An Ultrawideband UAV-Based Metrology Platform for In-situ EM Testing of Antennas, Radars, and Communication Systems

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***Abstract*— In this paper, an ultrawideband in-situ metrology UAV system to characterize antennas in the far-field region is presented. The proposed system uses a customized antenna probe designed to operate from 2.5 GHz to 32 GHz. In comparison with previous works, this system has a new probe with a unique design to obtain better match in the co-polar beam patterns and high cross-polarization isolation, ideal for testing dual-polarized radar and communication systems. The UAV test system is developed taking into account the electromagnetic interaction between the UAV and RF system. High position accuracy, flight stability, and excellent dual-polarization performance are key features in this new system. Design trade-offs of the proposed system for various applications, and its preliminary results, indicate this new concept is suitable for in-situ antenna measurements of radar and communication systems.**

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

I. Introduction

Aperture and antenna arrays used for radar and communication systems are commonly characterized and tested in a controlled environment such as outdoor or indoor antenna test ranges. In most of the cases, the antenna under test (AUT) is characterized alone without other subsystems such as front-end, radome, pedestal, etc. When the antenna aperture is integrated with other radar or communication sub-systems and put it in operation, antenna performance is not the same as tested in a controlled environment. Antenna performance degradation due to electromagnetic interference (EMI) between an antenna and a sub-system can be worse if the system is operating under adverse environmental conditions. Rain, ice, snow, dirt, pollution, temperature, ground reflection, clutter can impact gain, polarization, side-lobes, and main beam direction. The need for in-situ characterization of the antenna for a radar or communication system that is operating in its real environment, is required to guarantee acceptable performance of the system in real operational environment. [1], [2].

Radar and communication systems use a small portion of operational commercial frequency bands (<10% fractional bandwidth). However, depending on the application, this can be anywhere in the frequency spectrum from 1 GHz to 90 GHz. Some examples in the radars bands in the U.S include the air traffic control (ATC) and DOD early warning defense uses from 1.215 GHz to 1.390 GHz, maritime and weather radar uses 2.7 GHz to 3.1 GHz. DOD surveillance radar uses from 3.1 GHz to 3.6 GHz. NOAA weather radar, FAA TDWR uses 5.5 GHz to 5.9 GHz. Airborne radars operate in five different bands (8.5 GHz to 10.5 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, cloud radars, and synthetic vision radar operates from 92 GHz to 100 GHz [3].

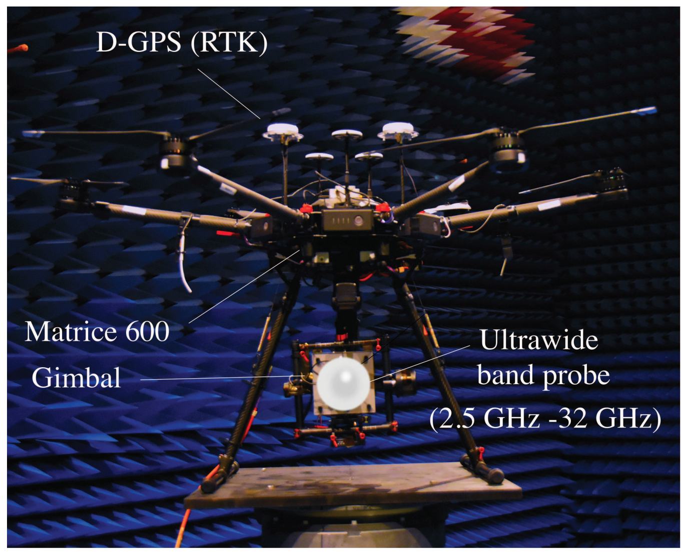

Fig. 1: Picture of the ultrawideband (2.5 GHz to 32 GHz) metrology UAV-based platform for in-situ testing of radars and communication systems during test in the OU indoor far-field chamber.

In the case of weather radars, the most common radars operate below 10 GHz. In most of the cases, weather radars use dual-polarization capabilities, that enable hydrometer classification. The need of high performance dual-polarized antennas with co-polar pattern mismatch below $\pm$ 0.1 dB and cross-polarization level lower than -40 dB is critical for this mission. To achieve such performance over $\pm$45 degrees field of view,

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it is quite challenge using phased array antennas, specially when the radar is deployed in the field [4]–[7]. The field of RF measurement and characterization using UAVs, ranging from micro and small to medium and large frames, 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 high degree of precision and performance at lower costs [8]–[28].

The predecessors to this work have explored the feasibility of performing accurate UAV-based far-field antenna measurements through simulations and by establishing design guidelines to mitigate many error sources [29], and studying the effects of coupling between the UAV structure and the probe antenna through EM simulations and indoor anechoic chamber characterizations [30] for the selection of the best type of probe antenna that meets the mission requirements [4].

This work proposes a UAV platform integrated with a single source probe antenna to enable full characterization and calibration of communication system and radar systems that operate in a range of frequency between 2.5 GHz to 32 GHz. The new probe has unique features that enable very similar electromagnetic performance in the whole frequency range. This paper is organized in five sections. Section II, describes the proposed system. Section III discusses the main design trade-offs including platform dimensions, endurance, payload, induced platform scattering and performance. The section IV presents preliminary simulated and measured results. Finally, Section V summarizes and highlights the most remarkable findings and impact of these results.

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: $\pm$5.5 m to $\pm$0.5 m
	Position accuracy	RTK: $\pm$1 cm to $\pm$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 (up 1 hr with 3 sets of batt.)
	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 and USB connections
	Operation. Freq.	2.4 GHz
	Running time	3 hrs
	DC voltage	12 VDC
	Operating temp.	-15°C to 50°C
Antenna Probe	Model/Maker	UWP232/PAARD-OU
	Frequency	2.5 GHz-32 GHz
	Beamwidth	100°-20° (E-, H-planes)
	Gain	6 dB-17 dB
	Return loss (RL)	12 dB @ (2.5 GHz-32 GHz)
	Dimensions	10 cm x 4 cm x 4 cm
	Weight	< 1.5 lb
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

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 2.5 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 I.

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 up to 30 dBm. High dynamic range and amplitude (0.001 dB), and phase resolution (0.01°), make this transmitter an ideal candidate for this UAV metrology concept.

4) Antenna probe: In the proposed system, the used antenna is designed to perform symmetric radiation patterns in the E- and H-planes with a beamwidth between 100° for the lowest frequency (2.5 GHz) and 20° for the highest frequency (32 GHz). The proposed antenna used as a probe is a lens corrected quad-ridged conical corrugated antenna. This antenna was designed for high compactness and low weight, ideally to be carried in the Matrice 600P and Robin MX/DJI gimbal. Half-power beamwidth (HPBW) below 40° is ideal to minimize degradation of the cross-polarization isolation and ripples in the co-polar patterns produced by induced electromagnetic scattering in the UAV platform. Fig. 2 shows the geometry models of the proposed and commercial probes, realized gain, and E-plane and H-plane half power beamwidth (HPBW) comparison. Table II, summaries the overall performance of the proposed antenna in comparison with the commercial Quad-ridged antenna.

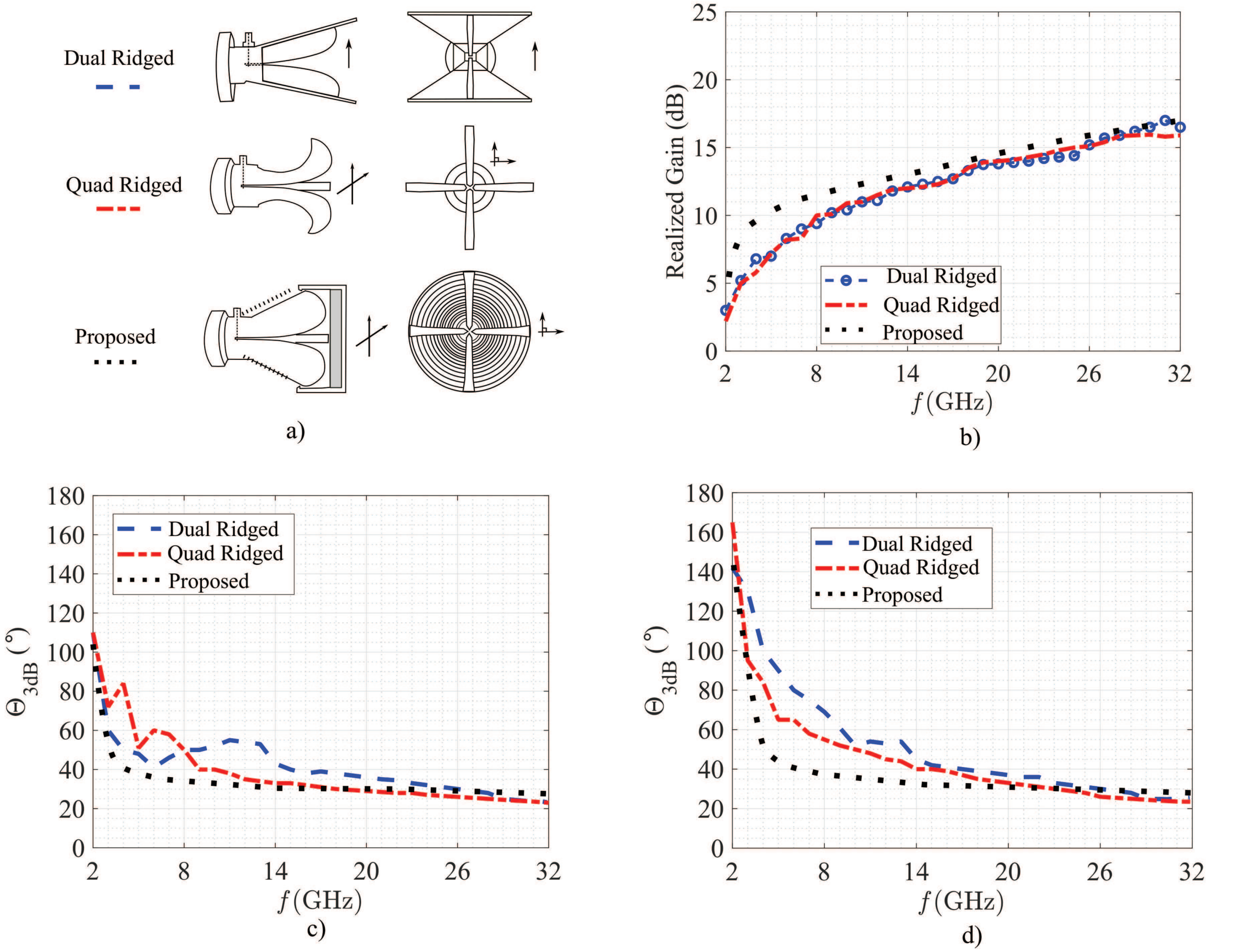

Fig. 2: Illustration of the antenna probes, and performance comparison of the proposed and commercially available ridged horn antennas [31], [32] (a) side views of the ultrawideband antenna probes (b) realized gain versus frequency (c) HPBW versus frequency in the E-plane (d) HPBW versus frequency in the H-plane.

TABLE II: Performance summary of the proposed and commercially available ridged antennas.

Probe Type	Freq. (GHz) (f_{min}/f_{max})	HPBW (°) E-plane (f_{min}/f_{max})	HPBW (°) H-plane (f_{min}/f_{max})	Gain (dB) (f_{min}/f_{max})	RL (dB)	Size (in) (x-y-z)	Weight (lb)
Dual Ridged	2/32	110/22	142/18	3/16.5	< -10	4.3 x 4.13 x 4.13	1.1
Quad Ridged	2/32	110/23	165/23.5	2.2/16	< -10	4.3 x 4.13 x 4.13	0.53
Proposed	2.5/32	60/29	100/29	6/17	< -12	4.3 x 4.3 x 4.4	1.5

III. Design Trade-offs

Accurate in-situ antenna pattern characterizations using drones are very popular nowadays. In most of the cases, drones are customized for each application that typically operates for small frequency ranges (< 10% fractional bandwidth) to obtain accurate antenna patterns of a deployed systems. The main disadvantage of using narrow band probes for a particular application is the dedication of a UAV platform and probe for a specific mission. Assigning a UAV platform for a single task is not cost effective. In the other hand, reusing the same UAV platform for other bands requires tedious characterization and RF calibration of the probe with UAV platform to guarantee good antenna test during flight. Ideally, a single probe mounted on UAV that operates in a wide frequency bandwidth is desirable. One of the biggest limitations of using a ultrawideband antenna as a probe is the antenna beamwidth variability with frequency. Commercial antennas with broadband characteristics, such as single or double ridged horn antennas may satisfy the bandwidth requirements. However, RF performance is not ideal for UAV test measurements. The half-power beamwidth changes from 160° to 40° over a frequency range from 1 GHz to 30 GHz and cross-polarization isolation of -25 dB (without the drone) is degraded due to induced electromagnetic scattering from the

TABLE III: Performance comparison between proposed and comercial probe with UAV-platform.

Probe type	Parameter	Vertical polarization (V-pol) 3 GHz	10 GHz	20 GHz	30 GHz	Horizontal polarization (H-pol) 3 GHz	10 GHz	20 GHz	30 GHz
	HPBW (E-plane)	68°	52°	38°	22°	68°	52°	38°	22°
	HPBW (H-plane)	135°	55°	38°	22°	135°	55°	38°	22°
	X-pol (E-plane)[1]	-25 dB	-25 dB	-23 dB	-22 dB	-25 dB	-25 dB	-23 dB	-22 dB
	X-pol (H-plane)[1]	-27 dB	-28 dB	-28 dB	-27 dB	-27 dB	-28 dB	-28 dB	-27 dB
Quad ridged	ICoR (E-plane)[2]	±1.2 dB	±0.47 dB	±0.45 dB	±0.2 dB	±1.13 dB	±0.48 dB	±0.25 dB	± 0.25 dB
	ICoR (H-plane)[2]	±1.25 dB	±0.5 dB	±0.33 dB	±0.13 dB	±1.5 dB	±0.65 dB	±0.34 dB	±0.22 dB
	IXp (E-plane)[3]	+6 dB	+7 dB	+4 dB	+2 dB	+7 dB	+3 dB	+5 dB	+5 dB
	IXp (H-plane)[3]	+11 dB	+13 dB	+4 dB	+6 dB	+5 dB	+6 dB	+3 dB	+2 dB
	HPBW (E-plane)	60°	32°	30°	29°	60°	32°	30°	29°
	HPBW (H-plane)	100°	38°	31°	29°	100°	38°	31°	29°
	X-pol (E-plane)[1]	-53 dB	-50 dB	-52 dB	-40 dB	-53 dB	-50 dB	-52 dB	-38 dB
	X-pol (H-plane)[1]	-50 dB	-49 dB	-45 dB	-40 dB	-50 dB	-49 dB	-45 dB	-40 dB
Proposed	ICoR (E-plane)[2]	±0.16 dB	±0.35 dB	±0.46 dB	±0.55 dB	±.1 dB	±0.2 dB	±0.16 dB	±0.34 dB
	ICoR (H-plane)[2]	±0.03 dB	±0.22 dB	±0.42 dB	±0.45 dB	±0.07 dB	±0.25 dB	±0.08 dB	±0.15 dB
	IXp (E-plane)[3]	+10 dB	+11 dB	+12 dB	+14 dB	+5 dB	+8 dB	+9 dB	+13 dB
	IXp (H-plane)[3]	+10 dB	+11 dB	+12 dB	+14 dB	+5 dB	+8 dB	+9 dB	+13 dB

[1] X-pol represents the maximum cross-polarization isolation in the HPBW across the frequency range.
[2] ICoR represents the maximum degradation in the co-polarization of the antenna mounted on the UAV in the HPBW across the frequency range.
[3] IXp represents the maximum degradation in the cross-polarization of the antenna mounted on the UAV in the HPBW above -50-dB XP level, across the frequency range.

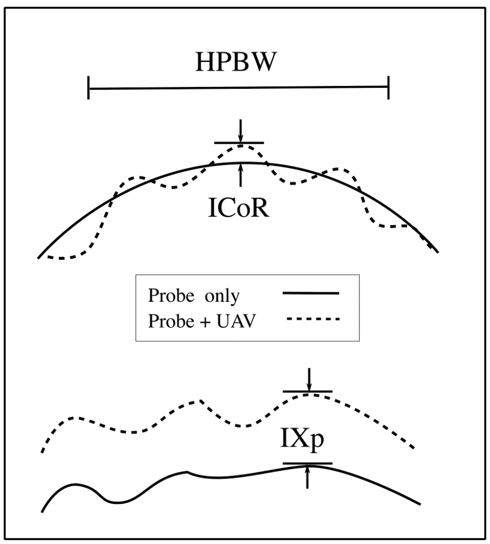

Fig. 3: Representation of the maximum induced ripples in the co-polar patterns (ICoR) and maximum induced cross-polarization (IXp) due to the UAV platform.

UAV platform, specially when the lower frequency is used. For lower frequencies than 3 GHz, UAV platform with larger payload is required to carry larger probes. This limitation in the payload will compromise flight endurance, probe alignment, and flight stability. In this paper, a lens corrected quad-ridged conical corrugated antenna is designed for high compactness and low weight, ideally to be carried in the Matrice 600 and Robin MX/DJI gimbal. Table II and III, summarize the overall performance of the proposed antenna in comparison with commercial Quad-ridged antenna.

IV. Preliminary Results

Numerical simulations of the proposed antenna with and without the UAV platform (Matrice 600) and gimbal were performed using Ansys HFSS. The HFSS integral equation (HFSS-IE) solver that uses the method of moments (MoM) was used to solve for the sources or currents on the surfaces of conducting and dielectric parts of the drone. HFSS-IE with adaptive refinement meshing is effective for radiation and scattering studies of large conducting structures. Table III, summarizes the overall performance of the proposed probe fully characterized with UAV platform. The maximum induced ripples in the co-polar patterns (ICoR) and maximum induced cross-polarization (IXp) due to the UAV platform as shown in Fig. 3 were calculated in E-plane and H-plane for each polarization in both antennas. Comparison between proposed and commercial probe with UAV-platform shows significant improvement of UAV metrology system. Lower ripples in the co-polar patterns lower is the contamination in the cross-polarization patterns. This is mainly attributed to the controlled beamwidth and lower cross-polarization performance of the proposed antenna. Due to the improved radiation characterization and performance of the proposed antenna, the induced degradation in the cross-polarization levels is smaller than that in the case of the commercial antennas. The proposed probe presents better performance compared to the commercial antenna across the operating bandwidth.

V. Conclusion

A new antenna probe was designed and and fully characterized with a UAV platform. This novel antenna enables a unique in-situ UAV metrology system that allows multiple missions using the same antenna probe and platform in a frequency range from 2.5 GHz to 32 GHz without the need of using different probes and re-calibration of the metrology system. Excellent probe performance in terms of co-polar patterns and high cross-polarization isolation are obtained. 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 measurements of antenna used in communication and radar systems.

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