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A holistic platform employing SDR to facilitate automated airport and waterdrome inspections using UAVs

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Abstract

Before landings and take-offs, airports and waterdromes require manual labour to complete necessary inspections and ground operations. The 5D-AeroSafe Horizon 2020[1] project has endeavoured to eliminate such manual processes while improving speed and efficiency of operations and security and safety levels. This paper describes a system named mRNAV, which is the combination of miniaturised unmanned aerial system transceivers mounted on a drone, to assist automated airport Navigation Aid Systems inspections and calibration by employing technologies such as Software Defined Radio and embedded sensors. Finally, utilising cloud infrastructures and a mobile link, inspection data are transported, analysed, and displayed in real time via a web user interface.

1. Introduction

The inspection of Radio Navigation Aids Systems[2] (NAVAIDS) is periodically performed manually in airports and waterdromes following a series of standardised procedures for calibrating, adjusting or testing navaids, as described by the Federal Aviation Administration [3] (FAA) in United States, the European Union Aviation Safety Agency[4] (EASA) in Europe, and the International Civil Aviation Organization[5] (ICAO) worldwide. This requires a considerable amount of fuel, personnel, preparation, and time arrangements with the Air Traffic Control[6] (ATC).

In general, these inspection procedures require a manned aircraft to fly above each radio navigation aid multiple times (in a circle) and perform various measurements, such as Azimuth measurements. Then, the Air Traffic Safety Electronics Personnel (ATSEP) uses this information, transmitted through a Private Mobile Radio (PMR), and adjusts the settings of a corresponding navigational aid manually, according to the manufacturer specifications and following the procedure defined from ICAO, FAA and EASA. This process is time-consuming because the aircraft must remain airborne while the ATSEP personnel set up the new settings for the navigation aid systems. Following this procedure, the aircraft is required to test the new settings again and again and report the results after each inspection.

This paper suggests an mRNAV system which employs an unmanned aerial vehicle (UAV), armed with miniaturised unmanned aerial system transceivers as payload, for aiding automatic airport and waterdrome operations. The proposed system assists in performing inspection operations procedures by eliminating the need of a manned aircraft, a substantial quantity of fuel, pilots and extra personnel, and, foremostly, the time to perform the inspections. Additionally, using multiple drones simultaneously reduces significantly the time required to complete a mission while there is no radio or drone interference with any manned aircraft at the airport [6].

[1] https://5d-aerosafe.eu
[2] https://www.systemsinterface.com/products/NAVAIDS/
[3] https://www.faa.gov
[4] https://www.easa.europa.eu
[5] https://www.icao.int
[6] https://en.wikipedia.org/wiki/Air_traffic_control

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The inspection information captured by the system is analysed on-board as well as off-board on a cloud infrastructure while the signals are transmitted through a 4G[7] (mobile) connection. Commercial Off-The-Shelf[8] (COTS) technologies, such as Software Defined Radio[9] (SDR), components (e.g., antennas, radios, sim cards, etc.) and UAVs (e.g., DJI Mavic 4, ARES ARS-1C, DIY Drones, etc.) were utilised to realise the platform. To achieve a safe and accurate (unbiased) flow of information, several security techniques, such as SSL certificates, are used. Moreover, a Human Machine Interface[10] (HMI) is developed during the project that aids the end-users to preview various radio metrics, drone's trajectory, and other inspection related information. What is more, the results suggest that the use of the proposed solution can aid ATSEP personnel in automatically inspecting and manually calibrating various navigational aids, such as Distance Management Equipment (DME), VHF omnidirectional range (VOR), etc., and perform various predefined procedures with precision and accuracy in collaboration with the ATC.
The rest of the paper is structured as follows:

- Section 2, where the background information about NAVAIDS inspections is presented,
- Section 3, where the implementation of mRNAV and HMI are presented and SDR technology is described
- Section 4, where the results of the mRNAV platform and the HMI for the 5D-AeroSafe project are presented, alongside a discussion and disclaimer about the results.
- Finally, Section 5, which concludes this paper with further discussion about 5D-AeroSafe and the proposed mRNAV platform.

2. Background on Navigation Aids Inspections

Air navigation services are important for the ATC, since they provide all the necessary information for conducting safe flights. The framework of aerial transport operations is set by the different states, and it includes safety even in adverse conditions, such as operating at night, in clouds/fog, etc. The operations in such conditions become feasible by means of NAVAIDS, which are electronic, radio-frequency ground equipment, that have been proven reliable to support Instrument Flight Rules (IFR) procedures in all phases of a flight [2] [1]. The integrity and accuracy of the NAVAIDS signal, as well as the navigation service performance within acceptable tolerance values, are calibrated and tested on a regular basis. Flight inspections against specific tolerance values for signal measurements and navigation service performance ensure the required verification of NAVAIDS performance and navigation service safety.
Ground and aerial flight tests are used complementarily to check the performance of NAVAIDS. A number of technical, operational, and economic factors are taken into account for the definition of the testing schemes and periodicities. Ground tests are performed by ATSEPs by using appropriate test equipment at the facility or at a point on the ground, remote from the site. They are fast and accurate, and can be carried out frequently, due to their limited cost and operational impact. The stability of the NAVAIDS in the ground check is the key to extend the periodicity of flight testing and avoid the disruption of airport operations during flight tests. On the other hand, flight tests are carried out in the air by a trained flight inspection crew (pilots and ATSEPs), by utilising a flight inspection aircraft with a suitably equipped platform (e.g., AFIS - Automatic Flight Inspection System).
Successful flight tests provide proof of an acceptable facility performance, due to the in-flight evaluation and the sampling of the signal in space that they can offer. The measured signal is the result of the system performance, affected by external factors, such as site conditions, ground conductivity, terrain irregularities, metallic structures, propagation effects (multi-path), etc. The periodicity of ground and flight NAVAIDS inspections depend on the type of the NAVAID, the technology, maintenance scheme, and monitoring of the equipment, as well as on the adopted regulatory framework.
One of the advantages offered by the inspection scheme and concept of operations implemented in the 5D-AeroSafe project is the significant reduction of the flights and the flight types needed for appropriate inspections [10] [4]. For instance, by using a UAV and embedded sensors, the need for piloted aircrafts for system calibration is eliminated. This, in turn, contributes to the reduction of Global Warming Potential (GHG) emissions and to the general decrease of impact to the environment (i.e., noise) in the vicinity of the area of interest [5] [8] [3].

[7] https://en.wikipedia.org/wiki/4G
[8] https://en.wikipedia.org/wiki/Commercial_off-the-shelf
[9] https://en.wikipedia.org/wiki/Software-defined_radio
[10] https://csrc.nist.gov/glossary/term/human_machine_interface

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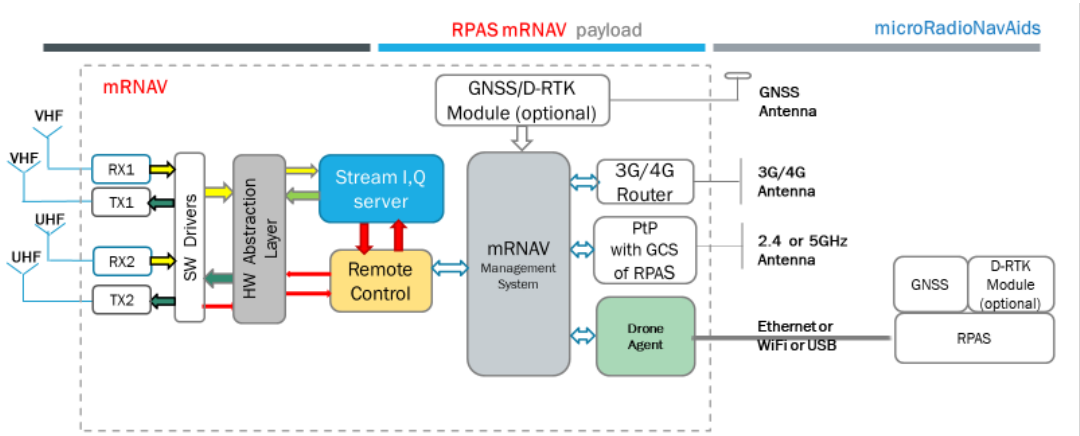
3. Implementation

3.1 Software Defined Radio (SDR)

Software-Defined Radio (SDR) is a radio communication technology that allows radio communication systems to be built entirely in software. This implies that activities usually performed by hardware components in a radio system, such as amplification, modulation, and demodulation, are performed by software operating on a computer or a computing capable digital device, such as IoT devices, mini computers, raspberries, etc.
The SDR technology provides several advantages over traditional radio systems that can benefit the civil, military, and/or commercial sector. According to Rahul Krishnan et al. in [7], such advantages include their re-programmability, flexibility, multi-band/multi-mode signal reception and transmission, and more. Furthermore, SDR technology enables the implementation of a wide range of radio communication protocols and standards while utilising the maximum digital space of the spectrum and meanwhile maintaining low cost for upgrade and maintenance.

3.2 Miniaturised UAS Transceiver (mRNAV)

The operation of the proposed mRNAV platform is based on an SDR approach, provided by the programmable transceiver, offering the capability to operate in compliance with different wireless communication protocols without the need to modify or update the included hardware. The recent advances in the SDR technology have led to a rapid increase in protocol developments and to the expansion of the related applications, such as aviation, cellular, WiFi and M2M communications, with a greater emphasis on optimising programmability, flexibility, portability, and energy efficiency.
The general schematic diagram of the mRNAV platform developed under the 5D-AeroSafe project is depicted in Figure 1. The platform was specifically designed to satisfy the operational needs of NAVAIDS inspection operations and other airport inspections covered by the 5D-AeroSafe project. The mRNAV system supports connectivity with a maximum number of 4 VHF/UHF radio bands, while it is equipped with a 3G/4G based connection for communicating with the 5D-AeroSafe cloud platform. One additional connection to the Real-Time Kinematic (RTK) adapter of the hosting drone is enabled, in order to receive telemetry data and send it to the cloud.



Use Case	RX1	TX1	RX2	TX2	Notes
D/C VOR only	V				
D/C VOR+DME	V		V	V	
DME only			V	V	
ILS LOC	V				
ILS GP			V		

Figure 1: Schematic diagram of the mRNAV module

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Moreover the mRNAV platform introduces innovative technologies, in order to miniaturise the flight inspection equipment and meet the RPAS payload and flight limitations (i.e., takeoff weight, flight time). The selected approach is based on the splitting of the flight inspection equipment in two segments:

- Air Segment, which includes the essential elements of the airside, namely the antennas, the transceivers, the hw/sw measurement units, and the data collection/storage units.
- Ground Segment, which includes the User Interface (UI), as well as the flight inspection equipment, which are not essential for the basic functionality (i.e. the display, the data analysis and recording unit, etc.).

The aforementioned segments are linked together through a telecommunication link. Figure 2 presents a diagram depicting analysis and storage functionalities, which are divided between the Air Segment (On-board) and Ground Segment (Back-end - Cloud infrastructure). This separation was necessary due to the limited processing capacity of the on-board segment. On a larger drone platform, having the ability to host bigger payloads, the two segments can be merged into a single on-board payload.

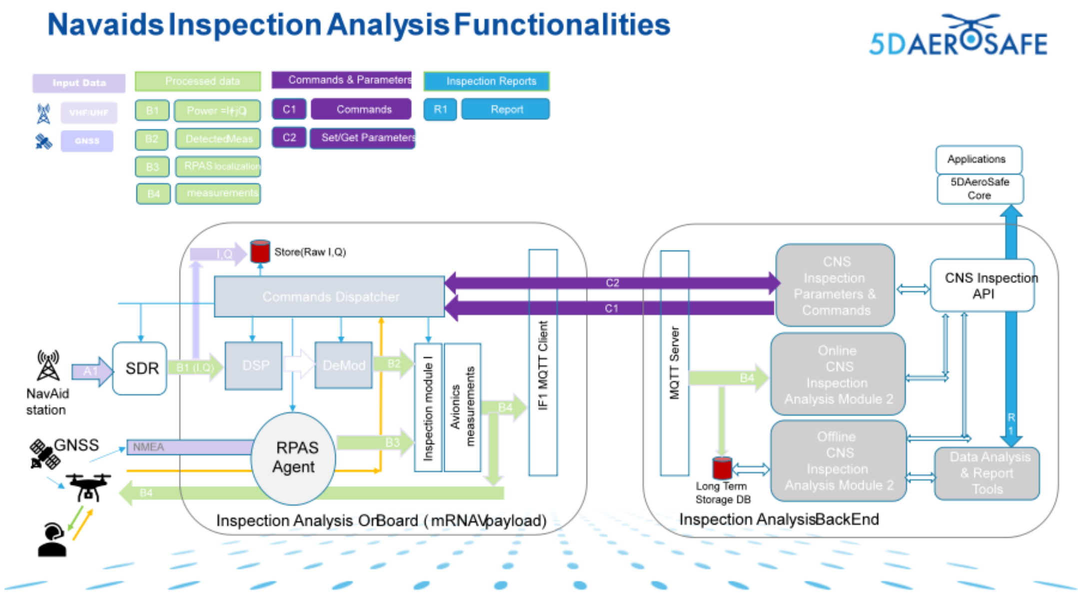

Figure 2: Analysis and storage of data in the two separated segments

Another key element of the two-segment architecture is the scaling possibilities. The separation in two segments enables the simultaneous use of several UAVs reporting to a common Ground Segment station and VGGCS (Virtual Generic Ground Control Station). This architecture would also enable the simultaneous inspection of different NAVAIDS. It would then decrease the number of coordinated actions with the air navigation providers as well as the time of allocation of the airspace during the flight inspections.
The basic measurements performed by the mRNAV platform are as follows:

- VOR (VHF Omnidirectional Range) phase
- Modulation depth and modulation frequency of the 30 Hz signal, the 9.96 kHz sub-carrier, and of the identifier signal
- Deviation and modulation frequency of the 9.96kHz auxiliary carrier
- THD (Total Harmonic Distortion) selective for the 30 Hz fundamental frequency and for the identifier signal

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3.3 Human Machine Interface (HMI)

An HMI web dashboard is built with the aim to aid ATSEP to preview the mission results in near real time, while performing a NAVAIDS Inspection Mission at an airport. All important mission results are transmitted through a 4G (GSM) link to a private cloud infrastructure.
Through a page named "Mission Preview" that is included in the HMI dashboard, as depicted in Figure 3, users can view the UAVs' flight inspection area. Additionally, users can preview the inspection path that drones will follow and various drone related information are provided as well as mission related information (e.g. landing points, emergency landing points, and takeoff points, etc) on the map preview area, at the centre right of the page.
In more detail, the "Mission Preview" page includes 5 main components: (1) the mRNAV data screen, at the bottom left corner, where the various navigational aid signals, pre-processed by the drone, are displayed, (2) the mission information pane, at the top left corner of the page, where users can view various information about the mission (i.e. Start date and time), (3) the drone information pane, at the top centre part of the page, where users can select inspection drones and preview information about them, (4) the inspector details (i.e. full name) alongside the mission details at the top left corner and, finally, (5) the main mission preview map at the centre right side of the page, where other drones and nearby aircrafts and vessels are depicted.

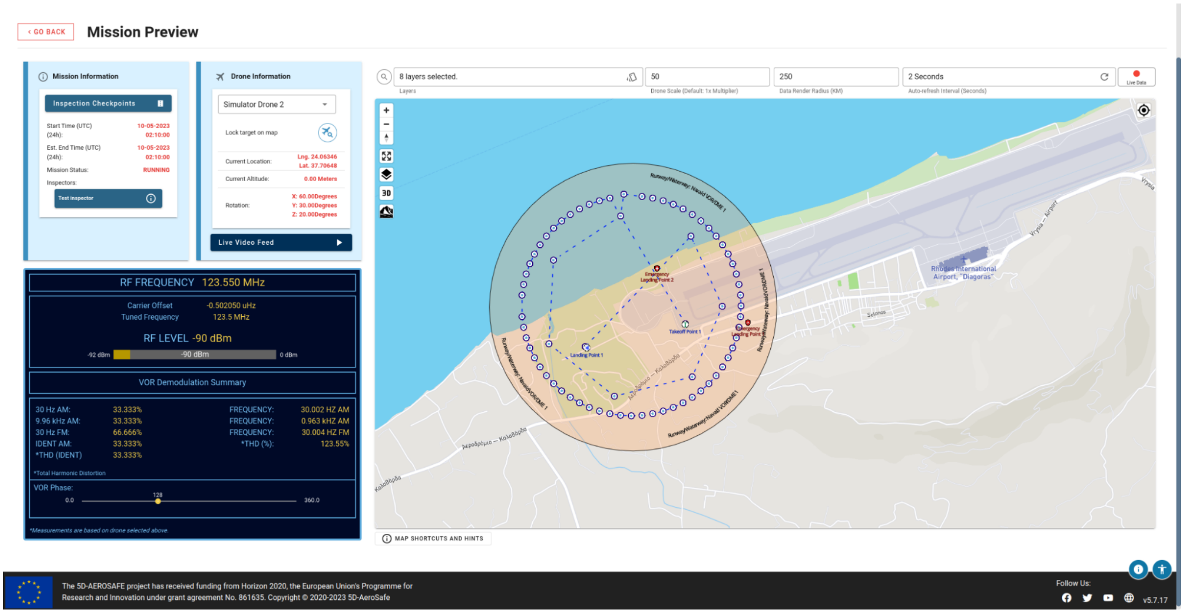

Figure 3: "Mission Preview" page

By selecting the "Live Preview" option, under the drone information pane, a live video feed from the selected drone is showcased in a popup window, which is presented in Figure 4 and can be adjusted to user requirements (i.e. size, side, etc.).
Figure 5 showcases the NAVAIDS information that is pre-processed and transmitted by the mRNAV system, and showcased to the users through the HMI. The information depicted on the mRNAV data screen is commonly used by ATSEP personnel for calibrating the NAVAIDS systems and for performing routine NAVAIDS' inspections. This data screen shows a visual representation of the mRNAV captured information.

4. Results and Discussion

4.1 mRNAV - Lab Experiments

A number of ground- and flight-based tests were conducted, in order to validate the mRNAV system's performance. A common set of measurements for both the ground and the flight tests has been selected to analyse and verify their correlation, and the appropriate flight profile to be followed. Key measurements like azimuth indication for a VOR, or modulation depth for the reference signal have been calculated with the proposed by ICAO DOC 8071 [9] processing and analysis procedure, so that transition from typical ground and flight testing to advanced drone testing will be seamless for pilots and ATSEP inspectors. Figure 5 above, presents the measurement results obtained by the ground and

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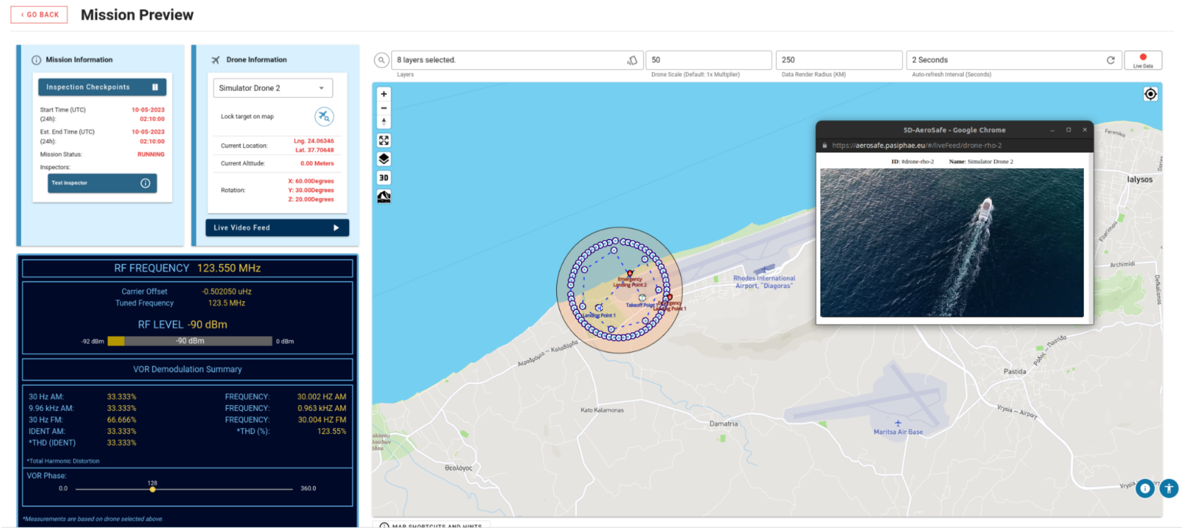

Figure 4: Live video footage popup window in mission preview page

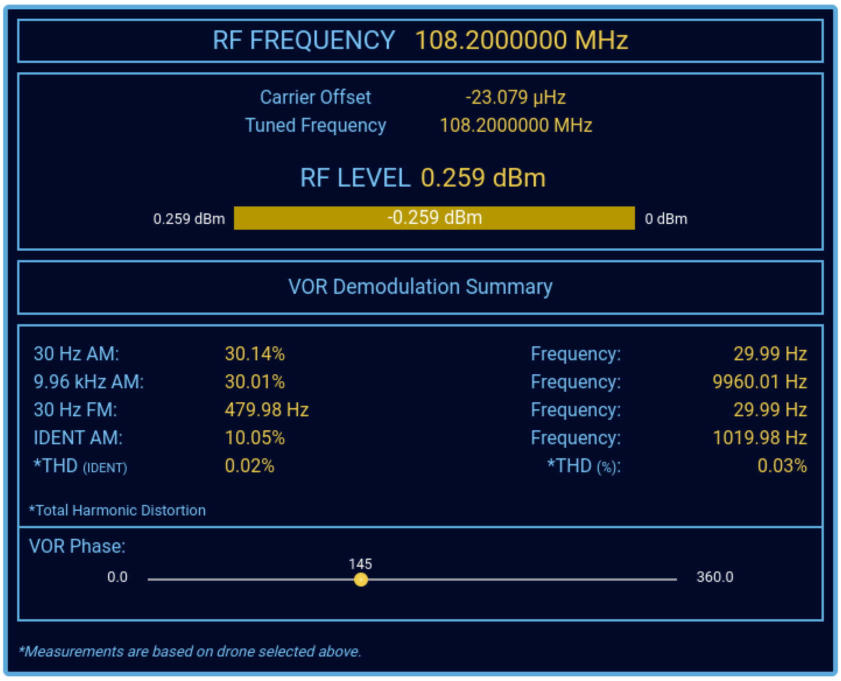

Figure 5: Examples of laboratory scale measurement results (VOR measurements)

short-range flight tests, regarding the VOR. Similarly, Figure 6 below depicts an example of measurements presented by the GQRX tool, which supports the SDR hardware and can be used as a data recording software to enable raw data logging and radio frequency measurements. Such software tools are useful for benchmarking, testing and verification purposes.

4.2 Disclaimer about results and future steps.

The measurement results were within the tolerance values that are broadly used for flight and ground testing of the corresponding NAVAIDS. No significant deviations have been identified during measurement sessions that would lead to ambiguity for the NAVAIDS performance and flight validation. The stability of measurements is an indicator that the drone based measurement technique would not only enable measurements on already operational NAVAIDS, but would also enable calibration of the NAVAIDS based on strong correlation factors. Although the proposed platform

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is very promising, the measurement techniques need extensive testing under variable technological and operational environments to be proven as adequate as current solutions. Consistency needs to be confirmed and acknowledged in the field by experts and needs to be verified towards real-time measurements for all of the NAVAIDS that this platform can support.

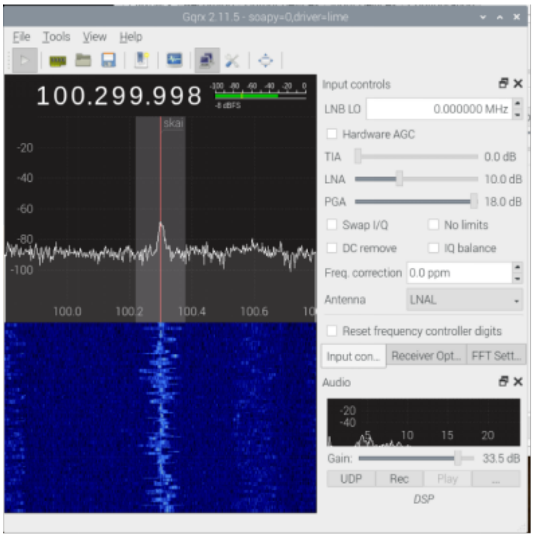

Figure 6: Examples of laboratory scale measurement results (measurements using GQRX tool)

5. Conclusion

The adaptability and flexibility of SDR on-board UAVs forge new regulations, routine procedures, and specification for airport ground operations. Operations such as flight navigational aid - flight inspections, runway/waterway inspections, lights inspection, etc., can become more precise, accurate, robust, and fast with the use of UAVs. Additionally, the integration of drones in routine airport ground operations can reduce costs, while avoiding usage of personnel and fuel for manned aircrafts. Consequently, such procedures can have a small environmental footprint and can result in a secure airport operation. The proposed solution presented in this paper can provide a robust and more efficient way to inspect and calibrate navigational aids, more frequently, while calibrating systems within tolerance values. The system's efficiency and robustness needs to be further validated from experts in current systems and new regulations should be created to accommodate the future use of such technologies in airports and/or waterdromes.

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