Challenges for UAV Operations in RF Dense Aerodrome Environments

Semahat Korkmazer
Product Manager
Rohde & Schwarz GmbH & Co. KG
Meckenheim, Germany
E-mail: semahat.korkmazer@rohde-schwarz.com

Anne Berntsen
System Engineer
Norwegian Special Mission
Gardermoen, Norway
E-mail: abe@nsm.aero mailto:your.name@domain.xxx

ABSTRACT

Reliable and predictable communication links are essential for the safe operation of Unmanned Aerial Vehicles (UAVs). Wi-Fi based communication technologies are widely adopted due to their high data throughput, low implementation cost, and broad availability. However, Wi-Fi operates in unlicensed frequency bands and provides limited guarantees regarding interference resilience, latency, and determinism. These limitations present challenges in RF dense and safety critical environments such as airfields.

This paper examines the use of Wi-Fi communications for UAV operations in airfield environments. The analysis considers the RF interference landscape typically present at airports, including adverse signal conditions such as low carrier to noise ratios and narrowband interference, which can significantly challenge test receivers integrated with UAV platforms. The implications for communication link integrity, receiver performance, and potential failure modes are discussed, with emphasis on operational safety and measurement reliability.

Field measurements are used to characterize link performance under varying conditions. To eliminate receiver induced measurement bias, a validated Instrument Landing System (ILS) test receiver was employed in accordance with ICAO performance requirements, enabling comparison with traditional flight inspection results. The findings demonstrate that Wi-Fi based UAV communication links may experience degraded performance in airfield RF environments, including intermittent connectivity loss and variable latency, highlighting key limitations and supporting the evaluation of alternative communication solutions.

INTRODUCTION

In scientific and engineering research, the standard protocol is to hold all independent variables constant while changing one factor at a time. This is crucial for safety-critical aerodrome studies, where any ambiguity threatens result integrity. By fixing ancillary variables, the effect of the target factor can be quantified precisely. The “one-factor-at-a-time” approach is the foundation of sound experimental design and essential for trustworthy, reproducible conclusions. Accordingly, a calibrated, high-reliability test receiver was used throughout the measurement campaigns in this study.

I. CHOICE OF TEST RECEIVER

A detailed characterization of the measurement environment is presented first, after which the receiver’s architecture is described at a high level. This contextual analysis establishes the foundation for the discussion that follows.

RF-Dense Aerodome Environment

Modern aerodromes concentrate many RF services (primary/secondary radars, ILS localizers and glide-slopes, VOR, DME, and ATC voice/data links) within a narrow spectrum. Because these allocations are adjacent (e.g., ILS localizer 108.10–111.95 MHz borders VOR 108–117.95 MHz, and DME 960–1215 MHz meets the SSR uplink at 1030 MHz), even small spurious emissions, harmonics, or intermodulation can impair multiple systems. Thus, ILS, VOR, DME, and ATC communications dominate the interference picture at airports, requiring inspection-grade test receivers with high interference rejection, superior sensitivity, and wide dynamic range.

Concept for a commercial test-receiver

Given the stringent environmental conditions associated with ground-based, airborne and UAS (drone) inspections, each receiver's enclosure is engineered as a bespoke solution while retaining a common RF-board architecture. This approach guarantees precise and reproducible analyses on ILS and VOR ground systems without compromising test integrity required to establish the correlation between ground- and flight-inspection regimes. [1] [2]

A core tenet of our development philosophy is designing the RF-receiver board, enclosure and ancillary accessories in a modular architecture. By decoupling these parts, the housing can be engineered solely to satisfy the environmental constraints of the target application while the RF frontend remains unchanged across product families. Consequently, the R&S® EVSF1000, although fully capable of supporting drone-based inspection, features a bespoke aircraft-grade enclosure that addresses the mechanical, thermal and electromagnetic challenges of permanent installation on manned aircraft. It plugs directly into a 11 V-32 V DC bus and contains an internal power-conditioning module that bridges transient supply losses (up to 200 ms per RTCA DO-160G 16, Cat A) and smooths voltage ripples, preserving mission continuity and measurement fidelity. Housed in a 95 × 177 × 360 mm chassis and weighing only 3.7 kg, it easily fits inspection aircraft and lightweight drones. Its mechanical design meets RTCA DO-160G shock and random-vibration requirements, guaranteeing reliable operation in demanding aerospace environments. [5]

In contrast, the R&S® EVSD1000 is delivered with a lightweight, vibration-tolerant housing and a set of accessories expressly optimized for the dynamic environment encountered by receivers mounted on unmanned aerial systems (UAS). It uses the same RF front-end and firmware as the EVSF1000, ensuring flight data are directly comparable to traditional measurements. The analyzer can acquire up to 100 records s^{-1} for parameters such as modulation depth and DDM/SDM, stores data onboard, and streams real-time results to a ground station. Its rugged construction complies with EN 60068-2-30, EN 60529 (IP43), EN 60068-2-6 and MIL-STD-810G (40 g shock), making it ready for medium-size UAV deployments for ICAO standard ILS/VOR verification. [3]

This modular approach enabled rapid development of the mechanical housing without redesigning the RF electronics, thereby streamlining certification, reducing development cycles, and ensuring that each product variant meets its specific operational requirements.

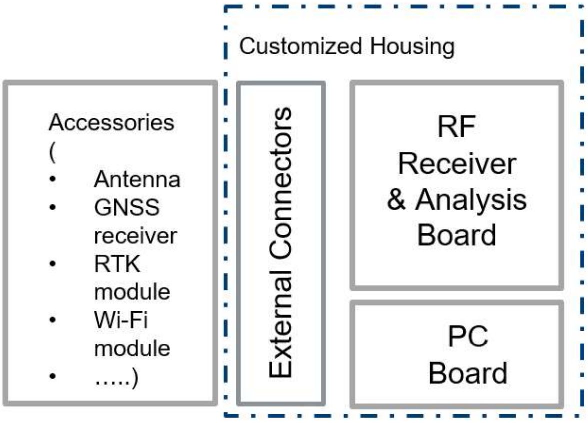

Figure 1. A commercial concept for ILS/VOR test receiver

Figure 2. Customized housing: R&S®EVSF1000 front- and back-view vs. R&S®EVSD1000 side view with connectors for the with display and connectors for the RF input and other accessories

RF board design: Advantages of Narrow -Band Preselection

The incorporation of a pre-selector in a super-heterodyne receiver constitutes a critical frontend function. By performing adjacent-channel rejection, cross-modulation suppression, and image-frequency attenuation before the mixer stage, the pre-selector delivers measurable improvements in selectivity, dynamic range and overload immunity. These benefits translate directly into higher receiver sensitivity, better coexistence in crowded spectral environments, and reduced design constraints on downstream circuitry, making pre-selection indispensable for high-performance UHF/VHF sensing systems.[7]

Furthermore, repeatability is reinforced by implementing a narrow pre-selection filter on the RF input level, ensuring that only signals within the specified amplitude range are processed. [3] [5] [7]

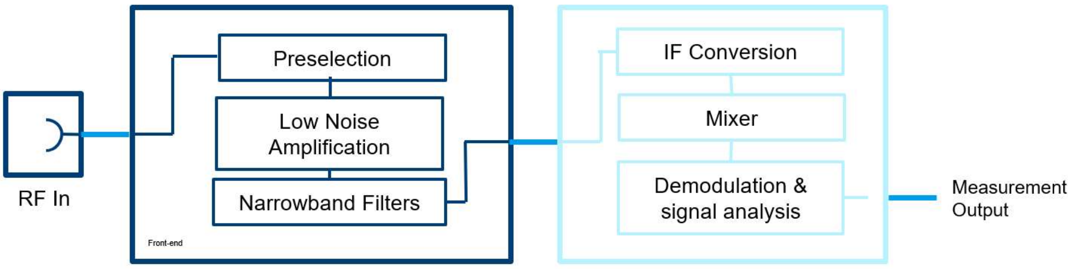

Figure 3. High-level common RF-Board architecture employing narrow-band preselection principles.

A fundamental principle in the development of an RF-receiver board intended for integration into bespoke enclosures is to maintain universally compatible interfaces, thereby enabling the PC board to handle auxiliary data, e.g., GNSS-derived time-stamps outside the RF front-end. Moreover, this approach gives users the flexibility to select the accessories that best suit their application, including the choice of data-link connection technologies.

II. FLIGHT CONFIGURATIONS & MEASUREMENT RESULTS

NSM has executed a series of flight evaluations employing multiple unmanned aerial system (UAS) platforms and heterogeneous communication architectures. This paper focuses on two test configurations. The first involves an experimental flight campaign using a rotary-wing UAS equipped with an EVSD1000 unit, operating over a Wi-Fi–based point-to-point link to the ground segment. The second configuration utilizes a fixed-wing UAS integrating an EVSF1000, interfaced through a dedicated long-range datalink for command, control, and telemetry transfer.

For the experimental test campaign for rotary-wing UAS, control of the drone and operation of the UNIFIS 1000 system were handled independently. DJI Matrice 300 that was selected for this campaign are using Wi-Fi with the Norwegian regulation for wi-fi signal strength. (Figure 5) During inspection flights, the UNIFIS 1000 received real-time RTK corrections from a local ground reference station (DGPS), enabling high-accuracy positioning. Utilizing a GNSS Ground Reference Station (GRS) provides a cost-effective alternative to subscription-based correction services such as CenterPoint RTX. However, when the GRS datalink is shared with the downlink used to transmit flight-inspection data from the drone, the operational area becomes constrained. In this configuration, the flight inspection must remain within a limited radius on ground of the GRS to maintain stable correction and data-transfer performance before taking into consideration other Interference that could occur.

Figure 4. DJI Matrice 300 with EVSD1000.

In the tested configuration with directional antenna on ground, the EVSD1000 optional Wi-Fi module operates as the Wi-Fi Access Point and DHCP server, issuing dynamic IP addresses across multiple subnets. This architecture has proven difficulties, with a high probability of link dropouts and challenges in re-establishing connectivity. A 90° change in the drone's heading frequently causes the system to lose the Wi-Fi connection, which in turn interrupts the RTK correction stream from the Ground Reference Station (GRS). Additionally, antennas positioned along the line of sight of the drone occasionally experience signal obstruction, leading to connection loss relative to the dedicated Wi-Fi antenna.

UNIFIS 1000 also experienced repeated disconnections from the Access Point whenever the EVSD1000 Wi-Fi antennas were oriented approximately 90° relative to the ground-station antenna. When flight paths and waypoints were programmed in the drone's mission-planning software, the aircraft initiated its flight by pointing the camera toward the initial waypoint. Upon reaching the designated start point, the drone executed a horizontal rotation to align with the operational azimuth—for example, pointing toward the Localizer (LLZ) facility during LLZ pattern inspections.

During this rotation, UNIFIS 1000 consistently experienced several-second datalink interruptions across most test patterns. A representative case occurred when departing from the base station located near the Glide Path (GP) antenna: as the drone approached the initial point of the approach-pattern track, it performed an almost 180° turn, during which a short but unavoidable loss of connectivity occurred.

Upon arrival at the first test site, an initial survey of the proposed base-station location near the Glide Path (GP) antenna was conducted. During this assessment, several concerns were identified related to flight-path planning, primarily due to the surrounding antenna structures and their potential impact on communication reliability. The first planned procedure was a VOR Orbit with a 1 NM radius.

Operational experience from this initial flight led to several adjustments for the remainder of the test campaign. Specifically, the VOR Orbit radius was reduced when operating over areas with high infrastructure density, direction of orbit based on use of GRS and antenna nearby that interfered with communication, to keep the test flights within the aerodrome boundary and maintain consistent datalink performance. Additionally, more detailed site surveys were incorporated to identify potential obstacles that could obstruct line-of-sight communication between the drone and the base station, thereby improving overall system stability in subsequent test runs.

Figure 5. First test site. Colored lines are flown paths of UAV.

The next test location featured an aerodrome environment where all radar and RF-emitting equipment were positioned on the opposite side of the intended UAV flight paths, minimizing potential interference. A preliminary inspection of the base station situated adjacent to the Glide Path (GP) antenna confirmed that the surrounding area was unobstructed, with only a small forested section located to the left of the runway.

A one-day UAV test campaign was conducted at this facility. During these operations, the UNIFIS 1000 system successfully executed Localizer (LLZ) crossover procedures at ±35° relative to the LLZ axis, a half-orbit VOR pattern, and multiple additional test trajectories. Throughout these flights, the datalink demonstrated significantly improved stability compared to the performance observed at the initial test site.

For the VOR Orbit procedure, the flight path was configured at a radius of 0.4 NM and an altitude of 200 ft above the facility. As shown in the figure above (light-blue track), a rapid preliminary survey confirmed that the surrounding terrain was largely unobstructed, consisting of open fields with no structures or vertical obstacles that could affect signal integrity or bias the measurement results.

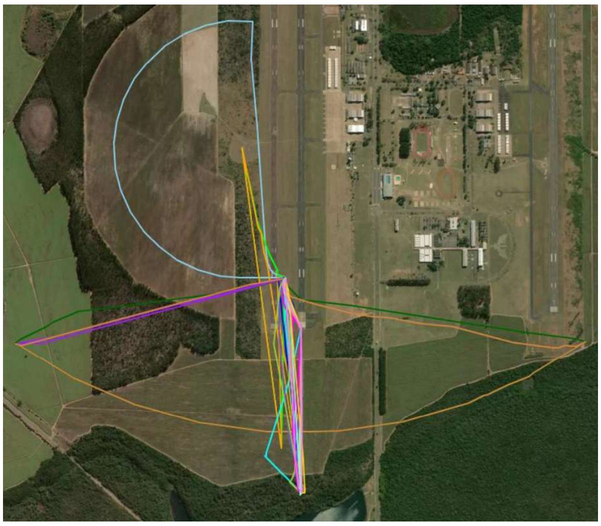

Figure 6. Second test site. Colored lines are path flown by UAV

Figure 7. VOR Orbit flight path.

During the test campaign, VOR Orbit patterns within a 0.5 NM radius were executed in accordance with established methodology from previous test sites. Differential GPS (DGPS) positioning was employed throughout the operation to ensure compliance with the required positional accuracy and to maintain precise trajectory tracking around the facility.

With comparison to traditional flight inspection aircraft, the results were very similar with some adjustments. General for all orbit and crossover patterns are that there will be a difference in signal strength between aircraft and drone. The drone will fly much closer to the facility than what the aircraft are capable of.

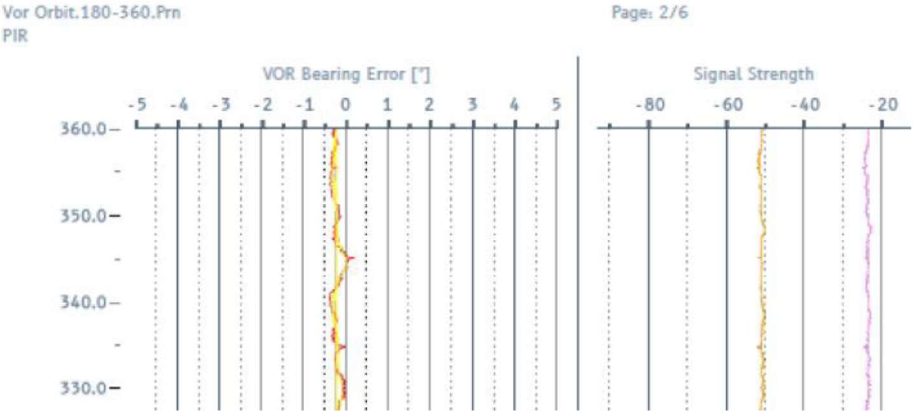

Figure 8. Plotter from UNIFIS1000 using EVSD1000

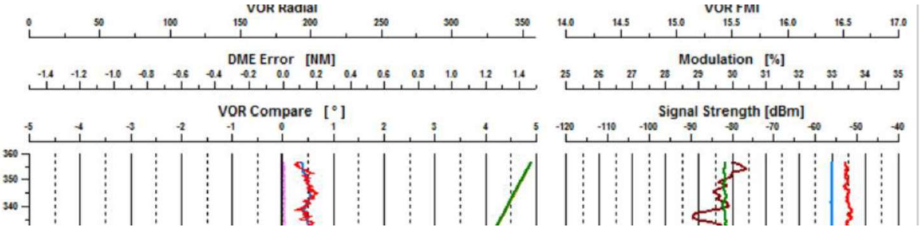

Figure 9. Plotter from traditional flight inspection aircraft using EVS300.

This site provided the most suitable environment for Localizer (LLZ) crossover testing, allowing measurements across the full ±35° sector relative to the LLZ course line without requiring flight over populated or restricted areas. Both clockwise (CW) and counter-clockwise (CCW) runs were conducted, and the UAV altitude was alternated between 200 ft and 300 ft to assess signal behavior at different vertical profiles.

During the initial segment of the CCW crossover run, the recorded data indicated noticeable signal noise. This disturbance coincided with the UAV's position behind a forested area located between the localizer antenna and the drone. Additionally, a large radar installation positioned along the flight path between the ground-based monitoring equipment and the start of the LLZ crossover trajectory likely contributed to further RF interference.

A comparison between UAV-based measurements and those collected from the manned aircraft showed that the UAV should ideally operate at an altitude higher than 300 ft to avoid terrain- and vegetation-induced multipath and signal shadowing. As visible in the site imagery, the initial part of the track appeared particularly susceptible to noise, which is consistent with signal obstructions caused by the forested area.

Figure 10. Amber colored line for LLZ Crossover CCW.

On the plot output, it is clearly observable where the system experienced intermittent communication loss, corresponding to points where the radar installation was positioned directly in the line-of-sight between the drone and the ground-based equipment. This obstruction resulted in temporary datalink degradation.

Furthermore, within the LLZ deviation (LLZ Dev) trace, the receiver registered elevated noise levels on the side of the centerline exposed to RF-emitting infrastructure. In contrast, the opposite side of the centerline—where no RF transmitters or reflective structures were present—showed a significantly cleaner and more stable signal profile. This asymmetry confirms that the detected disturbances originated from external RF interference rather than system-internal factors.

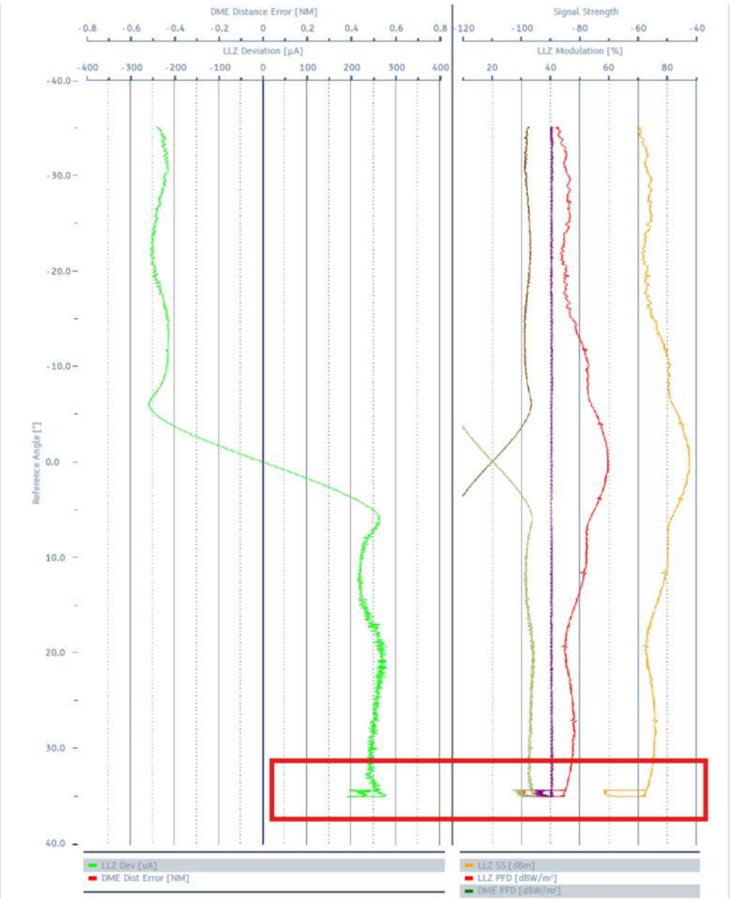

Figure 11. Plotter LLZ Crossover from UNIFIS1000 using EVSD1000.

NSM has also evaluated a second UAV platform, a fixed-wing drone equipped in this test configuration with the R&S EVSF1000 together with Radionor datalink, which provides dual channels for measurement and an encrypted, high-stability long-range datalink. In this setup, both the UNIFIS100 integration and the UAV's primary command-and-control functions were carried over the same communication link. Test data collected from this platform demonstrates its capability to perform long-distance inspections, functioning more like a traditional flight inspection system through the use of comparable GNSS corrections and standardized communication with ground facilities.

Since the EVSF1000 includes dual channels, the system enables simultaneous inspection of both the localizer (LLZ) and glide path (GP). This stands in contrast to smaller UAV platforms equipped with the EVSD1000, which support only a single channel and thus can inspect either LLZ or GP independently. This technical distinction is important when determining which UAV platform is most suitable for specific inspection profiles and operational requirements.

Due to regulatory limitations on UAV operations in aerodrome areas, the test was conducted at an approved airport featuring a relatively small aerodrome area, but equipped with a full ILS CAT I installation. A survey of the surrounding area revealed minimal physical obstructions, thereby reducing the risk of RF interference and enabling cleaner signal conditions for system evaluation.

Analysis of the inspection plot indicates clean and stable signal levels, with ground-collected data showing no observable noise disturbances throughout the approach. In this flight, the inspection run was initiated from approximately 8 NM. It is important to note that this evaluation was performed at a different test site than the one used for trials with the smaller UAV equipped with the EVSD1000. Overall operational feedback for this setup was positive, demonstrating stable and reliable communication performance with expected signal behavior and no interference. This is in clear contrast to the earlier LLZ crossover tests with the smaller UAV, where noise was easily detectable due to direct RF interference originating from a nearby radar source.

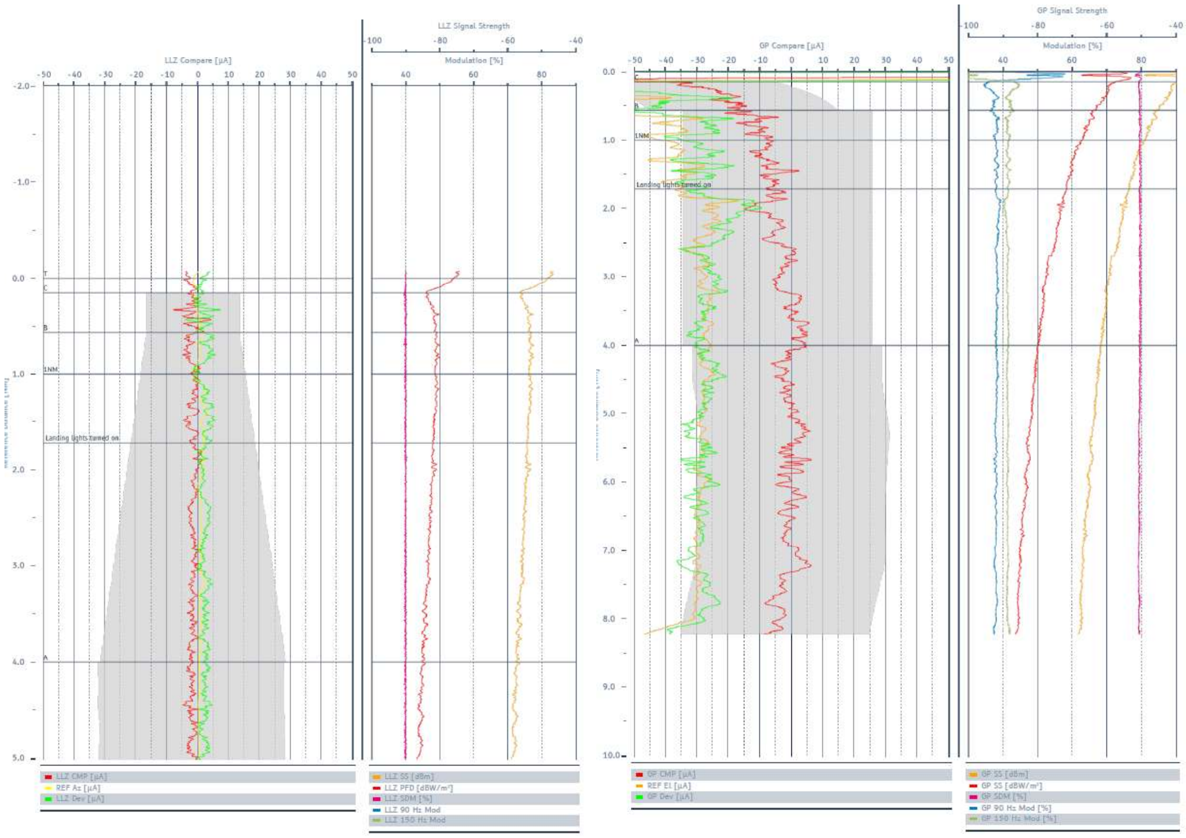

Figure 12. ILS approach, plotter for signal collected with EVSF1000

III. SUMMARY

The experimental flight-test results indicate that the use of Wi-Fi-based communication links can be challenging in aerodrome environments where numerous RF-emitting systems, such as surveillance radars, navigation aids, and communication transmitters, can interfere with both datalink performance and measurement integrity. In such RF-dense environments, signal attenuation, multipath effects, and transient link degradation may occur, adversely affecting system reliability and the stability of recorded flight-inspection data.

For smaller aerodromes, however, the use of Wi-Fi communication remains feasible provided that a detailed pre-site survey is conducted. This survey should include an analysis of RF emitters, assessment of line-of-sight constraints, and calculation of all operational distances and altitude profiles required for safe and interference-free UAV flight. Under these conditions, Wi-Fi can be a practical solution since the equipment is typically integrated into most UAS platforms, eliminating additional payload requirements and simplifying regulatory constraints related to bandwidth allocation and frequency coordination.

For larger and more complex aerodrome environments, the UAV test results indicate that LTE/5G-based datalink solutions provide significantly greater robustness compared to Wi-Fi communication. High-power radar emitters, navigation aids, and dense RF infrastructure common at major aerodromes create an environment where Wi-Fi links are more susceptible to interference, signal fading, and intermittent loss of connectivity.

In contrast, LTE/5G networks offer higher link stability, greater resistance to RF congestion, improved penetration through partial line-of-sight obstructions, and more consistent bandwidth availability. These characteristics reduce operational complexity and help ensure reliable telemetry, command, and payload-data transmission throughout the flight inspection tasks. As a result, LTE/5G datalinks are recommended for operations in large or RF-intensive aerodrome areas to minimize communication disruptions and maintain the integrity of measurement data.

However, when employing datalinks based on LTE/5G or similar cellular technologies, several additional constraints must be taken into account. These solutions typically require supplementary onboard hardware such as dedicated modems and high-performance antennas. This increases the overall payload mass and power consumption of the UAV, which may impact endurance, center-of-gravity limits, or permissible configuration for certain flight-inspection missions.

Furthermore, the use of LTE/5G communication introduces additional regulatory considerations that vary by country. These may include requirements for restrictions on the use of specific frequency bands, limitations on operational altitudes for cellular-connected airborne equipment, and compliance with national aviation and telecommunications authorities. Such regulatory dependencies must be evaluated during mission planning to ensure lawful and interference-free operation.

REFERENCES

[1] ICAO, Annex 10 to the Convention on International Civil Aviation, Aeronautical Telecommunications, Volume I, Radio Navigation Aids, 7. ed., Montréal, Canada: International Civial Aviation Organization, 2018.

[2] ICAO, Doc 8071 - Manual on Testing of Radio Navigation Aids, Volume I, Testing of Ground-Based Navigations Systems, 4. ed., Montréal, Canada: International Civil Aviation Organization, 2018.

[3] Rohde & Schwarz, R&S®EVSD1000 VHF/UHF NAV/DRONE ANALYZER – Brochure V3, Munich 2024.

[4] Rohde & Schwarz, R&S®EVSD1000 VHF/UHF NAV DRONE ANALYZER – Specifications V4 – Munich 2024.

[5] R&S®EVSF1000 VHF/UHF Airnav/Com Analyzer - Brochure V6.01, Munich 2021

[6] R&S®EVSF1000 VHF/UHF Airnav/Com Analyzer - Specifications V6, Munich 2023

[7] Hanson, R.W., Russell, S.F. and Hallock, D.B., 1970. UHF Solid-State RF Preselector Study.