Robotic Arm-based Antenna Metrology System for Aerospace Applications

Marie Piasecki [1], Bryan Schoenholz [2], James Downey [2], Christine Chevalier[3], Kevin Lambert [3]
[1] NASA Glenn Research Center: System Integration and Test Branch, Cleveland, OH, USA, marie.t.piasecki@nasa.gov
[2] NASA Glenn Research Center: Advanced High Frequency Branch, Cleveland, OH, USA
[3] HX5 LLC, Brook Park, OH, USA

***Abstract*—Robotic antenna metrology presents interesting opportunities to investigate novel approaches to traditional antenna and communication system evaluation. In 2018 the National Aeronautics and Space Administration (NASA) Glenn Research Center (GRC) began exploring the use of robotic measurement for antenna and communication system metrology to address unique needs for traceability and in situ testing of a novel antenna for use in unmanned aerial systems (UAS). Since that initial development of the Portable Laser Guided Robotic Metrology (PLGRM) system many additional capabilities have been added to support a wide variety of aerospace applications. This paper provides an overview of the system itself, existing capabilities, benefits over other measurement approaches, and future work.**

***Index Terms*—antennas, antenna patterns, measurements, aerospace, phased array, radome.**

I. Introduction

A consistent challenge in the development of aerospace communication systems is in understanding how antennas interact with the host structure. New and complex high gain antenna systems such as active phase array antenna (APAA) are becoming more common for mobile users [1][2], as such understanding the performance of these devices in their intended environment is required. Accurate performance characterization is necessary over the duration of the development lifecycle of these antenna systems. This includes testing in early stages of prototyping and proof of concept all to way to final integration and flight demonstration. For this reason, a Portable Laser Guided Robotic Metrology (PLGRM) system was developed. This system is designed to be flexible in accommodating various test configurations and capable of being shipped to test locations. Key features include the ability to locate and track apertures both visible or hidden, stitching of various measurements to generate large patterns, and the ability to sample various scan planes (i.e., planar, cylindrical and spherical) as well an non conical scans relative to the orientation of the antenna under test.

II. System Description and Implementation

A. Components

One significant differentiator of PLGRM from other robotic systems was the importance of having a system that could be transported to an aircraft hangar and measure antenna performance with the antenna installed. This led to the selection of a collaborative robotic arm with a mobile base as a central component of the system. With a mobile base the addition of a high precision laser tracker using six degree of freedom targets was necessary. The laser tracker and targets are critical for accurately tracking the location and orientation of the probe relative to the antenna under test (AUT) and/or its mounting structure. The standard radio frequency (RF) measurement system utilizes a Vector Network Analyzer (VNA) however signal analyzers, vector signal generators and frequency extenders have been integrated with the system to add over-the-air (OTA) measurement capabilities. Figure 1 below shows the interconnection of these various components.

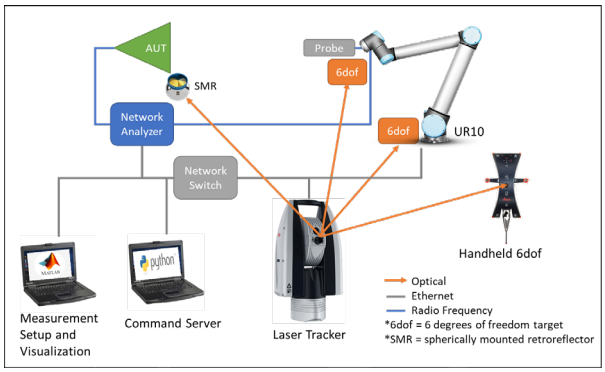


Figure 1 PLGRM Connection Diagram

B. PLGRM System Implementation

Measurements are setup in a MATLAB environment which determines the sample point locations based on the defined scan type, performs collision detection, collects the radio frequency measurement data, and plots both the animated system diagram as well as data visualization. A second control machine then uses Python for connection to and command handling of the various devices on the instrument network. A detailed description of the control structure can be found in [3].

III. Enabling Features for Aerospace Applications

This architecture was selected for PLGRM in order to enable a feature set that addresses needs critical for aerospace applications. In particular, the portability of the robotic arm along with the precision locating and tracking of the laser system enable key features for measuring novel

aerospace communication systems up to and including installation on a vehicle.

A. Adjustable Scan Plane

One of the benefits of a robotic metrology system is that the range of motion is not limited to a fixed set of motion stages. This allows a single robot to support a wide range of scans both in the near and far field including spherical, cylindrical, and planar [4][5]. Furthermore, the robot could also support a wide range of AUT orientations. This combined with the laser tracker allows the face of the AUT to be precisely located and then uses that location and orientation to define a scan surface that is aligned to the antenna and not having to align the antenna to an existing motion plane.

One application where this is particularly useful is in rapid prototyping on active antennas or tightly integrated communication systems. During development of these types of systems there can be a wide range of supporting equipment that must be located nearby the device under test. This can include instrument grade power supplies, control computers, sensors, and in some applications FlatSats. In many traditional antenna metrology systems integrating such supporting devices near the AUT can present challenges that limit quick measurements that support efficient design iterations. Figure 2 shows one such setup where an AUT is being measured with the PLGRM.

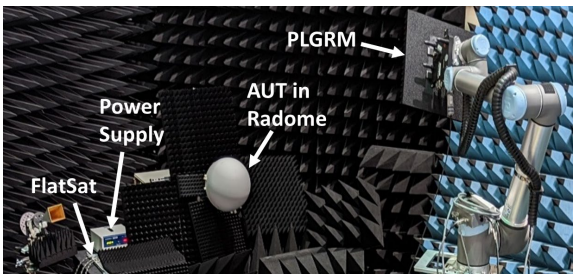


Figure 2 Example of AUT requiring complex ancillary equipment

In this example a space rated phased array was characterized using OTA testing while experiencing thermal cycles [6]. The AUT along with the supporting equipment was placed as needed in order to allow the array to function and to monitor temperature. Next the AUT is located in the space using a handheld 6dog target and laser tracker. When the AUT is setup and located in the environment foam walls are then placed in and around the supporting equipment. Finally, the software uses feedback from the laser tracker to guide the antenna measurement. This also has the distinct advantage of keeping the AUT still, which may be critical for delicate systems.

In addition to its use in measuring antenna patterns the PLGRM can support other types of testing including non-canonical surfaces. When combining this with mechanical models of the antenna itself the PLGRM is capable of locating individual sub-components of a larger aperture. This can be a great benefit to both calibrating a phased array element by element as well as troubleshooting arrays, even after they are installed.

B. Hidden Antenna

Another feature of PLGRM integral to supporting in situ measurements is the ability to measure a hidden antenna. Many aerospace applications cover an antenna with a radome after it is installed on the aircraft and therefore the PLGRM must be capable of precisely locating the antenna after installation. In this case the AUT location and orientation must be captured relative to a point visible to the laser tracker. With this information the control software can save the location of the antenna in a reference frame and use that information to precisely measure an antenna behind a radome.

C. Antenna Pattern Stiching

As noted earlier the PLGRM system establishes a scan surface based on the antenna location and orientation. There are many reasons why a particular scan surface might not be entirely within the reach of the robotic arm. This could be due to the scan type, the installed AUT orientation, or the size of the scan surface. In order to address these challenges, the PLGRM base can be relocated during a measurement. At the beginning of a test the location of the base of the robot is placed in the reference frame in addition to the AUT location and orientation. With that information the software can determine which points in a scan are within reach and which are not [3]. As data is collected the software also tracks which points have been measured. Once all reachable data is collected, the base of the robot can be relocated to a new position to collect additional data points. The data collected from all of these points is then combined into a single set of points stitched together from all the data. If doing a nearfield scan the data can then undergo a near to far field transformation with the complete data set. An example of an in situ scan in progress is shown in Figure 3. Here a large spherical surface was sampled around an aircraft. The scan size required a forklift to reposition the robot for collecting the various scan subsets. Since both the base and end effector of the robot are precisely tracked positional accuracy is maintained even with the nontraditional positioning method.



Figure 3 Measuring AUT in situ on NASA Ikana UAS

Here we can see how all of the features discussed are used in combination to support an aerospace in situ antenna

measurement. A hidden antenna under the radome was located after its installation to the aircraft and before the radome was installed. The scan surface was determined based on the location and orientation of the antenna in the radome. The forklift is being employed to get the probe to the height required to collect data. Finally, any AUT movement was tracked with targets mounted to the aircraft to correct for any drift in the aircraft position over time since it was supported by hydraulic landing gear. This allowed adjustments to the scan plane in real time thus maintaining positional accuracy of the sample points relative to the AUT and its support structure.

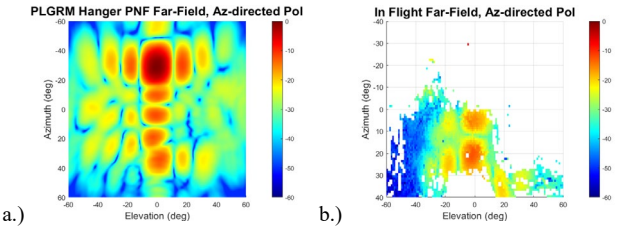
IV. Results

A. Traceability

Do to the flexible and portable nature of PLGRM it has the potential to provide antenna metrology throughout the development and integration of a AUT onto an aerospace platform. This creates a level of traceability can be crucial when trying to troubleshoot any issues or for characterizing an antenna as it is installed on the aircraft.

B. Comparing Hangar and Flight Data

The PLGRM was used to characterize the antenna performance of a novel conformal antenna installed on an aircraft. These results were compared with data collected during a subsequent flight campaign. [7] The data from the flight campaign was collected from an independent measurement system. However, flight testing was planned around measuring a specific portion of the antenna pattern. Antenna pattern measurements of all data collected for each measurement is shown in Figure 4. The antenna pattern on the left was measured in the hanger using PLGRM. Data on the right was collected over a series of flight passes. Note that the figure is inclusive of all data collected for the flights. Figure 5 compares the two patterns in the intended window and shows minimal difference between the two measurements on the sidelobes



a.) b.)

Figure 4 a.) Far-field pattern of ground testing with PLGRM, b.) Far-field pattern of in-flight testing

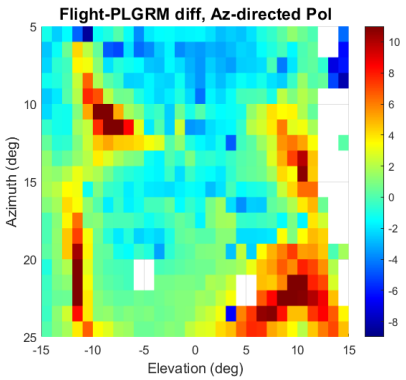


Figure 5 Far-field pattern comparison of PLGRM ground testing with inflight testing

V. Conclusion

Robotic antenna metrology systems have the potential to be a very powerful tool for aerospace applications. The accuracy and flexibility of PLGRM has led to an ever-growing list of measurement types and capabilities. This paper presented some the initial driving needs and then how that led to further developments. This included in situ measurements, hidden antenna measurements, and OTA system measurements. Future work and the approach to using the PLGRM to address those needs was also presented including phased array calibration, operational frequency extension, and system level emulation.

Acknowledgment

The authors would like to acknowledge the The Convergent Aeronautics Solutions (CAS) project and the Transformative Aeronautics Concepts Program (TACP) for supporting the continual development of the PLGRM System.

References

[1] J. M. Downey, B. L. Schoenholz, M. T. Piasecki, R. J. Kerczewski, “Phased Array Antenna for the Mitigation of UAS Interference,” in American Institute of Aeronautics and Astronautics (AIAA) Aviation Forum, Atlanta GA, June 25 2018.

[2] J. A. Nessel, J. M. Downey, B. L. Schoenholz, M. T. Piasecki, F. A. Miranda, “Potential Applications of Active Antenna Technologies for Emerging NASA Space Commincations Scenarios,” in European Conference on Antennas and Propagation, May 26 2020.

[3] P. A. Slater, J. M. Downey, M. T. Piasecki and B. L. Schoenholz, "Portable Laser Guided Robotic Metrology System," in Antenna Measurement Techniques Association Symposium (AMTA), San Diego, 2019.

[4] D. R. Novotny, J. A. Gordon, M. S. Allman, J. R. Guerrieri, and A. E. Curtin, “Three antenna ranges based on articulated robotic arms at the national institute of standards and technology†: Usability for over-the-air and standard near-field measurements,” in 2017 IEEE Conference on Antenna Measurements Applications (CAMA), Dec 2017, pp. 1–4.

[5] J. Hatzis, P. Pelland, and G. Hindman, “Implementation of a combination planar and spherical near-field antenna measurement system using an industrial 6-axis robot,” in AMTA 2016 Proceedings, Oct 2016, pp. 1–6.

[6] B. L. Schoenholz, J. M. Downey and M. T. Piasecki, "Design of a Thermal Testbed for Metrology of Active Antennas," 2022 Antenna Measurement Techniques Association Symposium (AMTA), Denver, CO, USA, 2022, pp. 1-5,.

[7] M. T. Piasecki, P. A. Slater, J. M. Downey, B. L. Schoenholz, and K. M. Lambert, “Active array measurements using the portable laser guided robotic metrology system,” 2019 Proceedings of the Antenna Measurement Techniques Association, Oct 2019.