A Miniaturized All-GNSS Bands Antenna Array Incorporating Multipath Suppression for Robust Satellite Navigation on UAV Platforms

Simon Hehenberger, Veenu Tripathi, Sachit Varma, Wahid Elmarissi, Stefano Caizzone
Institute of Communication and Navigation, German Aerospace Center (DLR), Wessling, Germany,
Contact email: simon.hehenberger@dlr.de

***Abstract* — Nowadays, an increasing trend to use autonomous Unmanned Aerial Vehicles (UAV) for applications like logistics as well as security and surveillance can be recorded. Autonomic UAVs require robust and precise navigation to ensure efficient and safe operation even in strong multipath environments and (intended) interference. The need for robust navigation on UAVs implies the necessary integration of low-cost, lightweight, and compact array antennas as well as structures for multipath mitigation into the UAV platform. This article investigates a miniaturized antenna array mounted on top of vertical choke rings for robust navigation purposes. The array employs four 3D printed elements based on dielectric resonators capable of operating in all GNSS bands while compact enough for mobile applications such as UAV.**

Index Terms — *GNSS, DRA, UAV, antenna array, miniaturization, choke ring, multipath, metallization, installed performance.*

I. INTRODUCTION

Current state of the art mobile satellite navigation receivers is vulnerable against interference (both intentional and unintentional) due to the weak signal strength of the satellite signals and the single antenna receiver structure. Several innovative solutions exist that employ multi-antenna arrays to strongly mitigate interferences [1-3]. Furthermore, significant effort has been invested in the miniaturization of such systems [4-5] in order to comply with the strict GNSS antenna dimension regulations in the automotive and aeronautical sectors. In [6], for instance, a 3D printed miniaturized multi-antenna array, able to operate at all GNSS bands while still fitting into a 100mm footprint, is introduced. The trend to use autonomous UAV platforms in security critical applications such as surveillance and logistics opens a new application scenario for robust navigation. However, due to UAVs small platform size and highly dynamic operating environment, sufficient miniaturization of the antenna array and multipath mitigation is critical but no easy task. GNSS antennas, in general, shall be designed to radiate in right-hand circular polarization (RHCP) and suppress all left-hand circular polarized (LHCP) modes to be resilient against multipath errors. The most prominent contribution to LHCP radiation of a GNSS antenna is its back lobe. Usually, horizontal choke rings are applied to mitigate the back lobe. However, their weight and bulky size render them useless when considering small body mobile platforms like UAVs. In a recent development [7], a novel choke-ring design composed of vertical layers was presented, which drastically reduces back lobe radiation while obtaining a compact size and lower weight than a similar horizontal choke design. Nevertheless, further miniaturization of these vertical chokes is required for them to be utilized on platforms with stringent size constraints, such as UAVs.

The present work utilizes the antenna array introduced in [6] as a starting point and introduces two improvements:

1. Utilizing a novel feed metallization approach to create the feed-strips on the 3D printed ceramic cylindrical dielectric resonator antennas (DRA).
2. Mounting the array on top two sets of miniaturized vertical choke rings to suppress multipath in the E1 and E5a band, respectively.

Details of these two improvements are the topic of section II. and III. respectively.

II. SINGLE ANTENNA MANUFACTURING

The individual DRA elements are manufactured by an additive manufacturing technique employing the PREPERM ABS1000 filament with high ceramic content providing a permittivity of $\varepsilon_{r,fil} = 10$. 3D printed ceramic substrates are challenging to work with at RF frequencies for two major reasons. First, they require precise material characterization at RF frequencies due to imperfections like air gaps introduced during the printing process, which causes an effective reduction in relative permittivity. Material characterization was already carried out in [6] by measuring the resonance frequency shift of a narrowband patch antenna on the 3D printed substrate. It was found that the printing process reduces the effective permittivity of the resulting cylindrical DRA to $\varepsilon'_{r,fil} = 8{,}1$. The second problem when utilizing ceramics is that they are generally challenging to metalize, which implies difficult feed-strip creation on the DRAs. For the original resonator design depicted in Figure 1a., the feed-strips were created by utilizing adhesive copper strips glued onto the cylinder. This “quick and dirty” solution yields satisfying results. Nevertheless, a more precise and reproducible method for feed-strip metallization had to be found.

a. b.

Figure 1. 3D printed ceramic cylindrical dielectric resonator antennas (DRA). **(a.)** DRA with copper feed-strips. **(b.)** DRA with feed-strips on an adhesive Kapton polyimide sheet.

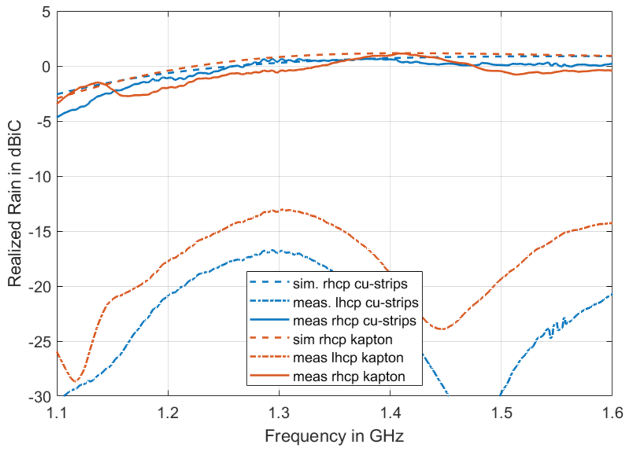

Figure 2. Comparison of simulation and measurement of DRAs with feeds metalized by adhesive copper-strips, and with Kapton polyimide adhesive sheets in terms of RHCP and LHCP realized gain as a function of frequency.

A promising solution explored in this work is to create the feed strips on a thin sheet of single side adhesive Kapton polyimide and attach them to the cylindrical resonators side and top face, connecting the copper strips with solder, allowing a precise positioning of the feeds relative to each other, as shown in Figure 1b. The simulated and measured performance of the two antenna elements depicted in Figure 1. is compared by their realized RHCP and LHCP gain as a function of frequency in Figure 2.

Due to the increased accuracy in the metalization technique, it is expected for the DRA metalized with Kapton sheets to perform better in terms of realized RHCP and LHCP gain in both E1 and E5a bands. This expectation is also confirmed by the simulation results in Figure 2.

III. Multipath Mitigation via Vertical Choke Rings

Robust navigation on UAV platforms requires effective LHCP back lobe suppression to mitigate the effect of multipath signals due to reflections from ground or nearby objects. Moreover, mitigation of the back-lobe is desirable to reduce the impact of the platform itself on which the antenna is installed. For this purpose, this work is building on the investigation of the all-metal vertical choke ring design in [7].

Since vertical choke rings only effectively suppress back lobe radiation within narrow bandwidths, two distinct sets of rings are required to achieve multipath mitigation within the desired bands of operation E1 and E5a. Furthermore, a miniaturization of the structure is necessary to utilize the design on UAV platforms. A natural way to achieve miniaturization is to substitute the air in the choke cavities with a dielectric substrate with relative permittivity $\varepsilon_{\mathrm{r,choke}}$. This design approach provides an effective reduction of the individual cavity depths d_{E1} and d_{E5a} by a factor of $\varepsilon_{\mathrm{r,choke}}{}^{0.5}$.

The individual choke rings are composed of Rogers RO6010 RF-substrate sheets glued on top of each other with an RF-adhesive tape and placed beneath the antenna array, as shown in Figure 3. The use of adhesive tape with lower relative permittivity than RO6010 leads to a slight increase of the wavelength in the choke cavity with respect to the use of RO6010 only. The implied increase of the choke ring radii is compensated by the resulting ease of manufacturing.

A drawback of using the RO6010 material as cavity substrate is the limited degrees of freedom during the optimization of the choke ring design to available substrate heights h. A simulation study considering available substrate heights $h \in \{0.635, 1.27, 2.54\}$ mm and different number of rings $N \in \{2, 4, 8\}$ in the chokes for the E1 and E5a band respectively has been carried out. The most promising RHCP and LHCP realized gain patterns, as well as the resulting axial ratios (AR) for φ=0 in the E1 and E5 bands, are depicted in Figure 4 - 7, respectively.

It is found that significant back lobe suppression is achieved for all simulated cases. However, a noticeable change in RHCP gain and axial ratios in the upper hemisphere can be obseved in Figures 4 and 5, respectively, when comparing the antenna performance with and without choke rings. A detailed summary of the performance changes by different choke ring designs with respect to the standalone antenna is given in Table 1. Based on the simulation results, the vertical choke ring design with $N = 4$ layers in both sets of rings and a RO6010 substrate with $h = 1.27$ mm as the cavity substrate is selected.

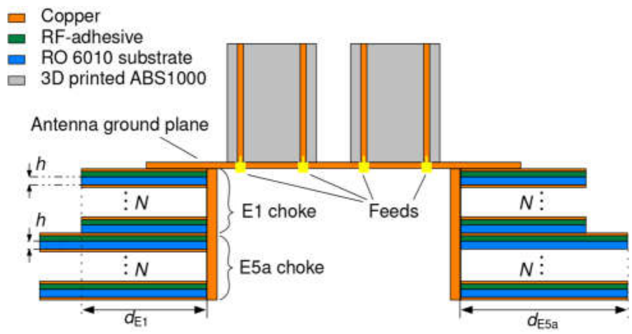

Figure 3. Side view of the stacked vertical choke rings composed of RO6010, glued together with RF adhesive tape for back lobe suppression in the E1 and E5a band, respectively.

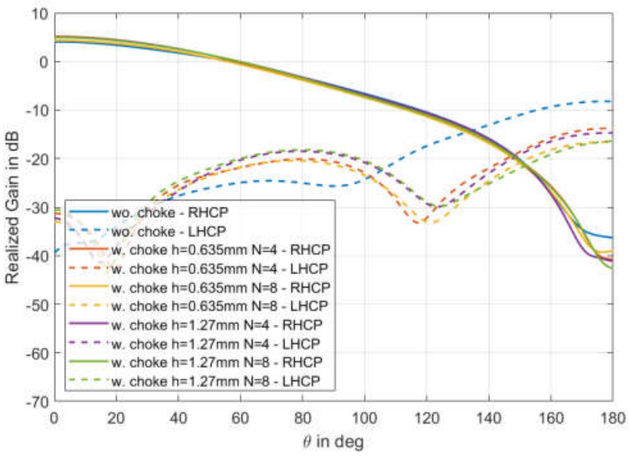

Figure 4. Realized RHCP and LHCP gain in the E1 band for choke ring designs with different substrate heights h and number of layers N as function of θ.

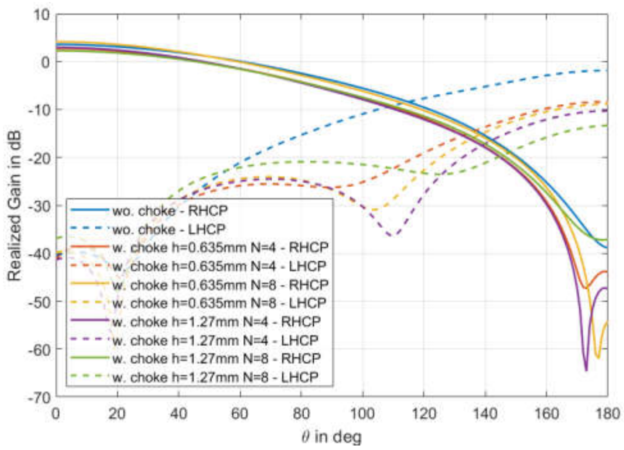

Figure 5. Realized RHCP and LHCP gain in the E5a band for choke ring designs with different substrate heights h and number of layers N as function of θ.

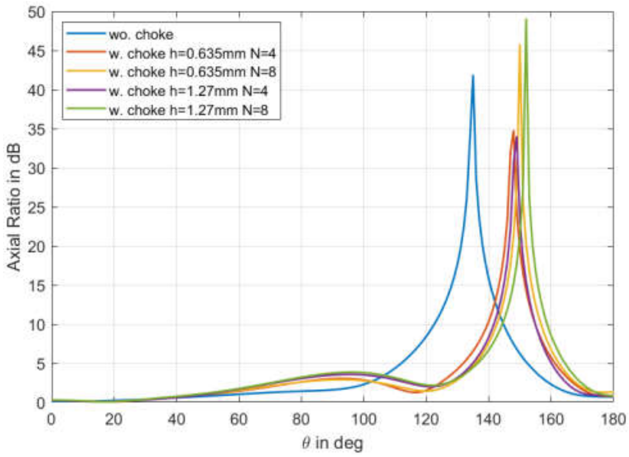

Figure 6. Axial Ratio in the E1 band for choke ring designs with different substrate heights h and number of layers N as function of θ.

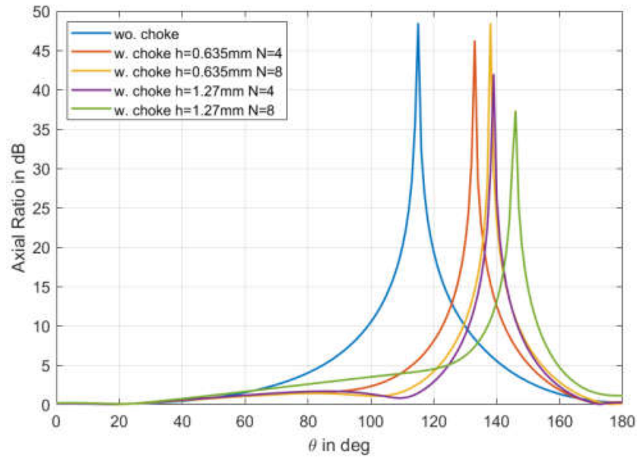

Figure 7. Axial Ratio in the E5a band for choke ring designs with different substrate heights h and number of layers N as function of θ.

Table 1. Realized RHCP gain at zenith, realized LHCP gain at nadir and the resulting Axial Ratio for $\theta = 60°$ and $\theta = 90°$ for in the E1 and E5a band with different vertical choke ring parameters.

N	h in mm	RHCP gain (θ=0°) in dB		LHCP gain (θ=180°) in dB		AR in dB (θ=60°/90°)	
		E1	E5a	E1	E5a	E1	E5a
-	-	4.05	3.59	-8.24	-1.86	1.03 / 1.59	1.53 / 6.4
4	.635	5.16	2.78	-13.76	-8.38	1.44 / 3.02	1.04 / 1.66
8	.635	4.33	4.15	-16.64	-8.86	1.53 / 2.89	1.05 / 1.33
4	1.27	5.01	2.97	-14.74	-10.29	1.70 / 3.50	1.17 / 1.65
8	1.27	4.97	2.27	-16.40	-13.32	1.76 / 3.75	1.64 / 3.04

I. CONCLUSIONS

The present work explains the improvement of a four-element miniaturized array antenna for robust navigation on UAV platforms. Individual array elements are manufactured utilizing 3D printed ceramics with high relative permittivity. A novel and easy to use metallization of feed strips on the ceramic cylinders with Kapton polyimide sheets is used, which improved reproducibility during the fabrication of the individual elements. The increased accuracy of relative feed strip positions further aids in the suppression of cross-polarization components. Multipath mitigation is achieved by mounting the 2x2 array on two vertical choke ring structures, which effectively suppress back lobe radiation in the E1 and E5a band, respectively. An effective reduction in choke ring radius is achieved by utilizing RO6010 substrate to fill the choke cavities. A simulation study provided insight into the performance of the choke design, and a suitable tradeoff between the number of rings and cavity width is found.

Acknowledgment

This work was partly funded within the framework of the ROSANNA project by the Federal Ministry for Economic Affairs and Energy (BMWi) on the basis of a decision by the German Bundestag.

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