Recent Development in UAV-based Antenna Pattern Characterization for Weather Radars

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***Abstract*—The evaluation and testing of the radiation characteristics of antennas are performed in antenna ranges, and in this context, in-situ measurements provide a means to verify the performance of the antenna such that its intrinsic radiation patterns are not substantially modified by its operational environment. Conventional outdoor range facilities are limited by space and cost constraints, and it would be impractical to develop such facilities for a single radar, let alone a network with a large number of radars. Continuing advances and the availability of relatively inexpensive commercially-off-the-shelf unmanned aerial vehicle systems allow the development of in-situ antenna measurement systems for a wide variety of operating frequencies. Such unmanned aerial vehicle-based antenna ranges are important for polarimetric radars, and in particular for polarimetric calibration since a complete control of the measuring instrument is possible.**

This paper presents an update of the current in-situ antenna characterization and calibration of a radar system using an unmanned aerial vehicle developed by the Advanced Radar Research Center at The University of Oklahoma.

***Index Terms*—weather radars, radar calibration, dual-polarized, antenna measurements, UAV, in-situ measurements, remote sensing**

I. Introduction

The Spectrum Efficient National Surveillance Radar (SENSR) is a cross-agency program formed by the Federal Aviation Administration (FAA), Department of Defense (DoD), Department of Homeland Security (DHS), and the National Oceanic and Atmospheric Administration (NOAA), which attempts to efficiently utilize a band of the Government-owned radio frequency (RF) spectrum and provide a new multifunction phased array radar (MPAR) system for weather, air traffic, national defense and law enforcement, meeting the needs of all four agencies [1]. For weather observations, the benefits of utilizing a phased array radar include fast scanning updates, relatively lower long-term costs, low profile, reconfigurability, adaptability, scalability and high graceful degradation [2]. These systems require accurate characterization of their components (e.g., antenna radiation patterns) such that calibration techniques can be performed to ensure that no biases are being introduced in the polarimetric weather radar products [3] (e.g., reflectivity, mean radial velocity, copolar correlation coefficient), which would adversely affect automated algorithms and the ability of operators to produce accurate forecasts.

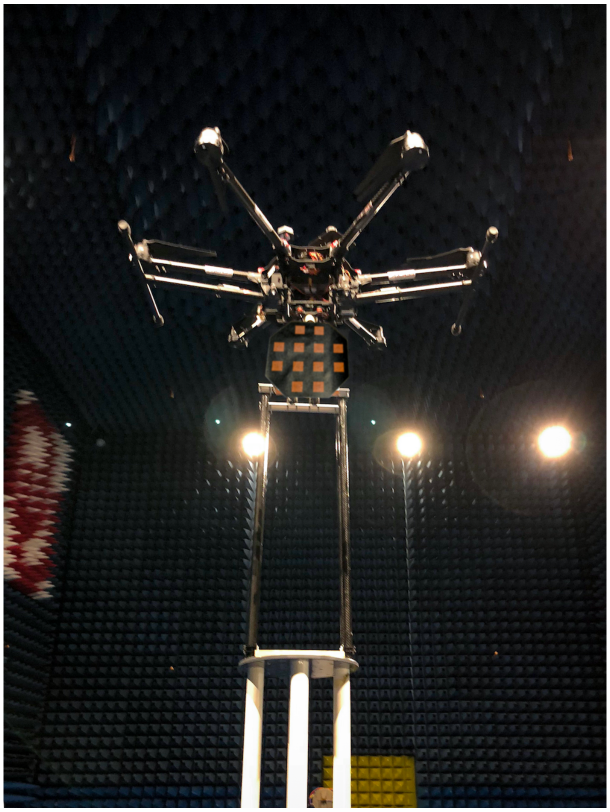

Fig. 1. UAV system for antenna pattern measurement and radar characterization and calibration developed at the University of Oklahoma, Advanced Radar Research Center (OU ARRC).

Characterizing large array antennas requires specialized indoor or outdoor RF range facilities that inherently intro-

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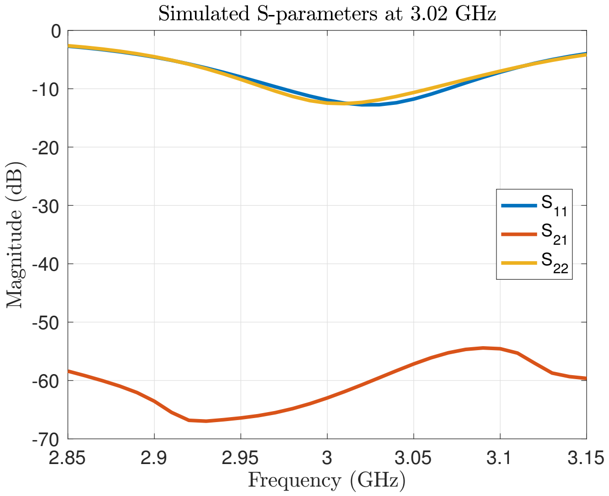

Fig. 2. Simulation performance of the new iteration of the probe antenna for the UAV-based antenna measurement system: S-parameters.

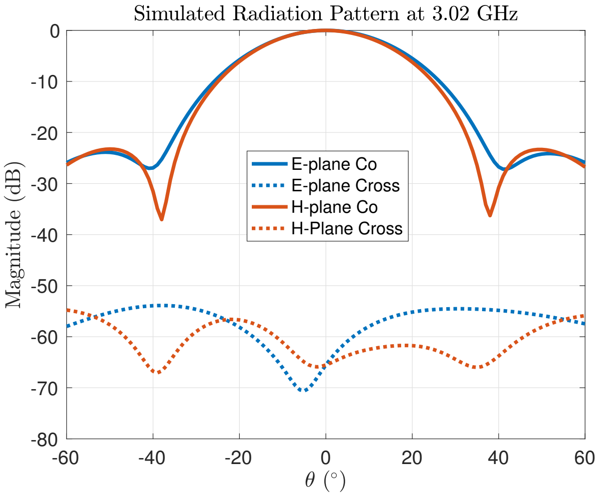

Fig. 3. Simulation performance of the new iteration of the probe antenna for the UAV-based antenna measurement system: antenna radiation patterns for E- (blue) and H-planes (red).

duce space and cost constraints when testing. However, an antenna characterized in an indoor facility does not necessarily perform identically in an outdoor environment under normal operating conditions [4]–[6]. An outdoor installation is necessary to adequately characterize antenna systems in their operational environment such that the environmental effects can be assessed, and to ensure that it meets its performance requirements [2], [4]–[6]. Unfortunately, it is cost-prohibitive and impractical to develop such facilities for a single radar, let alone for a network with a large number of radars. [4]–[6]. Previous work in this area required a wide variety of methods and equipment for calibration of different aspects of radar systems, including tethered balloons [7] and helicopters [8], [9]. In weather radars, calibration is commonly performed using a known fixed target as a reference, a tethered balloon, or by pointing the radar to zenith. Additionally, in such cases there is usually limited or no control over the measured target, and thus, uncertainty exists. Ideally, complete control of the in-situ measuring instrument would be necessary to accurately characterize the radar system, which can be achieved with the use of unmanned aerial vehicles (UAVs). Aided by continuing advances in UAV technology which offer low-cost consumer-grade electronic components with sufficient precision, researchers [10]–[22] have shown that it is possible to produce antenna pattern measurements using micro and small UAVs for a wide variety of frequencies in the RF spectrum. For measuring weather radars operating at microwave frequencies, however, aircraft stability, targeting precision and alignment errors are most critical in obtaining accurate measurements, where sub-centimetric accuracy is ideal. Additionally, antennas for applications in polarimetric weather radars operate in dual-polarized simultaneous transmission and simultaneous reception mode and require 0.1 dB co-polarization mismatch levels and below -30 dB cross-polarization levels for accurate characterization. So far, a systematic method to consistently attain the desired calibration accuracy which has not yet been devised [23]–[25]

In this paper, recent upgrades of the UAV-based system for antenna pattern characterization for weather radars [20], [26] is presented.

II. RECENT DEVELOPMENTS

The works of [20] and [26] presented the on-going efforts to produce a system capable of in-situ antenna measurements, and radar characterization and calibration for the SENSR program, see Fig. 1. The following subsections describe the upgrades made to the UAV system, the gimbal and the antenna.

A. UAV frame and gimbal

In addition to the specifications presented in [2], [20], [26], a few modifications have been made to the original setup. The UAV currently consists in a DJI S900 frame with folding arms, propellers and landing gear. A carbon plate has been added to the underside to hold a 6S 12C 20Ah Li-Po battery, the gimbal and the probe antenna.

A replacement of InfinityMR S2 gimbal used in the previous prototype with an InfinityMR PRO V2 enables larger payload capacity and position accuracy. This gimbal upgrade can hold a 12-element array without losing position accuracy and is balanced in all axes (i.e., roll, pitch and yaw). The flight controller was upgraded to a Pixhawk 2 with the Here+ RTK GPS with 2 cm HDOP. All operations are monitored through Mission Planner, which allows monitoring flight parameters in real time and for measurement flight patterns to be uploaded quickly in the field. It is also controlled simultaneously through an RC transmitter at 2.4 GHz, using a telemetry frequency of 900 MHz.

B. Probe antenna

An overhaul of the simulation and design, optimizing the antenna layer stack-up and via interconnection strategy, impedance matching, power distribution networks, extension

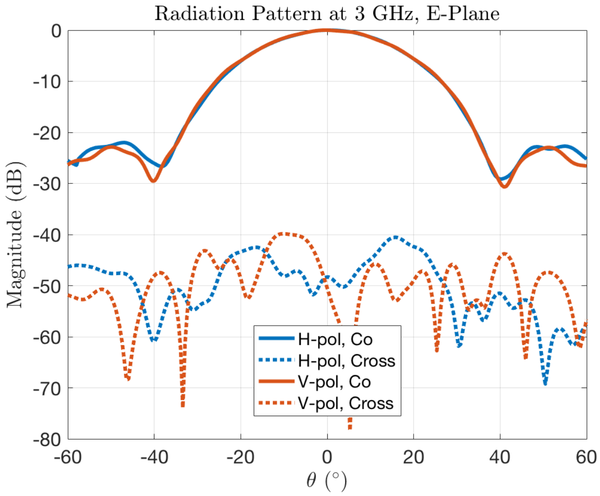

Fig. 4. Measurements of the new probe antenna in the E-plane, for co-polarization (solid) and cross-polarization (dashed), and for horizontal (blue) and vertical (red) polarizations.

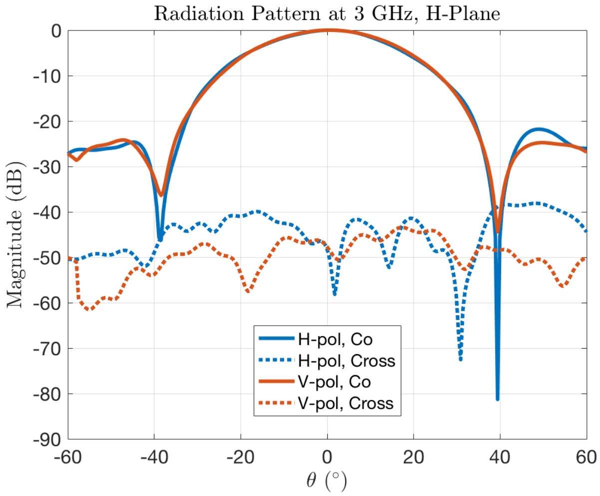

Fig. 5. Measurements of the new probe antenna in the H-plane, for co-polarization (solid) and cross-polarization (dashed), and for horizontal (blue) and vertical (red) polarizations.

to dual polarization, and inclusion of connector parasitic modeling has been performed. An overview of the resulting performance is shown in Figs. 2 and 3. It has been optimized to operate at around 3.02 GHz (the notional operating frequency of the MPAR system), and has a bandwidth of about 70 MHz. The cross-polarization isolation is simulated as being -55 dB in the worst case at broadside; however, mounting (and UAV) effects will degrade this, but it provides a better performance the previous version of the probe antenna (at around -30 dB). The matching between H and V has been optimized from an impedance (and pattern) perspective near broadside and over the entire antenna bandwidth. The overall beamwidth is around $24°$. in both dimensions–an improvement over the previous version by about 25%.

C. Chamber measurements

To ensure the performance of the antenna meets the required standards and to assess the level of the effect of the UAV and gimbal structure on the antenna radiation pattern, the system is measured inside an anechoic chamber at the facilities of the ARRC at OU. The measured results are presented in Fig. 4 and 5. The measurement was performed at 3.00 GHz. The cross-polarization isolation is measured at -40 dB in the worst case at broadside. However, even $20°$ away from broadside, the cross-polarization remains exceptionally low on the principal planes. The gimbal should keep any such deviations less than $1.0°$. The matching between H and V has been optimized from the previous version.

D. Modeling of UAV effects on probe antenna

The signal of the probe is slightly modified when it is mounted on the UAV, due to interactions (e.g., coupling and reflections) of the probe and the structure of the UAV. Since a model of such phenomena would be extremely difficult to accurately derive analytically, a simple radiating element model is chosen as

$$E^{i}_{\mathrm{R,UAV}} = f^{\mathrm{P}}(\theta^{i}_{\mathrm{R}}, \phi^{i}_{\mathrm{R}}) \frac{e^{-jkr^{i}_{\mathrm{R}}}}{r^{i}_{\mathrm{R}}} \left(A + B\cos(C\theta)\cos(C\phi)\right), \tag{1}$$

where $f^{\mathrm{P}}(\theta^{i}_{\mathrm{R}}, \phi^{i}_{\mathrm{R}})$ is the value of the probe antenna pattern for the i-th radiating element in the incidence direction relative to the phase center of the probe, r^{i}_{R} is the distance to the i-th radiating element, and a ripple and roll-off model that is dictated by the constants A, B, and C. Such constants are determined ad hoc to match measurements and simulations previously done for similar antennas in a controlled environment. The modified pattern with the UAV structure effects and geometries are presented in Fig. 6. Such model is used within a simulation framework to analyze the possible error sources measurement biases due to the misalignment and positioning and orientation of the UAV and gimbal.

III. CONCLUSIONS

The current state of the UAV-based antenna characterization and radar calibration system for weather radars has been presented. With recent upgrades to the system, it is becoming possible to perform measurements of dual-polarized antenna systems and to calibrate them in the near future. Currently, the probe antenna mounted on the UAV system's gimbal is capable of -40 dB cross-polarization isolation with a beamwidth of $24°$. Additionally, with the upgrade of the RTK GPS system, sub-decimeter accuracy is achieved at around 2 cm. The next steps for the project is to perform field measurements of the MPAR system, as part of the SENSR program.

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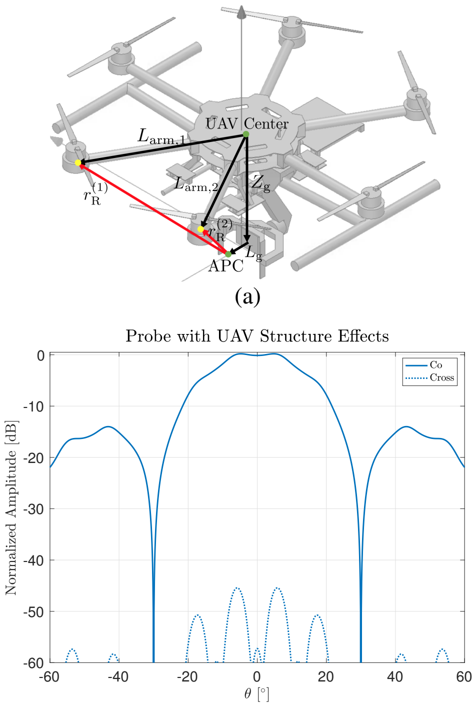

(a)

(b)

Fig. 6. (a) Geometry for two radiating elements at the extremes of the arms of an hexacopter. (b) Antenna pattern for probe mounted on UAV, with co-pol (solid) and cross-pol (dashed) components.

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