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INTERMODULATION AND AERONAUTICAL SAFETY[1]

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(Document submitted by TES America)

[1] *Document not translated by the secretariat of CITEL.*

Impact on the sector:

The phenomenon of intermodulation represents a latent risk for aeronautical communications, especially during critical phases of flight such as approach, landing, and takeoff. The overlap of **FM broadcasting** signals in aeronautical receivers can produce spurious signals, known as intermodulation products, in critical COM, ILS[2], and VOR[3] bands (108–137 MHz). This risk increases in airports located near urban areas with a high density of FM transmitters, whether authorized or unauthorized.

In recent months, incidents have been reported in the region and publicized by various media due to their impact, underscoring the relevance of the problem. In July 2025, Colombia's Civil Aviation Authority announced the partial suspension of operations at Rafael Núñez International Airport in Cartagena, restricting landings due to external interference from **FM broadcasting stations**. Similarly, in August 2025, five illegal FM broadcasting stations were dismantled in Medellín after confirming their impact on air-to-ground communications at Olaya Herrera Airport, temporarily affecting control operations. These precedents add to reports from the United States Federal Aviation Administration (FAA) and the International Civil Aviation Organization (ICAO), which have documented similar risks.

Although ground-based navigation systems such as ILS and VOR have been regulated since the 1980s under international standards protecting against **FM broadcasting** interference, communication receivers installed in aircraft and control towers remain more vulnerable. During approach, landing, and takeoff maneuvers, aircraft are simultaneously exposed to dozens of transmitters in line of sight; the sum of these signals can overload the receiver and generate intermodulation phenomena; spurious signals appearing within frequencies used for communications and navigation, affecting their quality and reliability.

[2] **ILS**: *Instrument Landing System* It is a navigation aid system that provides aircraft with lateral guidance (localizer) and vertical guidance (glide slope) to perform precision approaches under low-visibility conditions.

[3] **VOR**: *VHF Omnidirectional Range***.** It is a radio navigation aid that transmits a signal in Very High Frequency (VHF), allowing pilots to determine their heading and position relative to the ground station and to follow established air routes

Intermodulation is a random and changing phenomenon, which means it does not always occur in the same way or at the same frequency. For this reason, it is essential to identify which aeronautical frequencies are most likely to be affected. This depends on factors such as the location of the airport, the technical characteristics of authorized FM transmitters in the area, and the presence of unauthorized emissions detected through spectrum monitoring. This contribution explains the technical background of the problem and introduces a technological solution aimed at reducing the risks that intermodulation poses to the safety of aeronautical communications.

Executive Summary:

When interference is reported at airports, spectrum management administrations (SMA) are often forced to act immediately, given the criticality of the aeronautical service. However, it is not always possible to clearly identify the cause. In many cases, efforts focus on reviewing the technical parameters of authorized FM stations and detecting unauthorized emissions. While the latter may exacerbate the situation, they are not the main cause of what pilots or control towers experience. In extreme cases, SMA staff have even had to be taken onboard aircraft to directly witness interference occurring during approach or takeoff phases—interference not reproduced by ground-based measurements.

These cases, besides being demanding, highlight a particular technical condition: ground monitoring equipment typically has higher linearity than aeronautical receivers. Consequently, they do not record the same intermodulation effects that manifest in cockpits or control towers, nor do they replicate the real conditions experienced by aircraft during approach and takeoff.

A more detailed technical analysis establishes the following premises:

- **Intermodulation is inevitable.** It is inherent to receivers due to the RF environment of each airport, a result of receiver non-linearity.
- **The RF environment is defined by FM transmitters.** Propagation simulations can determine intermodulation products that may appear at different heights along the approach, takeoff, or tower locations.
- **The problem arises in the receiver.** Nonlinear response occurs when total received energy exceeds a critical level defined by the third-order intercept point (IP3)[4]. Minimizing this effect would require replacing aircraft receivers or reorganizing authorized frequency and power assignments—practically unfeasible.
- **Conditions change with altitude.** During approach, landing, or takeoff, aircraft receive varying levels of electric field intensity from FM stations. At higher altitudes, line of sight expands, altering both the number and levels of transmitters received, and thus the intermodulation matrix.
- **Unauthorized emissions complicate the scenario.** Their unexpected appearance introduces additional carriers that dynamically modify the intermodulation matrix, requiring continuous monitoring.
- **Ground measurements are limited.** Spectrum analyzers have greater linearity than aeronautical receivers, making it difficult to reproduce intermodulation in controlled conditions. While inspections can detect and sanction unauthorized or out-of-parameter transmissions, these are not the main cause of the phenomenon.

From this, it follows that the most viable strategy to mitigate these interferences is to dynamically identify the intermodulation products generated during approach, landing, and takeoff phases, and

[4] **IP3 (Third-Order Intercept Point):** It is a key parameter that indicates the level at which a receiver or amplifier generates intermodulation products due to nonlinearity. A higher IP3 value means better linearity and greater resistance to interference.

recommend the use of communication channels with the lowest probability of impact, based on the existing RF environment.

This contribution proposes a solution with a methodological approach based on the above premises:

- **3D Predictive Simulation:** Three-dimensional modeling considering flight altitude, aircraft trajectory, and electric field intensity levels (obtained through propagation simulation) for each FM transmitter registered in the database.
- **Continuous Monitoring:** Real-time detection of authorized and unauthorized transmissions in the FM band (88–108 MHz), dynamically updating the matrix of possible intermodulation products, and generating alerts and automatic reports associated with risk scenarios.
- **Integrated Approach:** Combining simulation and monitoring enables more accurate characterization of intermodulation probability, identification of the least affected channels, and support for decision-making by aeronautical and spectrum authorities.

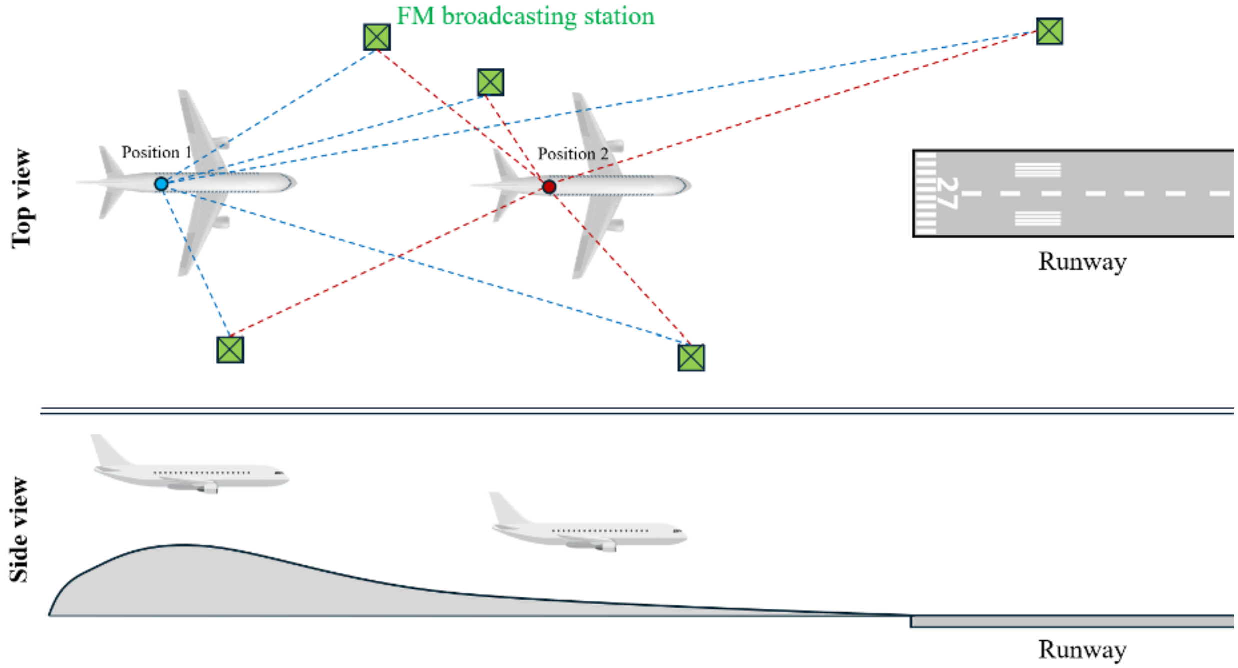

Figure 1: The simulation must consider each point of the aircraft's trajectory.

The purpose of this approach is to strengthen operational air safety by identifying and prioritizing frequencies less susceptible to intermodulation. While this phenomenon cannot be eliminated, it can be significantly minimized by anticipating the most critical scenarios and recommending safer channel usage. The continuous monitoring component also ensures detection of unauthorized signals that modify the intermodulation matrix, keeping the analysis permanently updated and supporting corrective actions.

Description of the Proposed Solution

The proposed solution combines real-time radio propagation simulation with continuous monitoring, aimed at anticipating and mitigating intermodulation effects on aeronautical services. This approach integrates predictive analysis techniques and real-time processing to identify risk scenarios and propose safer operational alternatives more precisely.

The technical architecture relies on cloud computing, providing scalability and processing capacity for large volumes of spectral data, and on edge computing, enabling distributed analysis of FM band monitoring, reducing latency, and improving response times. This combination allows calculations to be performed within seconds, even in complex scenarios involving multiple flight paths, three-dimensional altitude maps, and FM service electric field intensity levels.
The solution includes a **web platform** accessible from any browser or mobile device. Its graphical interfaces are designed so both spectrum specialists and aviation operators can interpret results, identify safer frequencies, and activate frequency-change plans when necessary. The system also enables the generation of customized reports and alerts.

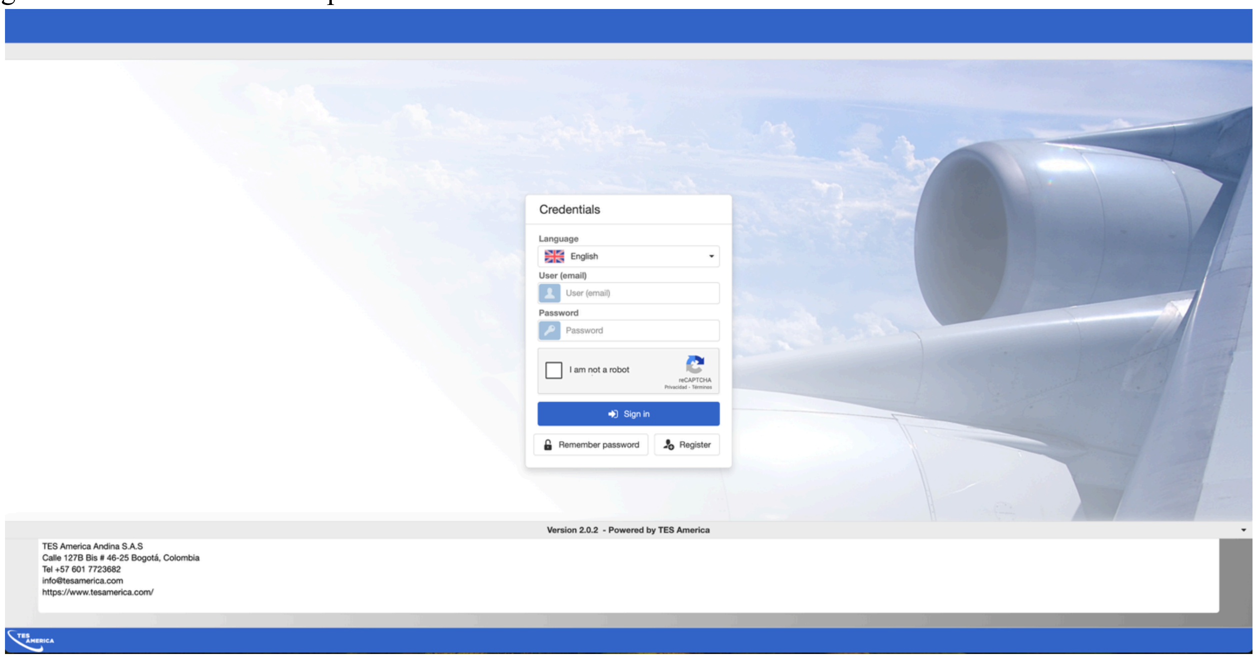

Figure 2: Platform login screen

1. Predictive Simulation

- Incorporates 3D maps and considers flight altitude and trajectory, modeling aircraft line of sight against FM transmitters.
- Integrates actual FM band (88–108 MHz) signal levels, including authorized stations and detection of unauthorized transmissions.
- Considers the technical parameters of aeronautical receivers to calculate the most probable intermodulation products.
- Identifies vulnerable frequencies and simulates alternative scenarios.

2. Continuous Monitoring and Data Fusion

- Operates with heterogeneous sensors deployed in airport and urban environments.
- Measures the FM band in real time, detecting both authorized and unauthorized or non-compliant transmissions.
- Generates automatic alerts and reports correlated with risk scenarios identified through simulation.
- Uses big data and spatial intelligence techniques to correlate spectral behavior with geographic and temporal variables.

3. Integrated Approach

- By combining simulation and monitoring, the approach shifts from reactive detection to predictive and preventive analysis.
- Facilitates aeronautical frequency planning, supporting civil aviation and spectrum authorities in decision-making.

- Anticipates critical scenarios, reducing the probability of intermodulation interference and improving operational safety.

In summary, the purpose of this contribution is to present solution alternatives aimed at strengthening operational aeronautical service safety by identifying and prioritizing less vulnerable frequencies, recognizing that while intermodulation phenomena cannot be eliminated, their effects can be significantly minimized. At the same time, continuous monitoring complements the approach by detecting unauthorized signals that alter the intermodulation matrix.