Light-Weight Wide-Band Metal-Only Reflectarray Antennas

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Abstract **─** A new class of metal-only reflectarray antennas (RAs) is reported. The proposed RA is based on a unit-cell constructed from a short-circuited conducting square. This, compared to the previously reported metal-only designs, leads to less weight and fabrication complexity. In addition, bandwidth enhancement can be accomplished by extending the idea to multi-layer unit cells. Gain stability with less than 0.1 dB variation over 1 GHz bandwidth at 12 GHz center frequency is achieved using the proposed two-layer reflector.

Index Terms **─** Antenna, ethernet, light-weight, metal-only, reflectarray, wideband, WiMAX.

I. INTRODUCTION

One of the advantages of microstrip reflectarray antennas (MRAs) over parabolic reflectors are their less manufacturing complexity, especially at high microwave frequencies [1]. Nevertheless, MRAs are not regarded as low-cost antennas, due to expensive low loss microstrip substrates. As well, MRAs are not reliable solutions at extra high temperatures, which is likely in near-sun space applications. In such situations, the dielectric substrate may become nonlinear and the thin metallization made by the printed circuit board (PCB) technology may become melted or deformed. Furthermore, the substrate blocks a fraction of electromagnetic (EM) energy due to surface wave excitation which deteriorates the overall gain. Thus, if it becomes possible to design MRAs without substrate, the application range of such antennas can be further extended. The idea of a metal-only RA is not new. The first RA was metal-only, constructed from an array of short-circuited (sc) rectangular waveguides as the reflector [2]. Another metal-only solution is suggested in [3], which is made from rectangular grooves in a metallic plate. Both of these designs are neither low-cost, nor light-weight, particularly below 10 GHz, due to large amount of metal and high fabrication complexity. Besides, it is unclear how their bandwidth can be broadened.

In the present work, a metal-only RA is proposed. This RA is based on a unit-cell constructed from an sc conducting square. This, compared to the previously reported cases, leads to less weight and fabrication complexity. In addition, bandwidth enhancement can be accomplished by extending the idea to multi-layer unit cells. Possible applications of such RAs are high-power applications, e.g., base stations, high-temperature applications, e.g., near-sun orbiting satellites, and terrestrial fixed-point wireless bridges, e.g., WiMAX and ethernet links. The proposed antennas can also be used for armature radio, since in less than 10 GHz, they can be constructed by elementary tools and materials. It is worth mentioning that the incident power must be kept sufficiently small to avoid electric discharge.

Applicability of the suggested method is verified using method of moments (MoM). Simulation results are carried out using FEKO® suite software.

II. THE IDEA

The idea supporting the proposed method stems from the fact that when a conducting patch, suspended over an infinite ground, is excited by a plane wave, the induced electric current density over its surface is mostly concentrated on the edges and the amount of EM energy at the patch center is negligible. Therefore, short-circuiting a patch from its center to the ground plane underneath may not significantly affect its radiation characteristics. This idea is validated in two steps.

First, the current density distribution over half-wavelength suspended and sc square patches over an infinite ground plane is computed. The results are reported in Fig. 1, for different shorting pin thicknesses and illumination angles. The gap between the patch and the ground is assumed to be $0.3\lambda_0$. The patch lies on the xy plane with the z axis perpendicular to it. The patch is excited by plane wave at normal and oblique incidence with, respectively, $\theta = 0°$ and $40°$. As usual, θ is the elevation angle in spherical coordinate. In addition, the wave and electric field vectors lie in the xz plane in both cases. The radii of sc pins are taken to be $r = 0.005\lambda_0$ and $0.05\lambda_0$, respectively, as thin and thick cases. We note in Fig. 1 that, the current distributions on suspended and sc patches are effectively the same.

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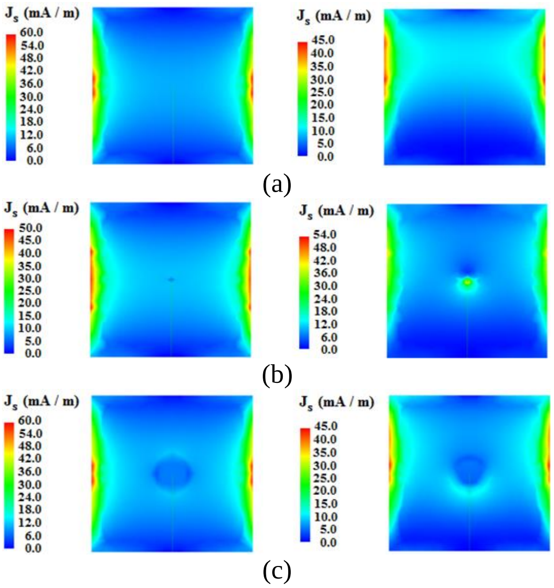


Fig. 1. Current density over $\lambda_0/2$ square patch at normal (left column) and oblique (right column) incidence: (a) suspended, (b) sc by thin pin, and (c) sc by thick pin.

At the second step, the magnitude and phase of the scattered near-field (NF) of the aforementioned patches are computed over a semi-circle of radius $10\lambda_0$ laying on the $\varphi = 0°$ plane and reported in Figs. 2 and 3. From these figures it is evident that the scattered fields are essentially the same at $\theta = 0°$, regardless of the pin thickness. While, for the case of thick shorting pins, discrepancy is undeniable as the observation angle increases.

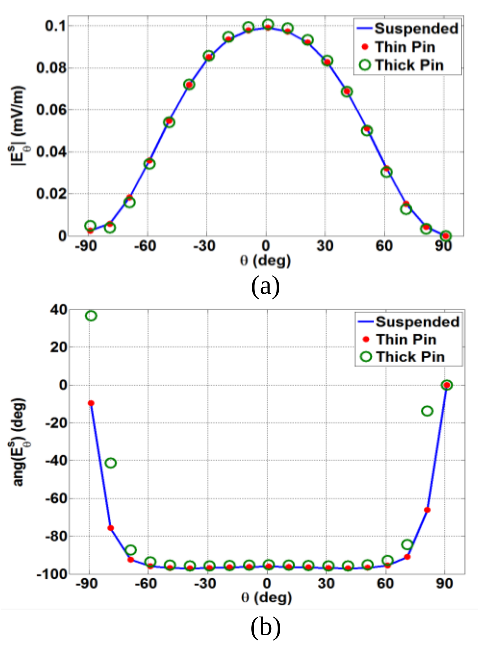


Fig. 2. Scattered NF of $\lambda_0/2$ square patch excited at normal incidence: (a) magnitude and (b) angle.

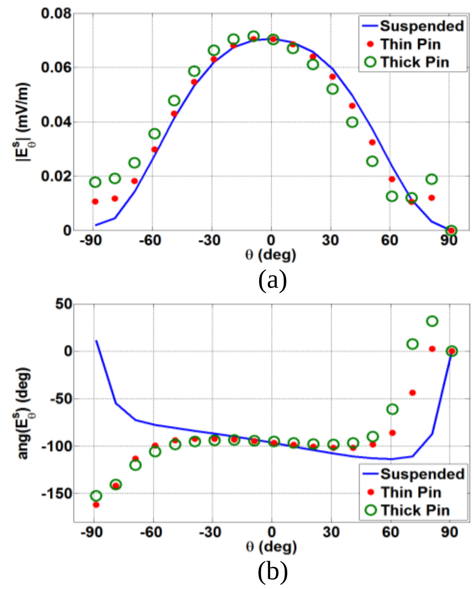
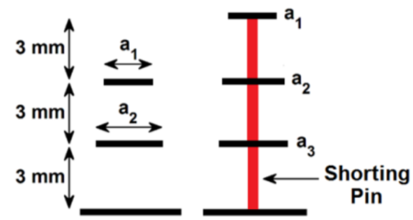


Fig. 3. Scattered NF of $\lambda_0/2$ square patch excited at oblique incidence: (a) magnitude and (b) angle.

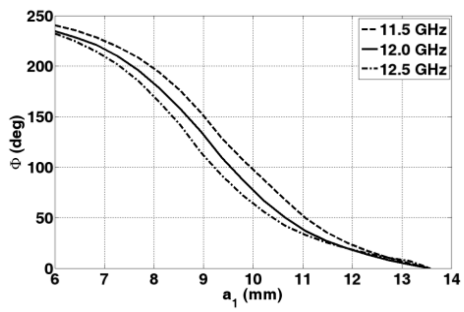
III. PROPOSED UNIT CELLS

In this section, delay characteristics of single-, two- and three-layer unit-cells, designed by the proposed method, are reported. The geometries of the cells are selected based on [4-6]. The center frequency and the cell periodicity are 12 GHz and 14 mm, respectively. The inter-layer spacing is 3 mm. For the two-layer cell, the side-length ratio of the first to second layer is 0.7. For the three-layer cell, the side-length ratios of the first to the third and the second to the third layers are 0.7 and 0.9, respectively. The side views of two- and three-layer cells are depicted in Fig. 4, wherein the suspended case is included for clarity. It should be noted that all the reported results during the paper are restricted to sc cases. Two short-circuiting pin thicknesses are studied with radii $r = 0.5$ and 1.25 mm, which are equal to $0.02\lambda_0$ and $0.05\lambda_0$, respectively, where λ_0 is the working wavelength. All unit-cells are excited at $\theta = 0°$ and 40°, at 11.5 GHz, 12 GHz and 12.5 GHz. Computed phase-shifts are reported in Figs. 5 and 6. As can be seen from Fig. 5, the delay characteristics at different frequencies are effectively in parallel for the single-layer cell with thin sc pin. Similar results were observed for multi-layer cases with thin pins which are not included for brevity. Yet, the parallel phase range decreases for cells with thick sc pins at oblique incidence. Nevertheless, by considering Fig. 6, this reduction can be compensate by increasing the number of layers. These observations can be explained noting that at normal incidence, the pin is properly shielded by the patch. On the contrary, when the cell is excited obliquely, the pin is illuminated and thus its contribution to the scattered field becomes significant. Logically, the role of shorting pins is more evident as they become thicker at oblique incidence. However, as noted before, the destructive effect of the pins can be compensated by increasing the number of layers.

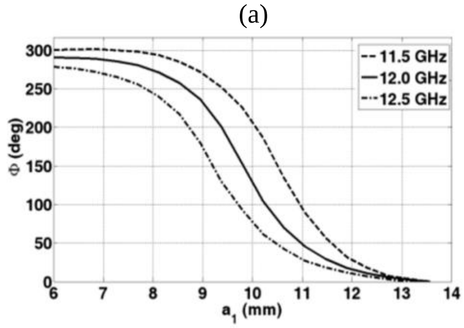


(a) (b)

Fig. 4. Side view of multi-layer unit-cells: (a) suspended two-layer: $a_1 = 0.7a_2$, and (b) short-circuited three-layer: $a_1 = 0.7a_3$, $a_2 = 0.9a_3$.

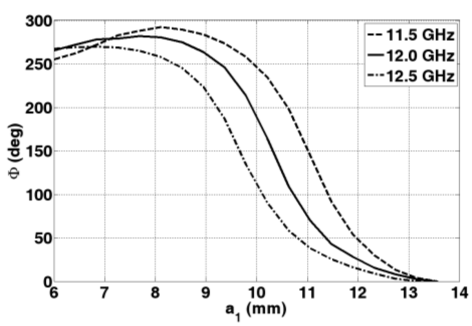


(a)

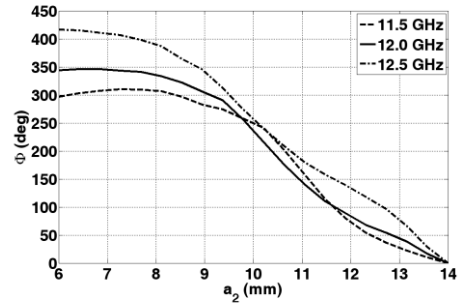


(b)

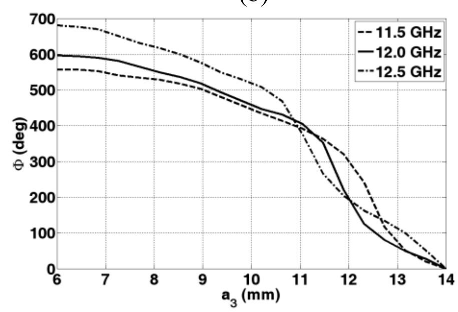
Fig. 5. Delay characteristic of the proposed single-layer unit-cell with thin sc pin at: (a) normal and (b) oblique incidence.



(a)



(b)



(c)

Fig. 6. Delay characteristic of the proposed unit-cells with thick sc pins at oblique incidence: (a) single-layer, (b) two-layer, and (c) three-layer.

IV. PERFORMANCE ESTIMATION

In this section, performance of the RAs designed based on the proposed method is estimated in the sense of overall gain using MoM. For efficient analysis, the multi-level fast multi-pole method (MLFMM) is exploited. Additionally, the reflector ground plane is assumed to be of infinite extent. The analysis frequency and radius of shorting pins is set to 12 GHz and 0.5 mm, respectively. The inter-element spacing of the RA elements is 14 mm. By designating the focal length and the reflector diameter with, respectively, F and D, the F/D ratio is computed following [7]. Specifically, the feed pattern is fitted by $\cos^n \theta$ function and then the optimum focal length is estimated based on the classical expression reported in [8]. The study is carried out for two configurations. The feed antennas in both cases are small-size and metal-only. This further reduces the computational complexity and makes it possible to analyze the whole structure, i.e., feed plus reflector.

In the first case, a large square-shaped RA with 30×30 single-layer elements is illuminated by a probe-fed square patch antenna with 13 mm side length and air substrate. For decreasing the blockage, the patch is placed over a finite square ground plane with 37.4 mm side length. This corresponds to F = 48 cm which is the distance of the feed from the center of the patch. Both center- and offset-fed arrangements are considered, where the offset angle is assumed to be 40° with respect to reflector normal direction. The corresponding gain patterns are reported in Fig. 7, which verifies the applicability of the proposed single-layer cells for high-gain applications.

The second case is a small square-shaped RA with 10×10 elements, illuminated by a short metallic horn antenna in center-fed arrangement. The optimum position of the feed is computed to be 15 cm from the reflector center. The radiation pattern of this feed is depicted in Fig. 8 which shows its gain stability over 1 GHz bandwidth about the center frequency. The simulated gain patterns for RA with single- and two-layer elements are reported in Fig. 9. As can be clearly seen, perfect gain stability is achieved using the proposed two-layer elements. Additionally, increasing the number of layers has decreased the side-lobe level (SLL). Thus, the suggested multi-layer unit-cells are responsive for wideband applications.

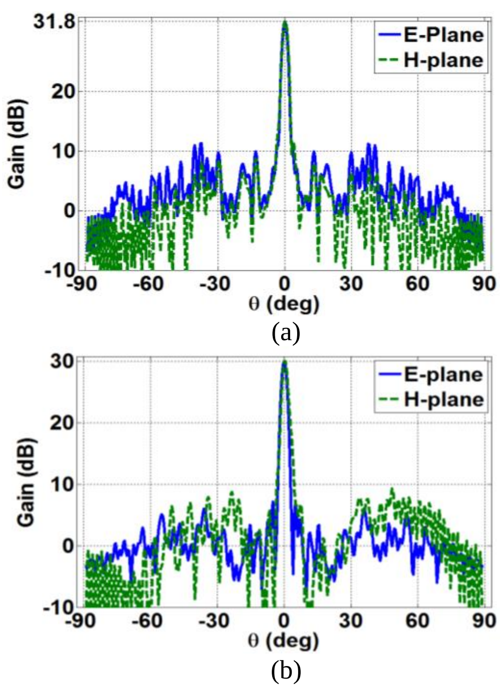


Fig. 7. Gain pattern of the 900 element RAs: (a) center-fed and (b) offset-fed.

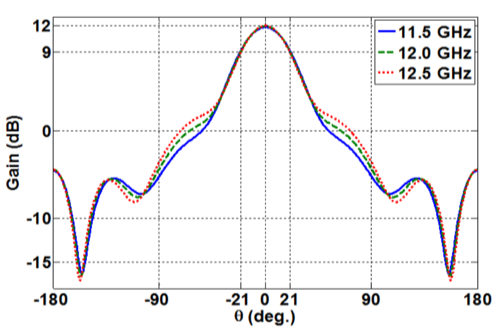


Fig. 8. Gain pattern of feed horn.

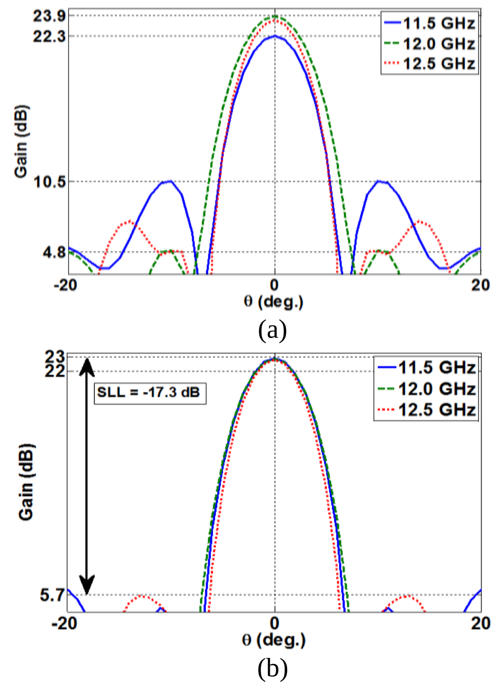


Fig. 9. Gain pattern of the 100 element RAs with: (a) single-layer and (b) two-layer elements.

V. CONCLUSION

Light-weight metal-only reflectarray antennas can be constructed based on short-circuited conducting patches. It is shown that delay characteristics of square patches are essentially unchanged when they are short-circuited from center using thin shorting pins. As the pin radius increases, discrepancy between delay characteristics of the suspended and the short-circuited patches become undeniable as the observation angle increases, although responses remains essentially the same at normal direction. These elements are shown to be a candidate for metal-only unit cells in designing light-weight metal-only reflectarray antennas. It is demonstrated that bandwidth of such reflectarrays can be broadened by extending the idea to multi-layer unit cells. It is observed that the sensitivity of the delay response to the thickness of shorting pins decreases as the number of layers increases.

REFERENCES

[1] J. Huang and A. Encinar, *Reflectarray Antennas*, New York: IEEE/John Wiley, 2008.

[2] D. G. Berry, R. G. Malech, and W. A. Kennedy, “The reflectarray antenna,” *IEEE Trans. Antennas Propag.*, vol. 11, no. 6, pp. 645-651, Nov. 1963.

[3] Y. H. Cho, W. J. Byun, and M. S. Song, “High gain metal-only reflectarray antenna composed of multiple rectangular grooves,” *IEEE Trans. Antennas Propag.*, vol. 59, no. 12, pp. 4559-4568, Dec. 2011.

[4] J. A. Encinar, "Printed circuit technology multilayer planar reflector and method for the design thereof," *European Patent EP 1120856*, June 1999.

[5] J. A. Encinar, "Design of two-layer printed reflectarrays using patches of variable size," *IEEE Trans. Antennas Propagat.*, vol. 49, no. 10, pp. 1403-14010, Oct. 2001.

[6] J. A. Encinar and J. A. Zornoza, "Broadband design of three-layer printed reflectarrays," *IEEE Trans. Antennas Propagat*., vol. 51, no. 7, pp. 1662-1664, July 2003.

[7] B. Honarbakhsh, "FR4-only microstrip reflectarray antennas," *ACES J*., accepted.

[8] J. Huang, "Analysis of a microstrip reflectarray antenna for microspacecraft applications," *JPL TDA Progress Report No. 42-120*, Feb. 15, 1995.

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