sensitivity and SNR range of the satellite channel and also for several cases of scintillation.
- radios tested, working in a 25 KHz channel, can manage the Doppler effect added to the VHF link due to satellite movement. Pre-compensation can be applied if needed.

VHF Data. Initial results show that:

- actual aircraft radios behaves as expected in terms of Sensitivity for the expected satellite channel range. In addition, preliminary tests with scintillation show good behaviour for moderate cases.
- the radio tested (Collins VHF2100) shows very good performances when Doppler is applied, behaving better than the specified requirement in ICAO SARPS. A pre-compensation mechanism can be used if needed.

Spectrum. Initial results show that :

- outcomes of the compatibility studies demonstrate that the space-based VHF satellite does not create harmful interference to services operating above 137 MHz.
- Compatibility of Unwanted AMS(R)S Out-of-Band and spurious emission below 117.975 MHz and compatibility in the frequency band of 117.975 MHz-137MHz is ensured by ICAO Frequency management.

VDL-Mode 2

- Compatibility between AMS(R)S and AM(R)S is accomplished by frequency allocation for the operation of the space-based VHF system.
- The Space-based VHF system will be complementary component to the actual terrestrial networks, providing seamlessly transition from a ground station to the satellite component.
- To address sharing studies under ICAO umbrella, but not under ITU-R.

General Summary

- **WRC-19 approved the Resolution 428:** *“Studies on a possible new allocation to the aeronautical mobile-satellite (R) service within the frequency band 117.975-137 MHz in order to support aeronautical VHF communications in the Earth-to-space and space-to-Earth directions*”

- **Resolution 428 noting b):** *“that the development of compatibility criteria between new AMS(R)S systems proposed for operations in the frequency band 117.975-137 MHz and ICAO-standardized aeronautical systems in this frequency band* ***is the responsibility of ICAO*** *”*

- **Resolution 428 invites ITU-R:** *“to take into account the results of the studies to provide technical and regulatory recommendations relative to a possible new AMS(R)S allocation within the frequency band 117.975- 137 MHz, taking into consideration the responsibility of ICAO referred to in noting b)”*

- **Resolution 428 invites ICAO:** *“to participate in the studies by providing aeronautical operational requirements and relevant available technical characteristics to be taken into account in ITU Radiocommunication Sector (ITU-R) studies and to take into account the sharing and compatibility conclusions reached at ITU-R in the SARPs to be developed for the AMS(R)S,”*

Considering outcomes from works done concludes that the new allocation of AMS(R) are:

- Technically feasible.
- Operationally feasible.
- Compatible with services in adjacent band.

ICAO and their States members should promote and support the activities in ITU-R and ICAO in order to achieve the new allocation for all AMS(R)S in the whole VHF aeronautical band 117.975-137MHz, under ICAO responsibility, AI 1.7 at WRC-2023.

Contents

Question #1 - Regulation

➢ **Should we resolve all the technical and operational questions of a potential space-based AMS(R) service before achieving the allocation of that service at WRC-23?**

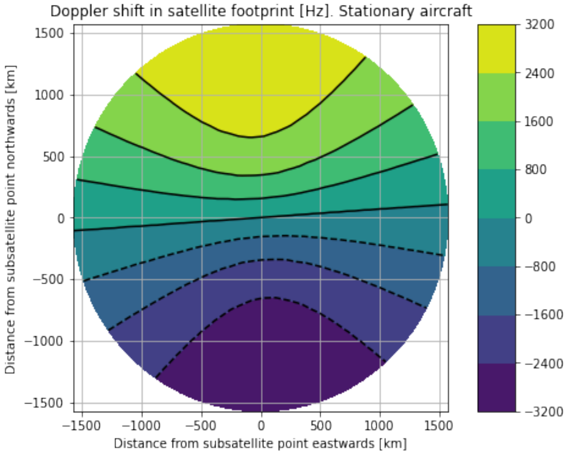
This is an important point as some of the apparent discrepancies are due to the understanding that ITU-R would be deciding on assignments for AMS(R)S, while ITU is just deciding on allocation. The ITU step is crucial and is required before any further assignment or operational conditions are decided by ICAO. The reasons:

- The allocation to AMS(R)S would be made by ITU at the light of the interference scenarios with respect to other services. It is assumed that the management of the assignments within the AMS(R)S band will be made by ICAO and will not be an ITU issue. Therefore, the interference assessment has to be made with respect to adjacent band services. This ITU decision will set the restrictions and conditions to use the AMS(R)S in order to protect adjacent band services.
- It is reasonable and convenient to develop a typical reference AMS(R)S scenario of using the band by AMS(R)S, to have it as reference of typical AMS(R)S parameters for the purpose of interference analysis. This is typical way of conducting interference studies by ITU: develop parameters typical for sharing studies; these parameters do not need being standardized, or being confirmed as the mandatory parameters.
- The final design or conditions to use the AMS(R)S band (and associated ICAO standards or ICAO operational procedures) will depend upon the final restrictions to use the band due to requirements to protect adjacent band services as decided by ITU-R.
- Consequently, the ITU work should be distinguished from ICAO work. ITU should take decisions on the way AMS(R)S would use the whole band 117.975 – 137 MHz. Whether ICAO will define standards in the short term for use of the sub-band 117.975-136 MHz and other standards for 136-137 MHz at later stage is purely a matter of strategy or internal needs from ICAO, but it is not a matter of ITU.
- The decisions at ITU level imply a high cost of studies and are adopted only every 4 years involving resources from all ITU Community. Therefore, ICAO should ensure firstly the AMS(R)S allocation in the whole band, as per already decided by WRC19, ensuring the whole band is studied by WRC 23. Then, once conditions to use the band (or different conditions for each sub-band, as appropriate) are decided by WRC23, ICAO can develop a strategy on standardization, operational aspects for the use of the allocation and adopt/recommend assignment procedures to civil aviation authorities.

Question #2a – Doppler compensation

➢ **Preliminary ITU studies have shown that it will be necessary to use LEO satellites which will result in a Doppler effect of +/-4kHz, which is incompatible with the Eurocae ED92C standards and therefore not consistent with considering (a) of Res 428 (…without modification to aircraft equipment).**

- A key driver of the design of the LEO satellite system is that it has to behave in such a way that not any modification will be required in the aircraft equipment. In this sense, and concerning the 4kHz Doppler, a Doppler pre-compensation mechanism is being defined to guarantee the compatibility of the satellite transmissions with the specified maximum frequency error. Basically, the transmissions from the satellite will be shifted in frequency in order to compensate the Doppler shift for the targeted aircraft (and a large area around it) in order to comply with the standards and messages can be received without modification to aircraft equipment.
- The Doppler introduced by the satellite varies from -3.2 kHz to 3.2 kHz in the satellite footprint and in the direction of the satellite movement, that is in latitude. On the other hand, the variation for the same latitude is much lower (see figure). It is then clear that aircrafts located in front or behind will be affected by a Doppler with a different sign, being necessary to apply a Doppler pre-compensation mechanism to guarantee that the aircraft receives correctly (for the case of VDL2).
- Several potential solutions are possible to do that, avoiding entering in technical details to save Intellectual Properties:
    - Using beam forming footprint radiation adapted to the Doppler effect observed by the aircraft. i.e, the satellite could radiate only in forward o rear direction with a pre-compensated shifted frequency, the satellite could radiate only perpendicular to the movement. Alternatively, a combined solution.
    - Omnidirectional radiation with multiple pre-compensated shift frequencies.
    - Above are for omnidirectional radiation, for point-to-point connection, the needed shifted frequency could be calculated using several solutions.



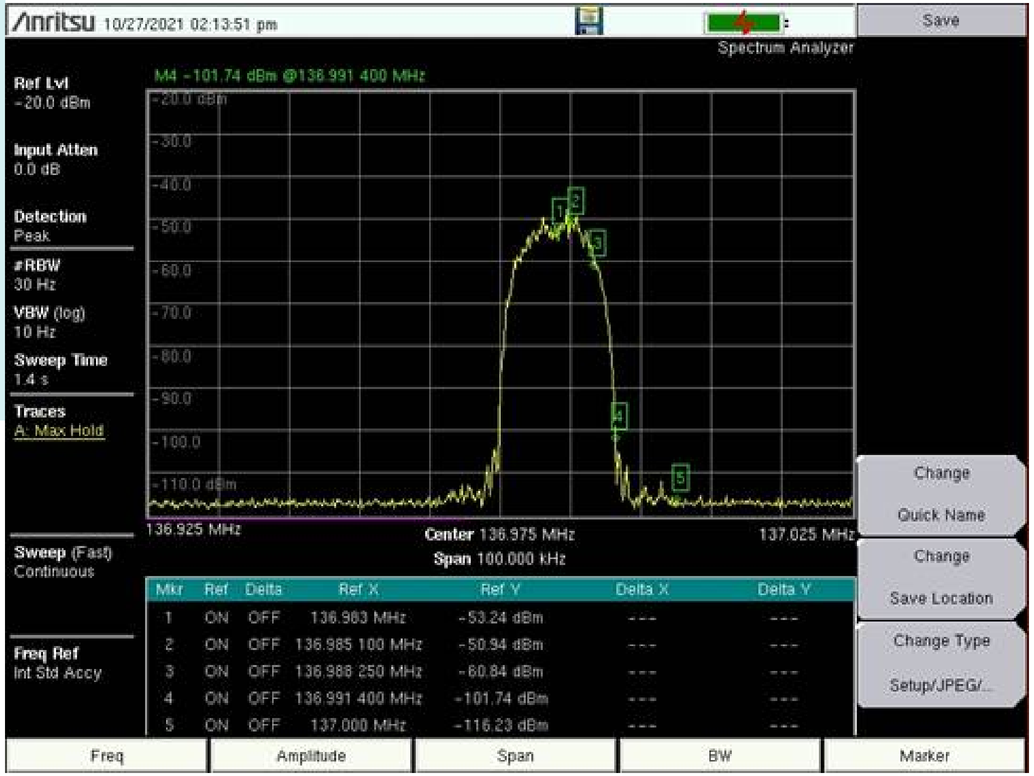
Question #2b – Doppler compensation

- **If you looked at the TSO for VHF comm there are different TSO classes for radios that support or do not support offset carrier.**
  - For Voice service could be not necessary to apply a pre-compensation based on the effective acceptance bandwidth specification of ICAO Annex X, Volume III section 2.3.2.3. From the specification, the effective bandwidth is higher than the maximum Doppler for both with offset carrier (8 kHz) and without offset carrier (6.8 kHz).
  - In addition, the VHF voice radios must support the operation in CLIMAX for continental area, implementing the offset carrier operation.
- **The voice and data issues with the compensation how this is resolved?**
  - For the voice service, based on ICAO Annex X, it is more tolerant to Doppler shift and could work without pre-compensation. For the data service, a pre-compensation mechanism will be implemented.
- **If the satellite shifts its transmit frequency to compensate for Doppler shift for aircraft in front of the satellite, won't that make it more problematic for aircraft behind the satellite to correctly receive the signal, since they would require a frequency shift in the opposite direction?**
  - refer to question #2a.
- **CSMA behavior when applying Doppler pre-compensation: if a pre-compensation is applied addressed to one specific aircraft, would other aircrafts with different Doppler be able to detect the channel busy even in case of not being able to decode the packet?**
  - The Doppler pre-compensation is valid for an area around the specific aircraft. Aircraft for which the pre-compensation is not valid are far away. For those aircraft, even if their CSMA did not detect the channel as busy and decided to transmit, their transmissions are unlikely to affect the original transmission (because of the distance) and will be received normally by the satellite receiver.

Question #2c – Doppler Spectrum assessment

- **An aircraft needs to the last channel 136.975Mhz (CSC) to get into the VDL2 Network, a possible compensation of the Doppler effect on emission would make the emission of the VDL2 CSC channel (136.975MHz) closer to the edge of the band (137MHZ).**

- The satellite transmitter mask is designed to comply with the out of band emissions taking into account the Doppler shift. We presented the transmitted signal of a COTS equipment with a shift of two time the Doppler and there was not emission in the adjacent band. In the worst case it will be shifted 8 kHz (two times the Doppler shift). This moves the last channel to 136.983 MHz max, still more than 60 dBc of out of band attenuation. We presented plots of COTS equipment exhibiting this out of band level. See Figure 7 in the ITU-R PNDR for AI 1.7.
- Note that the Necessary Bandwidth for the VDL-2 signal (worst case) is assumed to be 14.0 KHz corresponding to a 14K0G1DE class type signal (DO-224 Signal-In-Space Minimum Aviation System Performance Standards (MASPS) For Advanced VHF Digital Data Communications Including Compatibility with Digital Voice Techniques section 3.2.1.2.4) and R-REC-SM.1138.



Question #3a – Testing Details

- **Which radios did you test for the Doppler shift as there are different radios.?**
  - Voice: Collins VHF 2100; Jotron TR-7750(ground radio), Dittel; Data: Collins VHF-2100, IDTS MTP-200; Jotron TR-7750(ground radio)
- **Need to hear from avionics manufacturers**
  - In contact with Honeywell, Collins and Thales, and also with the collaboration of SITA as part of the VOICE project.
- **What assumptions of the bands did you use for these tests, etc.**
  - The tests will use a frequency for voice and frequency for data inside the AM(R)S band (117.975 to 137 MHz). A frequency coordination analysis has been carried out to select VHF frequencies not currently used in the demonstration region.
- **Error rate over Doppler calculation are not available and similarly many calculation are missing, power, etc.**
  - It is understood that the question is asking for BER or FER measurements when Doppler is introduced. Such measurements are on going, as they take some time to be carried out due to its statistical nature. However, it has been monitored the link status while Doppler is present, both a fix one and a Doppler variation and the link is not lost with the VHF2100 radios. The test carried out have been for different receiver input power.

Question #4a – Operational Details

- **Is it required that all aircrafts receive the packets addressed to all aircrafts? This is obvious for broadcast packets but may not be needed for unicast ones.?**

  - This situation will happen when the aircrafts are flying in regions located very far from each other, To note that in terrestrial networks the situation is equivalent, aircrafts located in places that are far from each other will not listen among them due to terrestrial coverage limits.

- **What will be the coverage/signal strength over land for administrations that are not using the system in terrestrial airspace (i.e. if it only operates in neighboring oceanic areas)?**

  - The satellite system will be deployed guaranteeing its compatibility with terrestrial networks, not impacting the ones not using it even being under the satellite coverage. This will be achieved with proper frequency coordination as it is done for terrestrial networks.

- **What antenna characteristic is used for the space segment to ensure a stable uplink from the AC to space?. What coverage is given for the downlink if the “uplink characteristic” of the receive antenna is also used for transmit into the downlink?**

  - There are several solutions for the satellite antenna. To guarantee a stable solution the antenna just shall guarantee enough gain in all the defined coverage. It can be achieve using omnidirectional antennas, isoflux antennas, or more complex antennas like array or reconfigurable antennas. The purpose of this study is not to define the technological solution of the antenna but to evaluate the feasibility of establishing communication with the required parameters. The final solution will depend on each manufacturer and will be a solution that combines the satellite solution with the satellite constellation solution that guarantees continuity of coverage and service.

Question #4b – Operational Details

- **Given that the VHF analog voice use case assumes a “party line” for flight crew situational awareness in a particular airspace sector, and VDL Mode 2 utilizes Carrier Sense Media Access (CSMA) to minimize data packet collisions, any Doppler compensation by the satellite would have to ensure that all aircraft in the intended coverage area would still be able to correctly receive the satellite signal on the intended frequency.**
  - For CSMA / VDL2, refer to question #4a. For VHF voice, party line, no Doppler pre-compensation could be implemented, refer to question #2b.

- **How is ensured that a 24/7 operation is possible for any sector by just selecting one frequency mapped to this sector?**
  - Satellite coverage will be overlapped up to a certain area, so a collateral sat could service just in case. Moreover, there will be a number of backup satellites. Space-Earth links will be at least duplicated.
  - By the frequency management point of view, there will be several different channels to be assigned to collateral sectors. Then at a certain distance, channels will be reused

- **How is it managed to monitor also the guard channel 121,5Mhz within the sector?**
  - the satellite payload receiver will have the capability to listen to several voice channels simultaneously.

Question #4c – Operational Details

➢ Can the current avionics work without modification?

- This is a key design driver for the satellite system, it will be designed and implemented to guarantee that no any modification is needed in the avionics. As examples:
  - The satellite EIRP will guarantee the minimum power flux density at the aircraft VHF antenna input for both voice and data services.
  - As answered in question #2, Doppler effect will be pre-compensated

➢ How is it managed to operate also at least on backup frequency within the sector?

- Each satellite will handle several frequencies.

Question #5a – VDL Compatibility

➢ Compatibility between terrestrial VDL and satellite VDL

- Complete compatibility at the air-ground protocol layer. Exactly the same protocol stack is used..
- On the co-channel operation, it should be seen the space-based VHF system as a complementary component to the ground-based VDL station. It means that in area where it is impossible to deploy a ground-based VDL station, hence no coverage from the ground, the space-based VHF station will take the hand-over. As both system are similar (same modulation, same CSMA protocol), both system will co-exist as it is already the case for the ground-based VDL stations which use the same channel. It should be noted that the impact is greater if considering only the ground component as there is the issue of the hidden transmitter. In the case between the space-based VDL system and the ground-based VDL station, this issue does not exist as both are in line-of-sight.
- It is important to ensure that the unwanted emissions of the space-based VHF system (in the out-of-band and spurious domain) do not affect the operation of the ground-based VDL station in the adjacent channel. The initial analysis made based on the typical out-of-band mask and on the typical spurious values shows that the operation of the space-based VHF would not affect the operation of the ground-based VDL station operating in the adjacent channel (50 kHz, 100 kHz frequency separation). See attachment for details.

➢ Ensuring that CSMA will work fine and that we will avoid specific issues that we find for terrestrial VDL, like, for instance the “hidden transmitter” issue.

- The satellite-based VDL station covers a very wide area, hence by design there are no hidden transmitters. The reason being that the satellite will be in light-of-sight with ground-based VDL station. In the event, the ground-based VDL station transmits, the space-based VHF station would not transmit unless the signal received is below the detection threshold.

Question #5b – VDL Compatibility

- **A few scenarios to consider for space-based VDL OPS, notably the switchover mechanism between space-based VDL and ground-based VDL:**
- **1. Aircraft from Europe to USA are on different channels.**
- **2. Aircraft up to within 250nm from a terrestrial VDL system**
- **3. If VDL are different service providers**
- **4. GRAIHO**

1. Aircraft flying between Europe and USA operate on exactly the same VDL CSC channel but with large gaps in coverage. Satellite-based VDL can fill the gaps in coverage. The underlying principle of the space-based VDL is that it appears to the aircraft as "just another VDL station" hence all the same, existing handoff mechanisms apply.

   In case of oceanic coverage, it should be mentioned that as this area is considered as international, an alternate frequency can be different to the one used in the USA and Europe.
2. For coverage near the coasts of continents the space-based VDL station allows the VDL service to be extended out to the oceanic region in a seamless fashion. The space-based VDL service can be provided on the same frequency as the terrestrial-based VDL stations or it can be provided on an alternate frequency to which the aircraft would be commanded to switch by the CVME, as it is done currently in the scope of VDL multi-frequency management.
3. Terrestrial-based and space-based VDL services can be provided using the same DSP ID or a different DSP ID. The "same DSP ID" approach is preferred because it does not require any changes in avionics configuration (no software modifications would ever be needed in the avionics)
4. Space-based VDL stations will be managed by the CVME just as the existing terrestrial-based VDL stations are already managed. The space-based VDL stations will be simply added to the inventory of VDL stations managed by the CVME with their own, appropriate coverage maps.

Question #5c – VDL Compatibility

➢ **Handover from the terrestrial VDL network to the satellite VDL network through the CVME (Central VHF Management Entity) and vice versa. How this will happen seamlessly for the aircrafts?.**

- The aircraft only receives and processes VDL frames and it cannot tell the difference between VDL frames originating from a ground-based VDL station and a satellite-based VDL station. Handoff between a ground-based VDL station and a satellite-based VDL station is identical to a handoff between two ground-based VDL stations. In the CVME, the space-based VDL station is simply just another station that it is managing, albeit with a much larger coverage map.

➢ **In a multi service providers how the transferring of frequencies will work between those entering oceanic and coming into terrestrial between service providers, and what are the conditions under that is initiated.**

- If the space-based VDL service was required to operate with its own DSP ID that is different from the existing DSP IDs then the transfer from satellite-based to terrestrial based would happen exactly the same way as transfers which occur currently when an aircraft that is configured to be allowed to access the VDL service of different service providers, for example ARINC and SITA, loses datalink service when it flies outside the coverage area of one service provider but then detects the availability of VDL service from the other service provider. This mechanism is already actively being used on the current aircraft fleet.

➢ **Even if the aircraft does not detect the busy channel state, could it cause a significate increase of collisions?**

- If they occur, transmissions from the aircraft performed while the channel is being used by another transmitter are likely to increase the level of collision. It is important however to mitigate this by the fact that, as highlighted in previous answers, the broadcast nature of the satellite signal transmission and the low blockage of the Line of Sight of the satellite signal for aircrafts in flight lowers the probability of such events where an aircraft is transmitting while the channel is busy. The increase in collisions, if any, will thus likely not be significant.
- An aircraft (a2) may not detect packets with a Doppler pre-compensation addressed to another aircraft (a1), not detecting a busy channel state. In this situation this aircraft (a2) may transmit, but it will not affect the aircraft (a1) caption from the satellite as they will be far from each other. On the other hand, aircraft (a2) could transmit to the satellite as it sees the channel free, but it would be received by the satellite always listening.

Question #5d – VDL Compatibility

- **Is it required that all aircrafts receive the packets addressed to all aircrafts? This is obvious for broadcast packets but may not be needed for unicast ones.?**
  - It is not necessary that all unicast transmissions be received by all aircrafts in the coverage area for the system to function. However, the reception of the signal by a subset of the aircrafts could lead the transmitters of the aircrafts not receiving the transmission to believe the channel is not busy and initiating a transmission themselves, which could result in collisions lowering the overall offered capacity of the VHF service volume. It is thus desirable that all aircrafts are able to sense the presence of energy on the channel for CSMA purposes.
- **What protocol will SATCOM VDLM2 use (FANS/ATN?). If ATN, how will the network avoid aircraft attempting to connect on their own initiative?**
  - The Space Based VHF is agnostic to the protocols running on top of the AVLC layer. Space Base VHF will use the same AVLC protocol as Ground Based VDLm2, the protocols that will be used on top of this are transparent (just as they are for Ground VDL). GSIF will indicate the available services (AOA and/or ATN) over Space Based VDL.
- **How will assignments to SATCOM stations be coordinated with terrestrial channel plans?**
  - Coordination of the channel assignments for Space Based VHF (either dedicated or shared) are expected to be performed through the existing mechanisms for frequency management for VHF spectrum.
- **What requirements will be placed on planning criteria for new or modified terrestrial assignments?**
  - Current proposal is to handle satellite frequency assignments like any other, thus a study will be made for each channel-region assignment considering adjacent frequencies.

Question #5e – VDL Compatibility

- **What is the function that moves an aircraft from a terrestrial to a SATCOM network (and vice versa) when each network is a different CSP? Both on entering and exiting oceanic regions.**
- **1. What are the technical and operational conditions that would initiate such a move?**
- **2. What agreements will operators need to have in place, if any?**

- If the space-based VDL service was required to operate with its own DSP ID that is different from the existing DSP IDs then the transfer from satellite-based to terrestrial based would happen exactly the same way as transfers which occur currently when an aircraft that is configured to be allowed to access the VDL service of different service providers, for example ARINC and SITA, loses datalink service when it flies outside the coverage area of one service provider but then detects the availability of VDL service from the other service provider. This mechanism is already actively being used on the current aircraft fleet

- **If the SATCOM and GS appear to be same CSP to the aircraft, does this introduce a risk with the current VDLM2 connection orientated protocol letting an aircraft potentially jump between sub-optimal stations as seen on terrestrial networks?**

- The risk already exists in existing networks either given to specific user terminals behavior or in areas where two or more stations (either two GS or one GS and the Space Station) appear to have similar signal quality from an aircraft terminal point of view. Geographical areas in which this can happen are limited. The addition of Space Based VHF, given the high coverage areas that the satellite radio will have, is likely not to increase this situation. The areas in which special attention should be taken are the boundaries of the satellite transmitters and the terrestrial transmitters coverage respectively.

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