Evolving to 4D Signal Strength Normalization

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BIOGRAPHIES

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James C. West is Professor of Electrical and Computer Engineering at Oklahoma State University, Stillwater. He received a PhD in Electrical Engineering from the University of Kansas, Lawrence, in 1989 and joined OSU that year. He has also served as an Antennas and Propagation Engineer at Boeing, Wichita from 1982 to 1984, Summer Faculty Fellow at NASA Goddard Space Center, Air Force Research Laboratory, and Sandia National Laboratories, and Visiting Scientist at the Naval Research Laboratory from August 1998 through July 1999. His research interests are in applied electromagnetics, including radiation, propagation, scattering, electromagnetic compatibility, and radar imaging.

Yan (Rockee) Zhang received PhD in Electrical Engineering in 2004 from University of Nebraska. He was a research scientist at Intelligent Automation Inc. from 2004 to 2007, and joined school of electrical and computer engineering of University of Oklahoma (OU) since 2007. Currently, he is an associate professor and presidential professor at OU, a member of the Intelligent Aerospace Radar Team (IART) and Advanced Radar Research Center (ARRC), and a senior member of IEEE. His research areas include aviation radars, sense-and-avoid radars, airborne weather radars, microwave systems and computational electromagnetics. He has 20 years experience developing innovative radar sensors and aerospace applications.

ABSTRACT

The FAA Flight Inspection Team has been preparing to significantly reduce signal strength measurement uncertainty for several years. The largest uncertainty is limited normalization data and its software implementation. Upon reaching the limits of what can be done with a 2 dimensional (2D) normalization and gain adjustment scheme, the Flight Inspection Airborne Processor Application (FIAPA) now provides added programming flexibility to begin correcting in all three dimensions and for frequency dependence. The combination of 3D and frequency dependence is referred to as 4D in this paper. The FAA has partnerships with Oklahoma University (OU) and Oklahoma State University (OSU) to assist with electromagnetic modeling and calibration using Unmanned Aircraft Systems (UAS). The purpose of this paper is to describe ongoing efforts to reduce signal strength uncertainty via implementation of a 4D correction scheme.

SIGNAL STRENGTH MATTERS

As Performance Based Navigation (PBN) moves forward with GNSS as the primary navigation sensor, the number of conventional navigation aids in the US is being reduced under the VOR Minimum Operational Network (MON) program.[1] This expands the standard service volume of VORs from 40NM to 77NM. In addition, DME service volume usage is expanding as a backup to GNSS outage, and GBAS facility inspections have introduced significantly higher signal strength accuracy requirements. As a result of these factors, the flight inspection role to assure adequate signal strength (coverage) is becoming more important.

CURRENT AND GOAL UNCERTAINTY

In order to reduce measurement uncertainty, it is important to first examine the independent sources of measurement error. For the inspection measurement, overall uncertainty may be characterized by the root mean square (RMS) of these independent error sources.[2] Table 1 below shows these error sources and their estimated values before and after the implementation described in this paper. The first two error sources are not addressed in this paper. The Cable/Connector goal can be achieved now since the FAA is currently measuring and documenting internal cable/connector losses between each receiver and antenna; however even this loss is frequency dependent as shown in Figure 1. Improvement on the final two errors sources is the focus of this paper.

Table 1: Signal Strength Error Sources

Independent Error Sources	Current Uncertainty (dB)	Goal Uncertainty (dB)
Receiver (individual receiver variation, bench calibration)	1.5	1.5
Antenna (individual antenna variation, bonding)	1	1
Cable/Connectors	3	1
Normalization model vs reality	10	2
Calibrations reference	3	.9
RMS Uncertainty	11	3

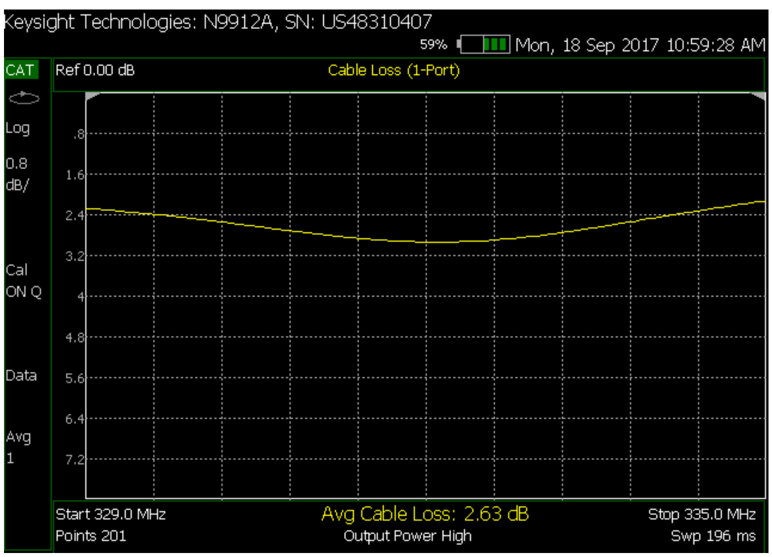


Figure 1: Glideslope Antenna Cable Loss, 329 – 335 MHZ

CURRENT FIS AND CALIBRATION

Ideal calibration of a FIS to report accurate signal strength depends on a number of factors. The overall antenna reception pattern as installed on the aircraft must be considered to achieve a repeatable result regardless of aircraft heading, pitch, or bank. Correcting for the antenna reception pattern is often called normalization. Once normalized, an overall gain adjustment is necessary to achieve a properly calibrated signal strength. Additionally, some adjustment is necessary for frequency dependence. Ideally, the FIS would allow a continuous correction for all of these factors which should lead to the desired measurement uncertainty of +/- 3dB.

In reality, the FAA's best system today provides a correction every 30 degrees laterally for each antenna, and the older system only provides a very limited normalization for VOR and localizer. Neither system provides a correction for pitch/bank angle to facility or frequency within band. Calibration for these systems is accomplished by flying the aircraft in level flight across the same point-in-space in 30 degree heading increments to determine the normalization factors. The overall gain to be applied for each antenna system is determined using ground measurement comparisons to a reference receiver such as a Portable ILS Receiver (PIR), Spectrum Analyzer, EVS-300, or EDS-300. Since the corrections are not frequency dependent and can only be applied every 30 degrees in the horizontal plane, the estimated uncertainty for the flight inspection measurement is +/- 11 dB as compared to ICAO standard of +/-3 dB.[3]

FIAPA FLEXIBILITY

The current implementation of FIAPA is still 2D with corrections interpolated based on a 30-degree model; however, plans are underway to input a 4D model in the next major software revision (3D + frequency dependence). The first FIAPA version was Operationally Approved for live inspections in October 2017. The next minor revision will be released in May 2018 which incorporates several hundred bug fixes, improvements, and new features. The FAA Flight Inspection Team (FIT) now has an established process and well qualified software engineers to incorporate advanced features such as signal strength correction for 3D orientation and specific frequency. The FAA flight inspection software has never been more readily adaptable and is now ready to make this leap in reducing signal strength measurement uncertainty. Preparation is underway to create a 4D calibration model that can be validated and then loaded into the next major FIAPA software revision.

ANTENNA NORMALIZATION (FAA/OU PARTNERSHIP)

A partnership with Oklahoma University is rapidly making progress to model, simulate, and predict each inspection antenna's reception pattern as mounted on the aircraft. The goal is to normalize signal strength so that corrections will result in reporting the same signal strength regardless of the orientation to the facility. This effort will also determine 3D normalization data and gain adjustment as it may vary within the frequency range for each antenna.

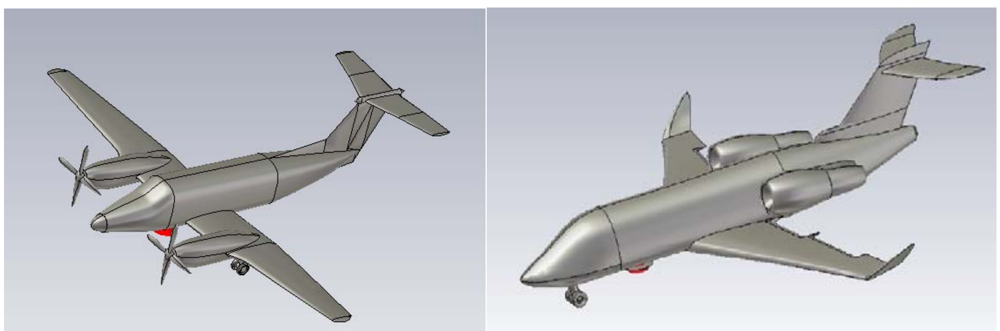
Aircraft Modeling

The first step of OU's investigation was development of 3D models for the King Air BE300PL and Challenger CL-604/5 aircraft. The objective with these 3D models was to achieve the optimal balance between the structural fidelity, accuracy and computational load during electro-magnetic (EM) simulations. In this step, existing aircraft information and a 3D laser-scanned model were used. **Error! Reference source not found.** Figure 2 shows the laser scanner used in the procedure and the mesh model as a result.

The laser-scanned model cannot be directly used in EM simulation due to a large number of cell elements and missing structures caused by optical scanning limitations. The model was then manually recreated in SolidWorks. To save cost for the Challenger model, "localized" 3D laser scanning (scanning around the antennas and other anomalies not accurate in the pre-existing model), photo image and traditional dimension measurement methods were used. Similarly, 3D SolidWorks models were created for the Challenger. **Error! Reference source not found.** Figure 3 shows the current version of the 3D models for both aircraft.

(a) (b)

Figure 2: (a) 3D laser scanning of King Air, (b) Resulting mesh model in simulation environment.



(a) (b)

Figure 3: The current version 3D models used in a simulation environment. (a) King Air BE300PL, (b) Challenger CL-604/5. Dimensions of these models are in 1:1 scale.

Note that the models for EM simulation do not need to be “perfect” in the sense that many details are not needed. For example, the current modeling process assumes the overall aircraft body is a perfect EM conductor, which is an approximate assumption and general practice for initial simulations. Because some structure details such as windows will not significantly affect the antenna patterns, they were not included in the current modeling. However, the models capture the dimensions, shapes and key details that matter to EM simulation and 3D antenna pattern predictions. The models are improved iteratively based on the simulation process at the cost of larger computational load requirements. Simulations are run for multiple frequencies and three aircraft configurations: clean, flaps approach/gear-up, and flaps approach/gear-down.

Antenna Modeling

Antennas modeled for the normalization are listed in Table 2. Most of the navigational aide antennas used for the signal strength measurement are included. One challenge of modeling these antennas is the lack of original design data from the manufacturers. On the other hand, the electromagnetic equivalence theorem allows replacing the radiator with an arbitrary structure as long as the surface equivalence condition is satisfied. Therefore, simplified monopole source models can be used to approximate the original blade or slot antennas, which yield closely similar far-field radiation patterns. This approach is called “equivalent monopole” method in our simulations. A unique monopole model is applied at each frequency in the simulation.

Table 2: Antennas being modeled for the flight inspection aircrafts

Antenna functions	Aircraft	Part Number	Freq Range	Current Modeling Method
VOR/LOC	BE-300PL CL-604/5	DM N4-33-3	108-118 MHz	Simplified monopole at specific location
VOR/LOC/GBAS	BE-300PL	DM N4-15-3	108-118 MHz	Simplified monopole at specific location
TACAN/DME	BE-300PL	DM NI7	960-1120 MHz	BASIC: Simplified monopole at belly location, IMPROVED: full annular ring slot model
Glideslope antenna	BE-300PL	522-0700-023	328-336 MHz	Simplified monopole at nose
Marker Beacon	BE-300PL	AT-640A/ARN	75 MHz	Simplified monopole
Marker Beacon	CL-604/5	522-0854-003	75 MHz	Simplified monopole
Glideslope	CL-604/5	FA67.10A	328-336 MHz	Simplified monopole at nose
TACAN/DME	CL-604/5	S65-1226-6	225-450 MHz + 960- 1220 MHz	BASIC: Simplified monopole at belly location, IMPROVED: Blade antenna model (on-development)

Even simplified models can be used as approximations. However, there are still two important aspects that need to be considered to improve simulation accuracy. The first is the wide-band return loss performance of antennas, which can be accurately measured in the laboratory. An example of the measured return loss response is shown in Figure 4. This information is important for the correct calibration of antenna response for different frequencies in the same operational band.

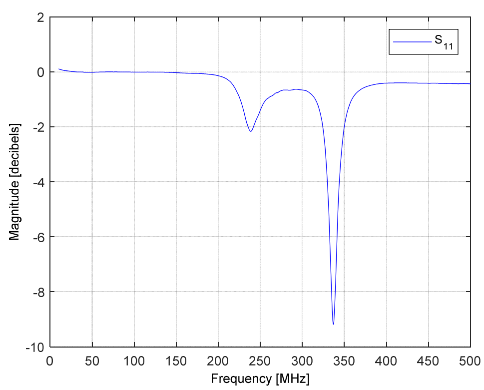
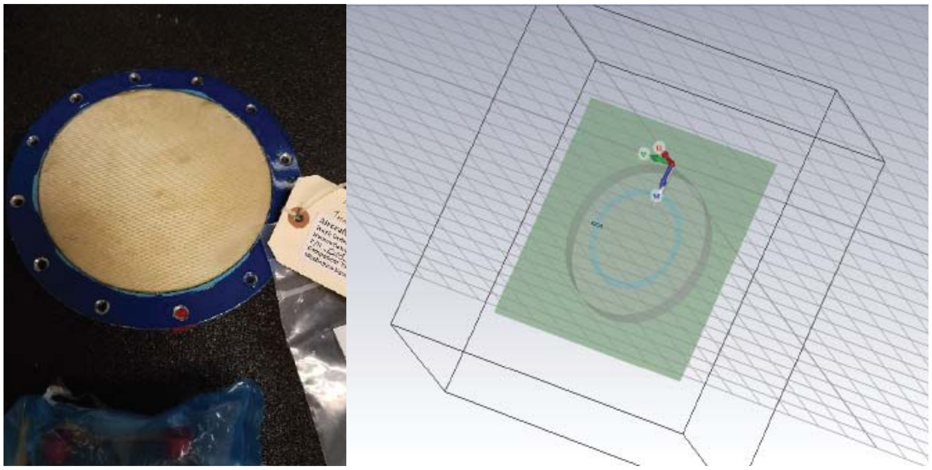


Figure 4: King Air GS antenna return loss

The second aspect affecting the simulation accuracy is knowledge of the internal antenna construction. Simulation using a more precise antenna model may result in better understanding of the antenna radiation pattern. This was simulated for the King Air DME antenna shown in Figure 5.



(a) (b)

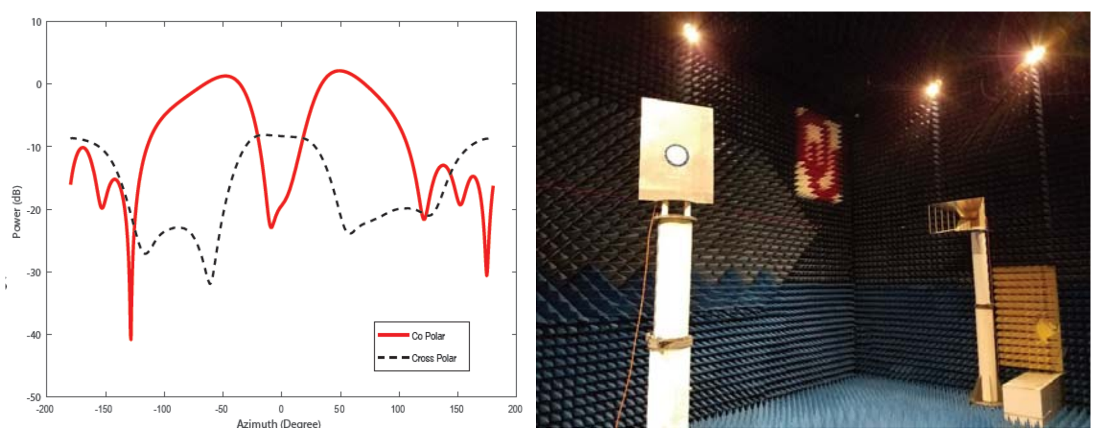
Figure 5: Example of improved antenna modeling, (a) King Air DME antenna as a typical annular slotted antenna and (b) The improved model for EM simulation.

However, simulation results of different models have shown that the DME antenna radiation pattern is close to that of an ideal monopole type antenna. Thus, the simplified monopole model is an effective solution for the current stage of simulation.

Validation Methods

The OU team is currently using multiple methods to validate the simulation and enhance the data quality. Due to the limitation of facility and logistics, direct measurement of the antenna pattern as installed on the aircraft is not currently feasible. However, the current approach represents a tradeoff between the available resources and accuracy.

In the first method, a comparison is made between the monopole approximation models and the enhanced, more accurate antenna models. The physical modeling is based on combined X-ray imaging and tuning in the simulation environment. This method validates usage of the monopole approximation for the EM simulations. The second approach for validation is chamber measurements. The individual antenna is properly mounted on a test fixture, and its radiation pattern is measured in OU's anechoic chamber. Measurements of DME antenna are illustrated in Figure 6. The chamber measurement is limited to one dimensional pattern cuts with no consideration of aircraft body effects, but it provides essential validation in terms of basic monopole pattern shapes and basic simulation effectiveness.



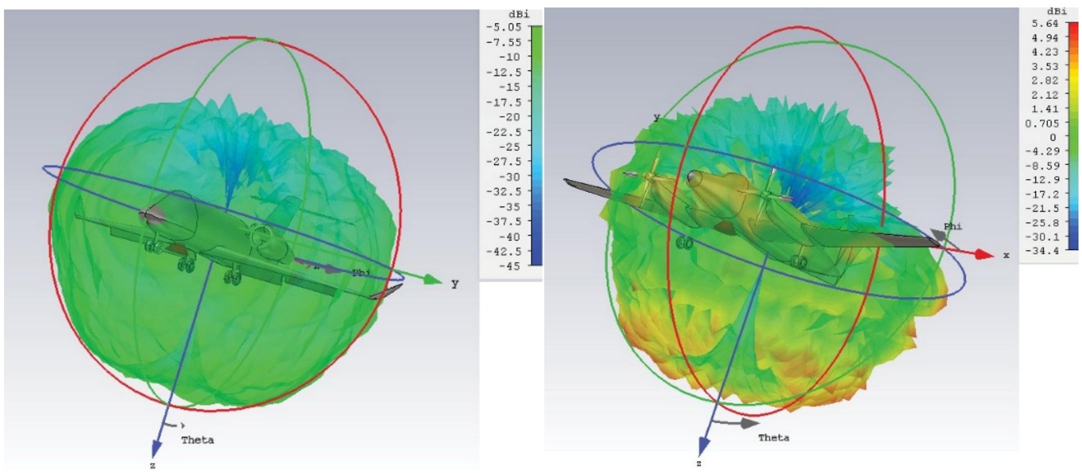
(a) (b)

Figure 6: **Example of improved antenna modeling, (a) Measured DME antenna pattern, (b) EM chamber setup.**

The third approach is to utilize flight test data for validation based on the calibration generated from simulations. This method combined with the OSU efforts discussed later in this paper should validate the improvement of the signal strength measurement accuracy.

Simulation Setup and Discussion of Results

Currently, the OU team is using commercial solvers (CST Studio and FEKO) for 3D pattern simulations with antenna and aircraft integrations. A Windows-Based server cluster is used to perform the simulation runs. Depending on the solver configurations, the number of meshed elements for each aircraft ranges from one million to two billion, and execution time ranges from a few hours to more than one week. The Integration Equation (IE) solver in CST was shown to be the fastest and most efficient for providing results. Figure 7 shows initial results obtained for two aircraft antenna installations.



(a) (b)

Figure 7: **Initial results of the 3D antenna pattern simulation, (a) Simulated 3D radiation pattern of GS-antenna on King-Air. (b) Simulated 3D radiation pattern of DME-antenna on Challenger.**

Integration of the antenna pattern simulations with FIAPA

The information provided by OU will be used to refine the normalization tables used within FIAPA. The current table is 2D and has lookup values spaced every 30 degrees. The OU data will allow us to refine the data to be better than one-degree intervals in 3D. To integrate the simulated 3D antenna patterns into FIAPA, the patterns are simulated at different frequencies within each operating band, converted to software-recognizable formats, transformed to a compatible coordinate system, and assembled into lookup tables for each frequency. This process is represented in Figure 8.

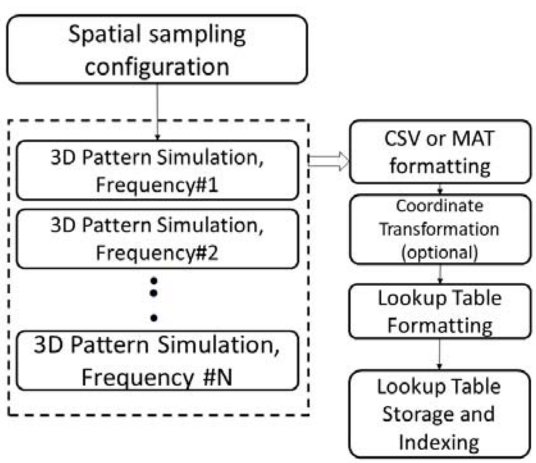


Figure 8: Procedures for integrating simulation data

GAIN CALIBRATION (FAA/OSU PARTNERSHIP)

Whereas the OU project is, primarily, concerned with establishing the relative gain around a flight inspection antenna through a theoretical electromagnetic modeling approach, a second project is underway to more accurately determine absolute gain of an aircraft mounted flight inspection antenna in certain directions using an empirical approach.

Project Plan Description

The plan for this project is to use a UAS to carry a signal measurement system to measure signal strength at an airborne reference point. The UAS measured signal strength, adjusted for an antenna with G=0 dBi, will be regarded as the 'truth' system for signal strength. The flight inspection aircraft will then be flown through the established airborne reference point to measure signal strength. Flight inspection antenna gain factors can then be calculated based upon the difference between the flight inspection aircraft measured value and the UAS measured 'truth' value.

There are several perceived benefits of the UAS approach. First, unlike the manned aircraft, the UAS aircraft is expected to have little to no effect on the UAS measurement antenna when the measurement antenna is suitably mounted on the UAS for this purpose. Second, the UAS can accurately be positioned and held at the airborne reference point to obtain a stable and accurate signal strength measurement. Thirdly, the UAS can assess the signal strength stability of the region of airspace around the established airborne reference point considering the vertical and lateral positioning accuracy of the flight inspection aircraft.

Implementation Plan

The initial set of signal types for signal strength evaluation consisted of VOR, localizer, glideslope, and DME. The initial plan was to transmit signals that could be received and measured by the aircraft flight inspection receivers for these signal types. Actual facility signals were considered for the signal strength measurements. However, one of the important experiment design parameters required the signal strength at the airborne reference point to be less than -70 dBm. This was important because the manned aircraft flight inspection navigation receiver, the RNA-34BF, measures signal strength most accurately (± 1dBm) when the signal strength is below -70 dBm. Use of facility signals also precluded the possibility of changing frequencies for the signal under test to evaluate frequency dependence. Therefore, in order to obtain the necessary flexibility for both signal strength and frequency levels, the decision was made to construct a base station transmit system capable of transmitting the required signal types.

Since the operational requirement for signal strength calibration was anticipated to be infrequent, a portable antenna mast system was chosen. The constructed base station transmit system consists of a thirty-foot portable mast with a VHF antenna for VOR and localizer, a UHF antenna for glideslope, and an L-band antenna for DME. Signal generators capable of generating these signals are required as well as RF amplifiers for transmitting sufficient power for measurement at the airborne reference point. Figure 9 illustrates the base station mast and antennas.

The UAS measurement system initially consisted of a handheld spectrum analyzer and a calibrated isotropic antenna. The UAS itself is a large, heavy lift multicopter that is capable of a 15-minute flight, including a 5 minute measurement hover time at the 1500' altitude measurement point when loaded with the measurement system. The payload weight of the UAS, consisting of the handheld spectrum analyzer, the measurement antenna, the spectrum analyzer and measurement antenna holding fixtures, and miscellaneous other parts total approximately twelve pounds. The UAS maximum payload is 50 pounds. The aircraft was equipped with an onboard camera with a live feed to the ground which was angled to allow it to observe the screen of the spectrum analyzer. Measurements were triggered from the ground through an onboard mission computer system developed at Oklahoma State University called Stabilis. Every measurement trigger created a log of the corresponding aircraft GPS location, altitude, attitude, and heading from the aircraft's systems. The aircraft was capable of being flown by a single pilot and was operated at Oklahoma State University's Unmanned Aircraft Flight Station under an FAA Certificate of Authorization allowing flights up to 2500' AGL.

Figure 9: Base Station Mast and Antennas

The airborne reference point was chosen such that the signal angle of arrival at the flight inspection aircraft was consistent with an angle that would often be encountered in actual flight inspection maneuvers for these NAV aid signal types. That angle was chosen to be approximately 1.3º. This is achieved by locating the airborne reference point approximately 10 NM away from the base station transmit antennas and specifying an altitude of approximately 1500 feet above ground level (AGL). This altitude was high enough for safe flight inspection aircraft operation and low enough for a smaller UAS to practically attain. The target signal strength to be produced by the base station transmitters at the airborne reference point was established at -75 dBm.

Obviously, the basic UAS measurement maneuver is to ascend to the airborne reference point, take a measurement, and descend. Additional UAS maneuvers were needed to assess the vertical and lateral signal strength stability in the region of airspace around the airborne reference point. By characterizing the signal strength in this way, the flight inspection aircraft measurement errors could be quantified due to the limitations of the flight inspection aircraft to make the signal strength measurement exactly at the airborne reference point. Using input from the flight inspection pilots, the region of airspace about the airborne reference point where the flight inspection aircraft could be practically positioned was established as ± 20 feet vertically and ± 100 feet laterally. The UAS measurement maneuvers were required, then, to characterize the signal strength variation in this cylinder of airspace about the airborne reference point.

For the flight inspection aircraft measurement maneuvers, only four attitudes with respect to the base station transmitted signal were employed: inbound, outbound, clockwise, and counter-clockwise.

Testing Results

The initial testing results showed, unfortunately, that the gain of the isotropic measurement antenna was just too small to obtain enough signal to make accurate measurements without having to resort to larger RF amplifiers at the base station. Using the calibration data from the isotropic antenna manufacturer, the gain of the antenna was calculated to be -44 and -21 dBi at VOR/LOC and glideslope frequencies, respectively. Therefore, a change to the initial implementation plan was required. Instead of the isotropic antenna, a commercially available dipole antenna was used for measuring the VOR, LOC, and GS signals. The antenna includes two sets of dipole elements, one for VOR/LOC frequencies and one for GS frequencies that can be easily configured in the field. The dipole base was mounted toward the front of the UAS and oriented downward, placing the dipole below the UAS body to minimize interactions as shown in Figure 10. A disadvantage of the dipole antenna is that UAS must be oriented to keep the peak of the radiation pattern directed toward the base station. A monopole probe antenna with a 1 wavelength diameter ground plane was fabricated to receive the DME signals. The monopole antenna mounted on the UAS is also shown in Figure 10. The monopole is expected to give a nearly omnidirectional horizontal receive pattern, minimizing sensitivity to yaw errors in the UAS platform. However, some dependency on pitch-and-roll may occur.

Figure 10: UAS with VOR/LOC measurement dipole mounted beneath (left) and vertical monopole (right)

Flights were conducted on Feb. 9 and Feb.13, 2018. The horizontal (lateral), vertical, and yaw sensitivity tests described above were performed around the measurement test point with LOC, GS, and DME signals. VOR signals were not measured during this flight campaign. However, the LOC and VOR frequencies differ only slightly (108.1 MHz versus 108.0 MHz) so the VOR signal levels can be assumed to be the same as the LOC levels. The raw received signal levels (not corrected for antenna gain) during the lateral position sensitivity test measurements are shown in Figure 11. The LOC and GS signal levels are quite stable, changing much less than 1 dB as the lateral position changed by +/300', and are near the desired -75 dBm received levels. Unfortunately, the measured DME signal level fluctuates considerably between the samples. Subsequent analysis showed that the pulsed DME signal was not well suited to measurement by the portable spectrum analyzer. This required a second change to our initial implementation plan. Instead of using the regular DME pulsed signal that could be received by the flight inspection aircraft receiver, a continuous wave (CW) signal at the DME signal carrier frequency was employed instead.

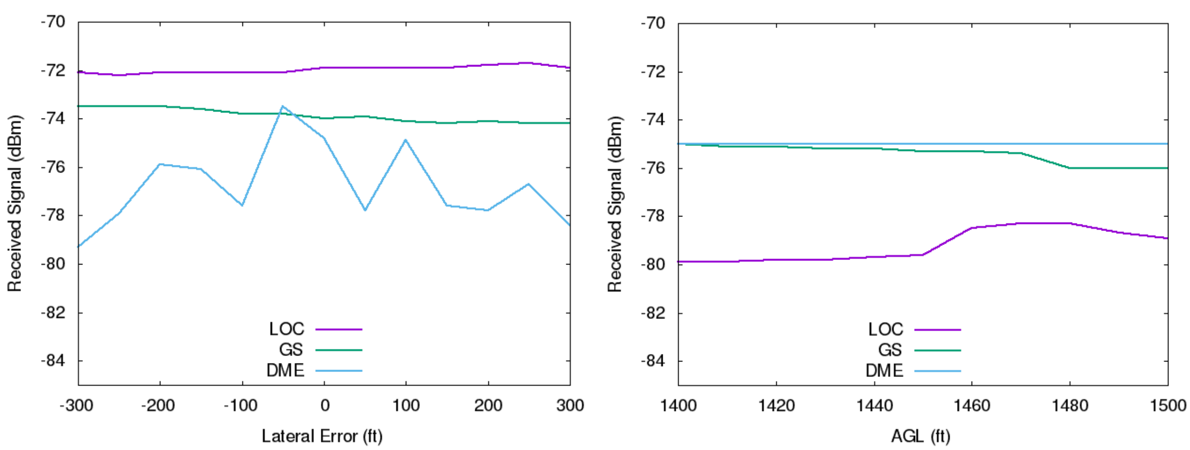


Figure 11: Lateral signal sensitivity (left) and vertical sensitivity measurements (right)

The vertical sensitivity measurements are also shown in Figure 11. The DME signal levels proved much more stable using the CW signal source. Little variation was seen in the signal between 1400' and 1500'. The GS signal also proved very stable in this test, changing less than 1 dB as the altitude of the UAS above ground level changed from 1400' to 1500', but is marked by a drop of approximately 0.5 dB as the UAS transitioned through 1470'. The LOC signal was stable at approximately -80 dB from 1400' to 1450', but then abruptly increased by about 1 dB and remained approximately constant at -79 dB as the altitude increased to 1500'. Finally, the 360° yaw measurements are shown in Figure 12. The dipole radiation pattern is clear in the GS measurements, with nulls at +/- 90° as expected. The LOC signal shows a dipole null at +90°. However, the pattern includes a dip of only 5 dB at -90°. Additional flight testing after the measurement campaign showed that an interfering signal masked this dipole pattern null. The LOC and GS received signal levels show very little dependence on yaw near the peak of the pattern at 0°, the direction from which the signal will be incident during actual measurements. The DME signal level is approximately isotropic and is very stable around 90°, the yaw angle that will be used in those measurements. The DME signal levels show the most dependence on angle at -90º, where the receiving monopole is on the side of the UAS opposite the radiating base station.

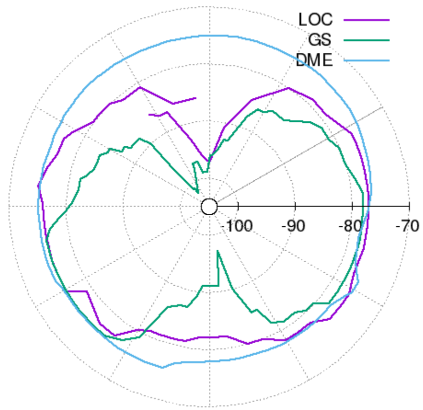


Figure 12: Yaw signal sensitivity measurements (dBm).

Table 3 shows the signal levels measured by the UAS at the test point when corrected for the measurement system antenna gains. Also given is the mean signal level received by a FAA flight inspection aircraft averaged over 4 passes for comparison. The measured UAS and aircraft signal levels agree to within 3.2 dB or better with the VOR (assumed to be equal to the LOC signal level for the UAS measurement) and GS signals. The LOC and DME agreements are somewhat poorer, but are still within 6 dB. Efforts are underway to further quantify the measurement antenna gains when mounted on the UAS system to improve the accuracy of the signal strength measurement system. This will be accomplished in the anechoic chamber at OSU and will reveal what effects the UAV body has on the measurement antenna as currently positioned in the UAV holding fixture.

Table 3: Measured signal levels.

Signal	Mean Aircraft Signal Level (dBm)	UAS Signal Level
LOC	-75.5	-70.4
VOR	-71.8	-70.4
GS	-69.3	-.72.5
DME	-79.5	-73.3

Gain Calibration Test Result Conclusions

The testing accomplished so far has demonstrated the feasibility of using a UAS-based system to measure the signal level of navigation signals at a specified airborne reference location. Signal strength levels near the desired -75 dBm level were measured at the airborne reference location for all signals considered. The UAS attitude can be sufficiently controlled in yaw and pitch and roll to perform measurements when a using a dipole antenna measurement system without introducing significant measurement errors. After changing the DME signal type to CW, the measured signal strength variation within 20 feet vertically and 100 feet laterally about the airborne reference location was less than 1 dB for all signal types. Table 4 summarizes the signal strength uncertainty for various quantities mentioned in this discussion of absolute gain determination from an empirical approach. The total uncertainty as shown in Table 4 shows the overall feasibility of this effort to establish signal strength measurement within the ICAO ± 3 dB standard.

Table 4: Summary of Signal Strength Uncertainty for UAS Method

Error Source	Uncertainty (dB)
Flight Inspection Aircraft Positioning Error, as determined from UAS lateral and vertical sensitivity measurements, ±20 feet vertically, ±100 feet laterally.	~ 0.5
Gain determination error for UAS GS and DME Measurement Antennas (VOR/LOC TBD)	~0.5
FSH8 Spectrum Analyzer Total Measurement Uncertainty, 10 MHZ<f<3.6 GHZ	0.5 typical
RMS Uncertainty	**0.9**

LESSONS LEARNED

1. The initial signal strength measurements for DME using the normal, pulsed DME signal type revealed signal measurement variations of 2-6 dB with the spectrum analyzer, whereas VOR, LOC, and GS measurement variations were less than 0.5 dB. To reduce the measurement variation for DME, a continuous wave type signal that is much more suitable for spectrum analyzer signal strength measurements will be employed in the future.
2. Although the isotropic antenna was very attractive due to the several measurement benefits, the small gain of this antenna at VHF and UHF frequencies proved to be problematic.
3. The current development cycle within FIAPA is well established. Implementation even of advanced capability expansion is happening now. Within days of providing sample normalization data to the FIAPA team, development was underway.

FUTURE WORK

1. Future flight tests are scheduled to validate the normalization data gained in the OU efforts.
2. The normalization data needs to be organized into lookup tables. However, as the capability of FIAPA has increased the size of these tables can become large and unwieldy. Efforts are underway to develop a more efficient scheme in which to organize this data.
3. The work to incorporate complex 4D correction tables into FIAPA is expected in the next major revision of FIAPA.
4. A normal Operational Test and Evaluation process must be completed to assess the expected reduction in signal strength uncertainty to roughly 3dB.
5. Upon completing the development of the UAS signal strength measurement method, it will be used to evaluate the measured signal strength variation at the airborne reference point with each setup of the portable base station at the same location in the same orientation. This testing should include changing atmospheric conditions. If the resulting variation of the signal strength is within tolerances, using the portable base station operationally without UAS measurement flights to confirm the airborne reference point signal strength may prove to be a possibility.

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