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Phased Array Scan Performance Review for SATCOM: Dielectric Resonator vs. Patch Antennas

Theodoros Pavlidis*(1),(2), Artem R. Vilenskiy(1), Thomas Schäfer(2), Marianna V. Ivashina(1), and Ahmed A. Kishk(1),(3)

(1) Dept. of Electrical Engineering, Chalmers University of Technology, Gothenburg, Sweden (*pavlidis@chalmers.se)
(2) Satcube AB, Gothenburg, Sweden
(3) Concordia University, Montreal, QC H3G 1M8, Canada

***Abstract*—A comparison of arrays employing dielectric resonator antennas (DRA) and patch antennas as elements is presented. The bandwidth of the arrays under study is over 40% at broadside, covering the K/Ka-band SATCOM and mmWave 5G bands. The element analysis is performed for the principal planes in an infinite array environment. Numerical results suggest the scan performance of DRA phased arrays is limited by the dielectric loading of the array aperture.**

I. Introduction

The development of satellite communications (SATCOM) and 5G Advanced and beyond mobile communication networks has spurred the demand for advanced antenna arrays capable of operating in several frequency bands using a single array aperture. State-of-the-art ultrawideband arrays, using connected [1] or tightly coupled [2] radiators have achieved wide (over 45° in elevation) scan angles over multiple octaves, at the cost of increased profiles and/or manufacturing complexity. Patch antennas, on the other hand, have been a main-stay element type for phased arrays owing to their planar structure, ease of integration with electronics, and compatibility with PCB manufacturing. However, increasing the bandwidth of such arrays is usually done by increasing the antenna thickness, leading to decreased scanning range and a scan angle-profile trade-off.

A potential alternative element type can be found in dielectric resonator antennas owing to their reduced conductor losses and extensive bandwidth [3]. There is, however, limited information in the open literature regarding the performance of DRAs when employed in 2-D wideband, wide-scanning arrays. In [4], a wide-scanning 2-D DRA array is presented; however the array bandwidth was not disclosed. In [5], the E-plane performance of the array is given for a small element spacing, meaning that potential E-plane scan anomalies were not addressed. The authors of [6] presented a wide-scanning millimeter-wave (mmW) array with a bandwidth of approximately 5%.

In this work, we aim to address this knowledge gap by comparing the performance of wideband arrays employing DRAs and patch antennas as element types. The operating frequencies span the K- and Ka-band SATCOM transmit and receive bands and the mmWave 5G bands.

II. Array Structures

Figures 1(a) and (b) illustrate an exploded view of the patch antenna and DRA phased array unit cells (UCs), respectively.

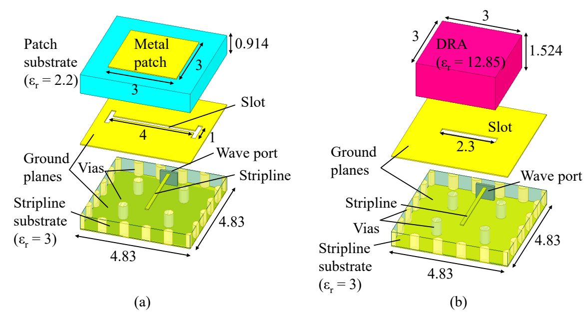

Fig. 1. Exploded UC view of (a) patch antenna and (b) dielectric resonator antenna phased arrays. All dimensions are given in mm.

In this study, the patch is placed on a Rogers 5880 substrate ($\varepsilon_r = 2.2$). The DRA consists of a solid dielectric block of Rogers TMM 13i ($\varepsilon_r = 12.85$). To simplify the comparison, we minimize the effects of stacking and shaping by selecting a single resonator and patch of a square shape. In both cases, the radiators are fed via striplines on the opposite side of the ground plane through electrically narrow slot apertures etched on it. Vias surround the stripline substrates to suppress the excitation of parallel plate waveguide (PPW) modes, while an inner row of vias suppresses the resonances of the resulting cavity. The element spacing is equal for both UCs and approximately $0.5\lambda_0$ at 31 GHz, where λ_0 is the free-space wavelength. Periodic boundary conditions (PBCs) are enforced on the UC sidewalls to simulate an infinite array environment, while a Floquet port is placed above the aperture.

III. Numerical results

The principal plane scan performance is simulated in an infinite array environment using the finite element method in Ansys HFSS. Fig. 2(a) shows the active reflection coefficient ($|\Gamma_{act}|$) at broadside and scan elevation angle $\theta = 60^\circ$ in the E-plane. Both arrays perform well for wide-angle scanning at lower frequencies. However their performance deteriorates as the frequency increases. The onset of two ARC resonances of the DRA UC is noted. In order to investigate further, the embedded element gain is calculated. In Fig. 2(b), the gain is shown normalized to its maximum theoretical value for a given scan angle and frequency [7], that is, $G_{\max} = 4\pi S_{\mathrm{UC}} \cos(\theta)/\lambda_0^2$, where S_{UC} is the UC area. The presence of two gain dips at the same frequencies is noted (scan blindness). The patch element ARC also deteriorates with increasing scan angle, although the scan blindness does not occur. This agrees with previous findings reporting stronger mutual coupling effects for dielectric resonators than the patch antennas [8].

The array performance is now compared for the H-plane scanning. The patch antenna array is notably mismatched over the whole frequency span [see Fig. 3(a)], although the scan blindness does not occur, since the array substrate on the radiating side is electrically thin, limiting surface wave excitation for the H-plane scanning [9]. The DRA array is mismatched over most of the targeted frequencies but remains matched only over a limited bandwidth. As shown in Fig. 3(a), two resonances appear in the ARC, along with two gain dips (scan blindness) seen in Fig. 3(b).

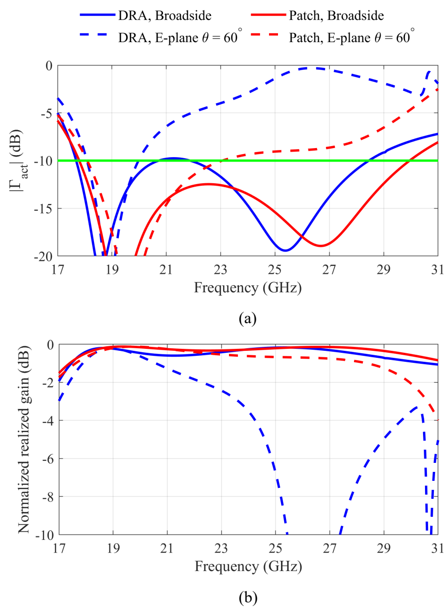

Fig. 2. Simulated broadside and $\theta = 60°$ E-plane (a) active reflection coefficient (b) normalized realized gain of the DRA and patch antenna elements in a 2-D infinite array environment.

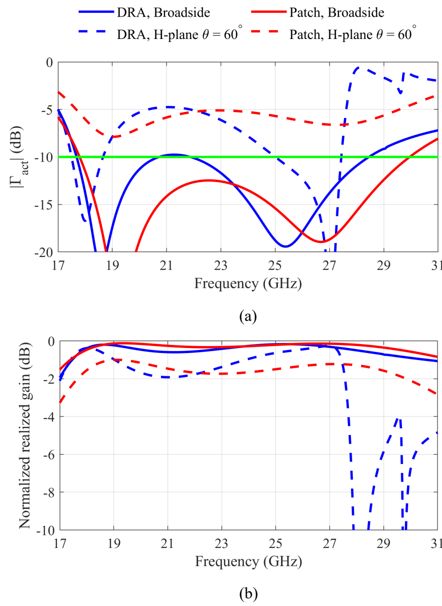

Fig. 3. Simulated broadside and $\theta = 60°$ H-plane (a) active reflection coefficient (b) normalized realized gain of the DRA and patch antenna elements in a 2-D infinite array environment.

IV. Conclusion

The scan performance of wideband arrays of DRAs and aperture-coupled patches has been compared. Numerical results have suggested scan limitations for DRA elements posed by the heavy dielectric loading of the aperture. While these effects were also present in phased arrays of patches, patch antennas satisfy the space constraints of a wide-scanning array lattice using lower permittivity materials, thus leading to an increased scan range. Results regarding the effect of design dimensions, the resonances of the radiators and investigations on the causes of the observed scan blindnesses will be presented at the conference.

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