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An UAV-Based Polarimetric Antenna Measurements for Radar and Communication Systems from 3 GHz to 32 GHz

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***Abstract*—In this paper, an UAV in-situ metrology concept to characterize antennas in the the far-field region, is presented. The proposed system is implemented with a quad-ridged horn as a probe and a transmitter mounted on a commercial hexacopter platform. The system was fully characterized and tested in an indoor far-field chamber to evaluate the impact of the scattering from the UAV platform on performance of the antenna probe in the transmit mode. Depending on the polarization, plane of incidence, and frequency of operation, the electromagnetic scattering of the UAV platform induces ±0.2 dB ripples in the co-polar patterns and less than 2 dB cross-polarization deterioration across the half-power beamwidth (HPBW).**

***Index Terms*—Antenna, array, calibration, metrology, far-field, phased array radar, radome, reflections, wet radome, SATCOM, 5G, UAV, UAS.**

I. Introduction

Antenna arrays commonly used for radar and communication systems are designed, characterized, and tested in a controlled environment (outdoor or indoor antenna test ranges). In most cases, a good agreement can be obtained in comparison with numerical simulated and measured results. However, this good agreement can be quite different when the antennas are integrated with the radar or communication system, radome, and other infrastructures in the field. External environmental factors such as antenna support, ground reflections, temperature, signal, dirt, pollution, interference, rain, ice, and snow over the radome, may change the radiation properties of the radome and thus the antenna. Depending on the operating frequency, the overall performance of the radar and communication system can be degraded. In most cases, this degradation increases the side-lobe levels and reduces the gain. While in some cases, it creates ripples in the main beam and also substantially degrades the cross-polarization levels [1], [2].

Most of the radar and communication systems use a small portion of the licensed spectrum (¡10% fractional bandwidth). However, depending on the application type, the operating bandwidth can be anywhere in the frequency range of 1 GHz to 90 GHz. There are numerous radio frequency bands allocated to support radar operations. For example, in the United States, the air traffic control (ATC) and the department of defense (DoD) early warning radars use a frequency band from

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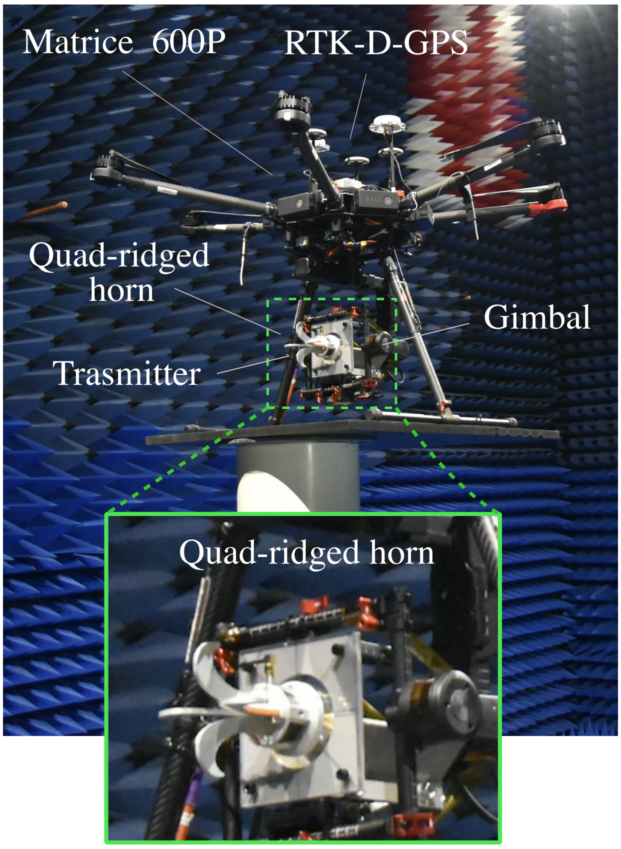

Fig. 1. Proposed ultrawideband (3-32 GHz) metrology UAV-based system for in-situ testing of antennas in radars and communication systems.

1.215 GHz to 1.390 GHz. Maritime and weather radars use 2.7 GHz to 3.1 GHz bands. DOD surveillance radar operates in the 3.1-3.7 GHz frequency band. NOAA weather radars, FAA TDWR, surveillance and air defense (airborne, ship-borne, land-based), fire-control, maritime, test range, SAR's, altimeters, scatterometer, airborne, and spaceborne radars use 5.250–5.925 GHz band. Airborne radars operate in five different bands (8.5 GHz to 10.55 GHz, 13.25 GHz to 14.2 GHz, 15.4 GHz to 17.3 GHz, 24.05 GHz to 24.65 GHz, 31.8 GHz to 36 GHz). Airborne fire-control, beacons, atmospheric research, cloud detection, and synthetic vision radars operate from 92 GHz to 100 GHz [3]. In the case of weather radars, high-performance dual-polarized antennas with co-polar pattern mismatch below ±0.1 dB and cross-polarization isolation

TABLE I
SYSTEM SPECIFICATIONS.

Category	Specifications	Value
UAV Platform	Model/Maker	Matrice 600P/DJI
	Dimensions	1.66 m x 1.52 m x 0.727 m
	Weight (no payload)	10 kg
	Max. takeoff weight	15.5 kg
	Position accuracy	GPS: ±5.5 m to ±0.5 m
	Position accuracy	RTK: ±1 cm to ±2.0 cm
	Max. angular velocity	Pitch: 300°/s, Yaw: 100°/s
	Max. pitch angle	25°/s
	Max. ascent speed	5 m/s
	Max. descent speed	3 m/s
	Max. serv. ceiling	2500 m
	Hovering time	20 min
	Operating temp.	-10°C to 40°C
Gimbal	Model/Maker	Ronin-MX/DJI
	Operation modes	Free, Follow, FPV
	Dimensions	28 cm x 34 cm
	MIU	Independent
	Connectivity	Bluetooth/USB
	Operation. Freq.	2.4 GHz
	Running time	3 hrs
	DC voltage	12 VDC
	Operating temp.	-15°C to 50°C
Antenna Probe	Model/Maker	Quad-ridged (QH2000)/SATIMO
	Frequency	2 GHz-32 GHz
	Beamwidth	160° -25° (H-planes)
	Beamwidth	110°-25° (E-planes)
	Gain	2.2 dB-15.5 dB
	Return loss	7 dB - 10 dB @ (2 GHz-32 GHz)
	Dimensions	11 cm x 10.5 cm x 10.5 cm
	Weight	≈ 0.24 kg
Transmitter	Model/Maker	Windfreak technologies
	Freq. operation	10 MHz to 32 GHz
	Tx. power	20 dBm (CW)
	Dynamic range	50 dB
	Amplitude resol.	0.01 dB
	Phase resol.	0.01°
	Dimensions	4 cm x 4 cm x 2 cm
	DC voltage	12 VDC
	Weight	¡ 0.1 lb

higher than 40 dB are required. To achieve such performance over ±45 degrees field of view, is quite a challenge especially when phased array antennas are used [4], [5].

Nowadays, antenna test and measurement, and radar characterization using UAVs are very popular, ranging from micro and small to medium and large frames. It has seen a fast-paced evolution in the past decade, in virtue of the increased availability of commercial off-the-shelf flight solution suites with a high degree of precision and performance at lower costs [6]–[19]. The predecessors to this work have explored the feasibility of performing accurate UAV-based far-field antenna measurements through outdoor simulations and by establishing design guidelines to mitigate many error sources [20], and studying the effects of coupling between the UAV structure and the probe antenna through EM simulations and indoor anechoic chamber characterizations [21] for the selection of the best type of probe antenna that meets the mission requirements [4]. In all previous applications, the used probes operate in a small range of frequencies. This represents a big limitation since full proof characterization with a UAV platform is required to identify possible patterns of degradation of the probe due to the induced scattering of the drone. This work proposed a UAV platform integrated with a front-end system that enables antenna and radar tests for the frequency range between 3 GHz to 32 GHz. Full characterization of the probe with the UAV platform was performed, and the results show this new concept can be used for different applications that require in-situ antenna and radar tests. This paper is organized into three sections. Section II describes the proposed system. Section III discusses the main design considerations, including platform dimensions, endurance, payload, induced platform scattering, and performance. Section IV presents preliminary simulated and measured results. Finally, Section V summarizes and highlights the most remarkable findings and impact of these results.

II. System Description

The proposed metrology system, shown in Fig. 1, was developed to provide an UAV platform with a single front-end equipment to perform in-situ antenna patterns, calibration of communication, and radar systems that operate in the frequency range from 3 GHz to 32 GHz. The system is mainly composed of three subsystems. The UAV platform, the gimbal, and the front-end subsystem which is composed of an ultrawideband dual-polarized antenna probe interconnected with a CW transmitter source. The summary of the system specifications is listed in Table 1.

1) UAV platform: The UAV platform is the hexacopter DJI Matrice 600P that provides a maximum flight time from 20 min to 60 min with three sets of interchangeable batteries. This platform provides excellent stability for a maximum payload of 2 kg. The system was tested with a wind load up to 20 mph providing excellent test results. Real-time kinematic differential GPS (RTK D-GPS) is integrated with the UAV platform, and it provides position accuracy lower than 2 cm.

2) Gimbal: The DJI Ronin-MX gimbal, which is used to carry the antenna probe, is very stable and flexible for accurate position alignment between the AUT and the probe. Independent IMU's make this gimbal to be accurate. This gimbal can be controlled automatically and manually or by point-of-interest (POI) through the mission planner application, with an accuracy of 0.02°.

3) Transmitter: On the gimbal, a CW transmitter source and antenna are used for AUT test in receive mode. The transmitter is a two-channel synthesizer that generates signals from 10 MHz to 14 GHz. An active multiplier is used to expand the frequency up to 34 GHz with an output power of 30 dBm. SWAP configuration of the transmitter, high dynamic range and amplitude (0.001 dB), and phase resolution (0.01°), make this transmitter an ideal candidate for this UAV metrology concept.

TABLE II
PROBE ANTENNAS MECHANICAL CHARACTERISTICS.

Probe type	Model/Maker	Dimensions (inches)	Weight (lbs)
Dual-ridged horn	SH2000/Satimo	4.13 x 2.4 x 4.1	1.1
Quad-ridged horn	QH2000/Satimo	4.3 x 4.13 x 4.13	0.53

4) Antenna probe: In the proposed system, two ultrawideband probes were taken into consideration. A single polarized dual-ridged horn antenna and a dual-polarized open boundary quad-ridged horn antenna. Both antennas operate from 3 GHz to 32 GHz, having a half-power beamwidth (HPBW) from 175°/160° to 28°. Figure 3 illustrates the antenna geometries, realized gain, and half-power beamwidth of both antenna probes. Small and light-weight probes are ideal for UAV-base

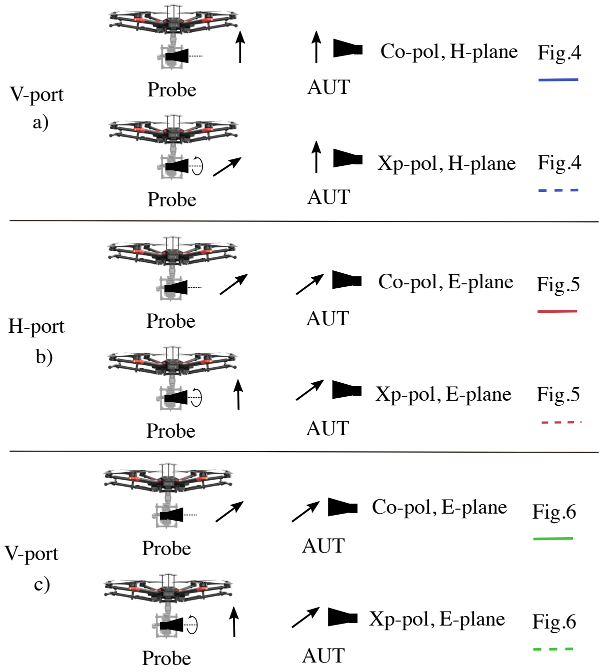

Fig. 2. Test setup configuration for probe characterization with and without drone.

metrology system, since they will be mounted in a gimbal for accurate alignment with the AUT.

III. Design Considerations

In many cases, commercial probes, mounted on the UAV platforms, are used assuming the probe antenna patterns can not be affected by the electromagnetic scattering and interaction between the probe and UAV platform. This assumption can be valid when the electrical dimensions of the antenna are large in comparison with the UAV platform. For microwave or milliliter waves applications, the UAV platform is always larger than electrical dimension of the antenna, thus the characterization of the probe with a UAV platform is required for accurate measurements of the radiation patterns of the antenna under test. Previous work done by researchers of the University of Oklahoma [16], [20], [21] performed exhaustive numerical simulation analysis to characterize the impact of electromagnetic scattering of the drone in the radiation patterns of the antenna probe. In the case of Matrice 800 and Matrice 600, a half-power beamwidth below 40° was suggested to reduce the scattering impact on the co-polarization and cross-polarization levels of the probe [21].

Another important aspect to guarantee an antenna or radar test using a UAV platform relies on the flight stability, position accuracy, dynamic range, and alignment between the AUT and the probe. Matrice 800/600 drone uses mature and proved technology that enables stable test operation in wind condition up to 20 mph with a flight time of 20 min to 60 min using 1 to 3 sets of batteries. Differential GPS based on real-time Kinematic (D-GPS RTK) algorithm was tested on flight conditions. Previous results demonstrated a drone position with an accuracy ±2 cm (in x-,y- and z-axis) [16], [17]. Having an accurate position of the drone during each mission is quite important to compensate for any position deviation due to the wind of anomaly in the flight path. A high dynamic range is required for antenna patterns test, about 30 dB SNR is desirable for far-field antenna patterns. In the proposed system, the synthesizer source can provide maximum power of 30 dBm to compensate for the path loss, especially at high frequencies, gain of 30 to 40 dB is required in the receiver path. The probe and transmitters were mounted on a Ronin-MX, and this was implemented with a smooth-track algorithm that ensures smooth movements during flight conditions. Probe, synthesizer, and batteries position on the gimbal is critical to guarantee balance and stability with a low-power consumption in the motors and IMUs. The slip ring on the gimbal allows 360° continuous rotation in azimuth. This feature enables the possibility of a wide range of probe position selection with respect of the UAV platform that helps to minimize the induce scattering of the UAV when the probe is transmitting.

IV. Antenna Probe Characterization

In this platform, a commercial open boundary quad-ridged antenna (SATIMO QH2000) was used as a probe and also as an AUT. This antenna is dual-polarized that enables antenna patterns to test with polarization diversity without the need of having the probe rotated. This antenna is compact and lightweight, which makes this antenna very convenient for an in-situ UAV- base antenna pattern test system. Full characterization of the probe with and without the UAV was performed. The indoor far-field anechoic chamber of the Advanced Radar Research Center (ARRC) was used. For this study, a frequency range from 3 GHz to 18 GHz was used due to the limitations of the antenna range system. Figures 4 to 6 show the far-field antenna radiation patterns with and without the UAV for transmit mode for V- and H-polarization ports. In the Figures 4 and 6, the solid lines represent the co-polar patterns, and dashed lines represent the cross-polar patterns. The black color represents the AUT measured with an isolated probe (no drone). The solid blue, red, and green lines represent the patterns of the AUT measured with a probe embedded in the drone. To facilitate the understanding of the measured results, Fig. 2 was created to illustrate the test setup configuration for the probe characterization using both V- and H-polarization ports. As it is illustrated in Fig. 4 and 6, the patterns of the SATIMO QH2000 antenna, used as a probe, do not have symmetry in the E- and H-planes. Strong induced EM scattering is expected for broaden beamwidth when is perpendicular to UAV the platform. This effect is illustrated in Fig. 4, where pronounced ripples (±1 dB) in the co-polar patterns are observed, mostly produced by the scattering of the drone, especially at higher frequencies. Due to the large beamwidth of the probe, especially in the lower frequencies (3 GHz to 5 GHz), the scattering fields, induced from the UAV platform, increase the cross-polarization level from 5 dB to 7 dB. For the higher frequencies (10 GHz - 18 GHz), where the beamwidth of the probe is below 40°, the impact of induced scattering from the drone is lower. Less than 4 dB is observed after 10 GHz.

Fig.5 shows the case when the antenna probe is polarized horizontally (see Fig.2b-c). In this case, the probe beamwidth is narrower, which reduces significantly the adverse effect of the scattering produced in the UAV platform. Ripples below ±0.2 dB are observed in the co-polar beam patterns and cross-polarization level increases 4 to 5 dB at the lower frequencies

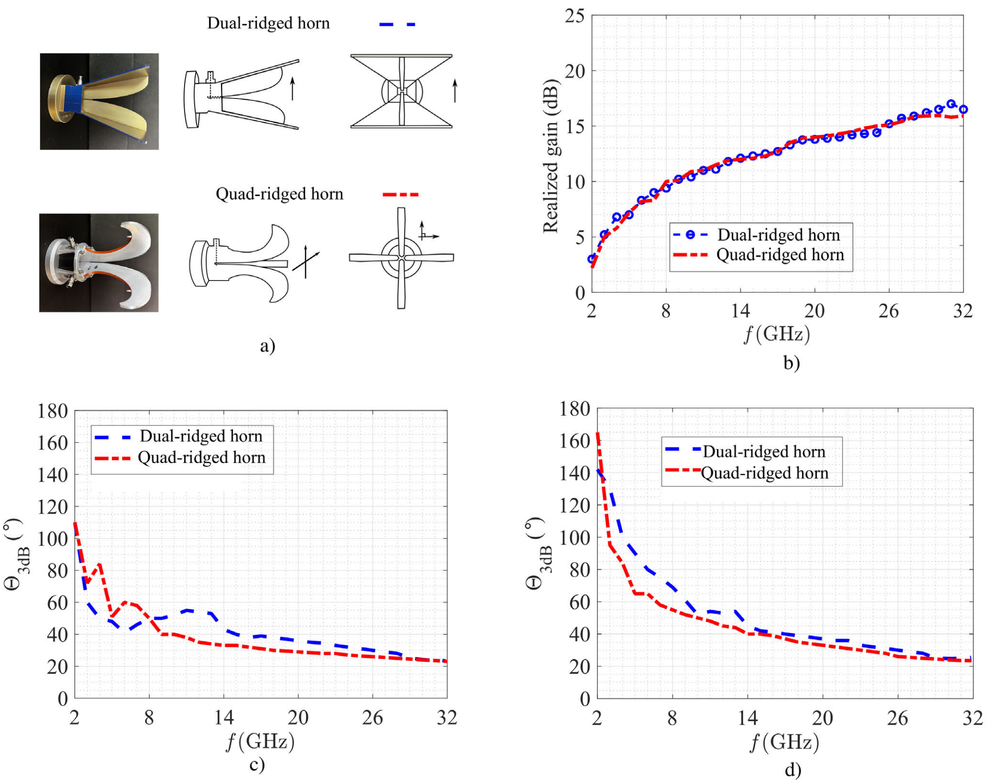

Fig. 3. Commercial antenna probes used in this study. (a)Pictures and basic geometry of dual-ridged horn (SH2000) and quad-ridged horn (QH2000). (b) Realized gain for both antenna probes (c) E-plane HPBW of dual-ridged and quad-ridged using V-port (d) H-plane HPBW dual-ridged and quad-ridged H-plane HPBW using V-port.

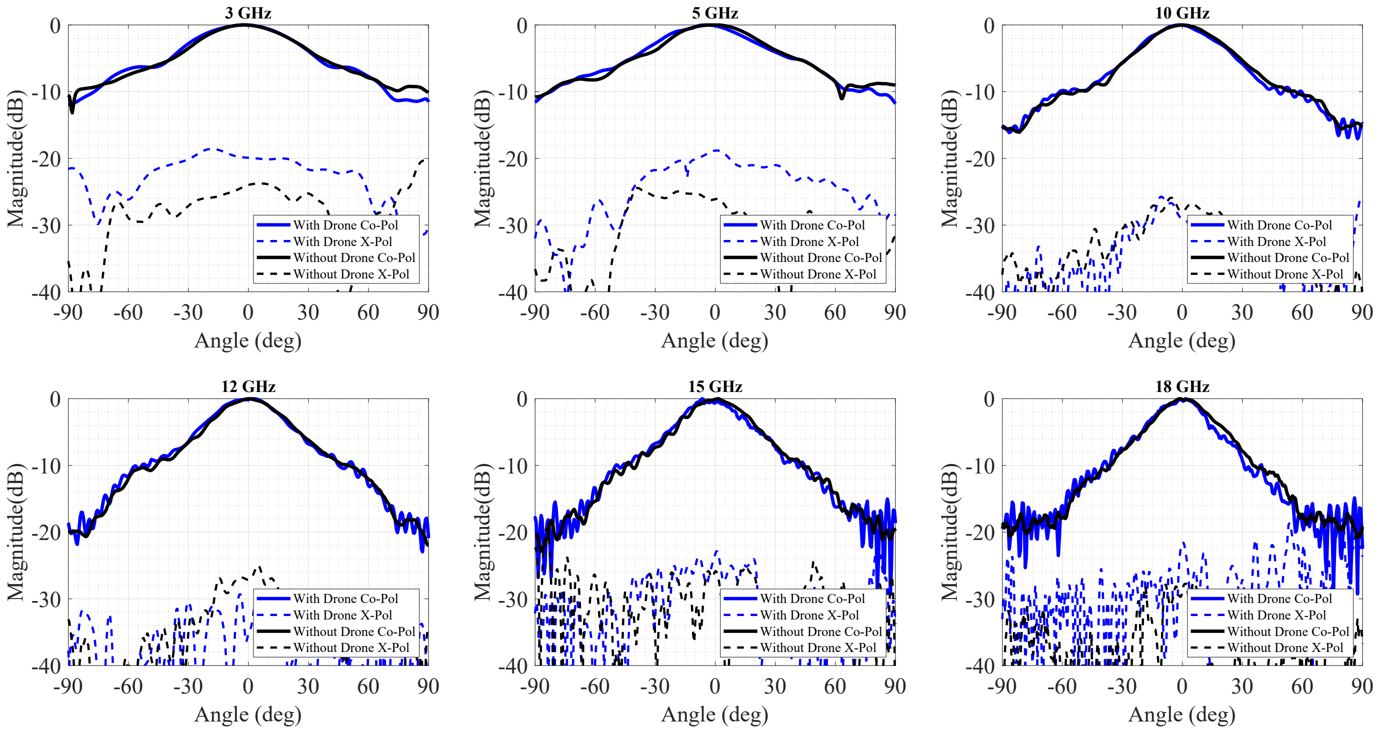

Fig. 4. Measured co-pol and cross-pol radiation patterns of the AUT in the H-plane using the proposed probe with and without the UAV platform when the probe uses the V-port.

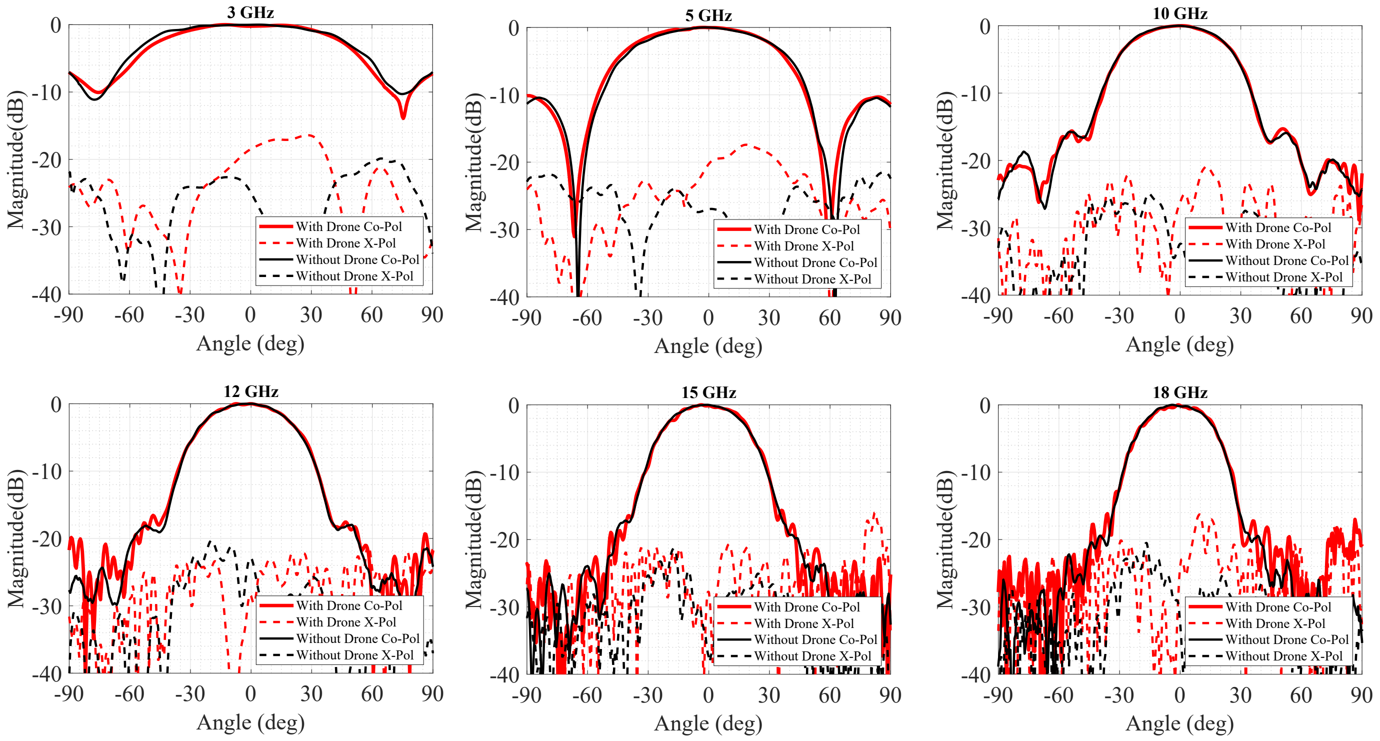

Fig. 5. Measured co-pol and cross-pol radiation patterns of the AUT in the E-plane using the proposed probe with and without the UAV platform when the probe uses the H-port.

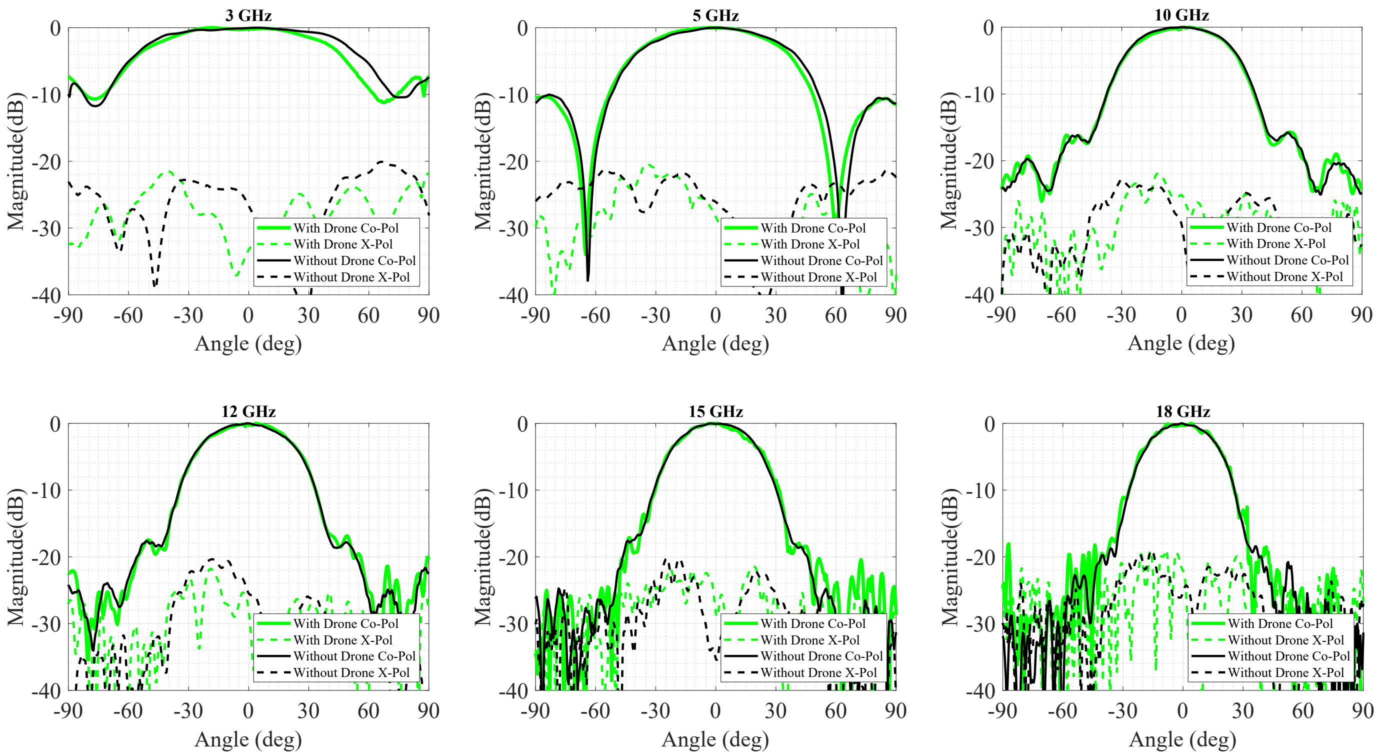

Fig. 6. Measured co-pol and cross-pol radiation patterns of the AUT in the E-plane using the proposed probe with and without the UAV platform when the probe uses the V-port rotated mechanically 90° with the gimbal.

and below 2 dB in frequencies higher than 10 GHz. Improved results can be obtained using the vertical polarization port rotated 90°. Fig.6 shows the measured results of the AUT antenna using this configuration. The co-polar radiation patterns present lower ripples (¡±0.1 dB) and cross-polarization levels are below 2 dB in the half-power beamwidth.

V. Conclusion

A new in-situ UAV metrology platform equipped with an ultrawideband transmitter probe is presented. The platform was designed to operate from 3 GHz to 32 GHz with a single front-end system. The proposed UAV metrology platform enables far-field antenna pattern measurements of radars and communications systems sub-rounded with its environment (radome, ground clutter, metal supports, rain, temperature gradient, rain, snow, ice, dirt, etc.). In this paper, measured results of an AUT using the proposed system are presented. The measured results validate the assumption a half-power beamwidth of 40° across the operation frequency is recommended to minimize the induced electromagnetic scattering from a large UAV (Matrice 800/600). The proposed system uses a stable and mature UAV technology with a state-of-the-art RTK -DGPS with precise gimbal, which makes an excellent platform candidate for in-situ far-field antenna test and radar/ communication system testing.

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