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Bi-Layer, Broad-Band, Sub-Wavelength Reflectarray

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Abstarct: This study investigates the role of variable sized microstrip patch elements with a double layer substrate to reduce dielectric loss, antenna weight and system cost. Simulation results show that the phase range reaches 700° at C-band with a reflection loss does not exceed 2 dBs Which effectively proves the reflectarrays in this type of application. Circular patch loaded with W-slot is used as a primitive cell for the lower layer at 6 GHz while a λ/4 side length heptagon at 5.5 GHz is molded within the upper layer. Building and testing the designed reflectarray concurs the simulation results.

Key words: Broadband, sub-wavelength, reflectarray, C-band, wide-phase-range, W-slot

INTRODUCTION

Reflectarray antennas compared with other high-gain antennas are widely used in some long-range communications systems because of their many advantages (Costanzo and Venneri, 2014a, b). At present, these antennas apply to wideband applications if frequency bands close to each other are chosen, the stacked layers forms a reflectarray with a wide-phase range (Florencio *et al*., 2014). Compared to single-layer structures this technique leads to a reduction of the dielectric losses (Abdullah *et al*., 2014, 2015). Pitchers like light-weight, inexpensive, low-profile, simply fabricated, conformable antennas require for wireless space-borne applications. These make reflectarray realization easy compared to traditional high-gain antennas stated earlier (Chaharmir *et al*., 2010). The complex power divider feeding network in phased-array antenna is no longer needed in reflectarray, since, all the radiating elements are illuminated by a common source (horn antenna for example). Although, the inherent narrow band limitation is the major drawback of this type of antenna. One of the recent approaches to overcome this glitch is by using the sub-wavelength element technique. The manufacturing tolerance of the unit cell element dimensions is one of the major obstacles of the designing in sub-wavelength level (Guo *et al*., 2014). The minimum separation distance between the neighboring elements affects the phase range of the designed antenna. As mentioned in Chatterjee (2015) the double layer arrangement improved the bandwidth of the reflectarray up to 16%. Combined the sub-wavelength elements technique along with double layers structure is a promising approach to broaden the reflectarray frequency range. A further benefit of this methodology is maintaining the minimum fabrication tolerance while enhancing the phase range of the research element (Abadi *et al*., 2015).

The aim of this research is to inspect the possibility of multiband antenna design by using a double-layered substrate with variable-sized sub-wavelength elements. This methodology offers an appropriate phase behavior all over the frequency bands as compared to the single-layered half-wavelength reflectarray. The gain bandwidth has been improved by using two-layered sub-wavelength. Each layer operates in limited C-band frequency range. These two ranges are close to each other to form broad range. Some element samples were manufactured and tested using the waveguide simulation method to indorse the simulation results.

MATERIALS AND METHODS

Designing and characterization of the elements: Searching the whole C-band for resonance frequency ranges of the designed elements. In these ranges, the reflected waves must deploy a gradual phase distribution for feasible operation. The next step is to analyze and optimize the two-layer system until a suitable reflection phase curve with reasonable reflection loss is obtained. The method of moment mentioned in Munk (2000) was used to perform full-wave analysis for the proposed double-layer structure. Figure 1 shows the proposed element of the first layer which consisted of a circular microstrip patch with W-slot, etched in the center and prepared to operate at 6 GHz. It is constructed on a FR-4 substrate having the following features, relative

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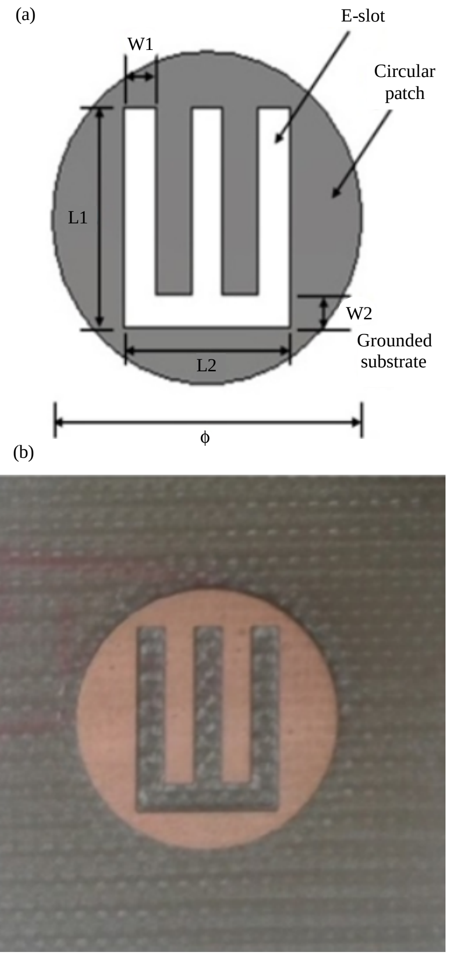

Fig. 1: a) Graphical of the suggested disk patch with E-slot at the middle and b) Picture of the manufactured prototype

permittivity (εr = 4.3) and thickness (t = 1.524 mm). The radius of the proposed disk patch is R = 7.5 mm as in Fig. 1a, the W-slot is integrated by combining three parallel slots and a one perpendicular slot, all the slot widths are equal W1 = W2 = 1.6 mm. Changing the lengths (L1, L2) of both slots leads to change the reflection phase ranges. The manufactured element is shown in Fig. 1b. Waveguide method is used to test the proposed element (Costanzo and Venneri, 2014a, b).

A power full microwave analysis tool is used to analyze the patch element performance. The designed model for each layer is prepared to work in an infinite array environment (Abadi *et al*., 2015; McKay *et al*., 2000). Infinite reflectarray structure with 0.55λ element periodicity is achieved using array model along with the Floquet method. Figure 2 shows the assigning of waveguide boundary conditions for this particular purpose.

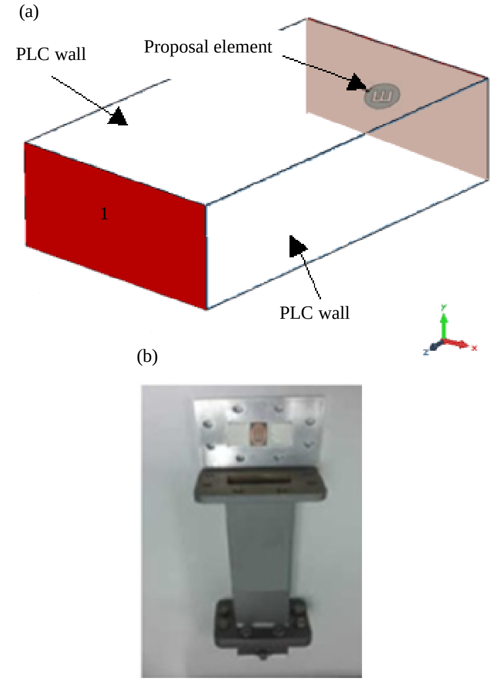

Fig. 2: Waveguide model: a) Section of C-band waveguide modeled and b) A single cell matches the C-band waveguide model

Figuer 3 depicts the reflection characteristics of the circular W-slotted patch element at the first layer. The unit cell element with R = 7.5 mm produces a maximum of -1.3 dB at 6 GHz as shows in Fig. 3a while Fig. 3b shows that the reflection phase range is about 320° with a static phase range around 236°.

For the second layer, the proposed element is a square patch with heptagon slot. The dimensions of the patches are Lpi (i = 1-4) which forced in (40×40) mm square form. For resonance reasons, the simulation is done with slot side Length (Ls) around λ/4; Fig. 4 shows the element structure.

Also, using the same analysis preparations mentioned earlier but with 0.25λ element periodicity. Figure 5 shows the reflection characteristics of the square patch with a heptagon slot element, the unit cell element with slot side length Ls = λ/4 produces a maximum of -1.38 dB at 5.5 GHz as shows in Fig. 5a while Fig. 5b shows that the reflection phase range is about 323°.

Broadband reflectarray design: The double-layered structure is investigated and analyzed to design a broadband reflectarray. A layer of the square patch with heptagon slot patches is placed on top of the layer of W-slotted circular microstrip patches. This promising composition is expected to have a superior performance;

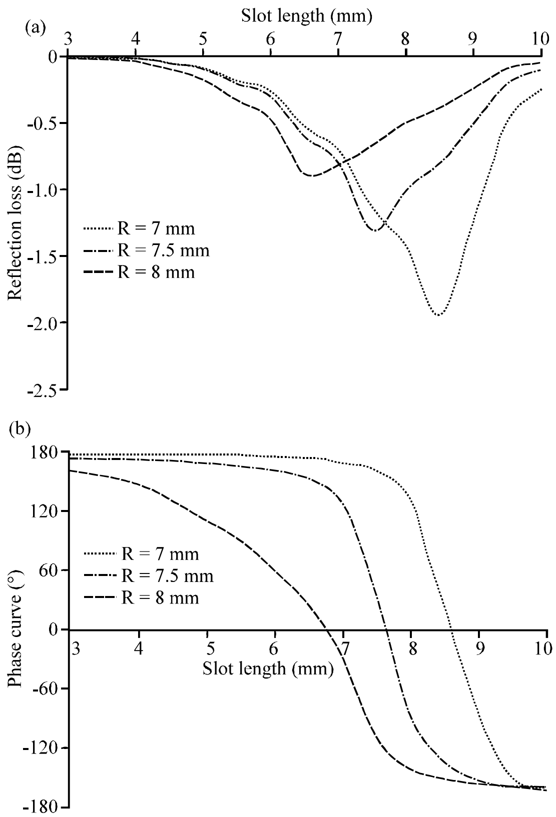

Fig. 3: Effects of element radius (R) on the; a) Reflection loss and b) Phase-curve of the unit cell

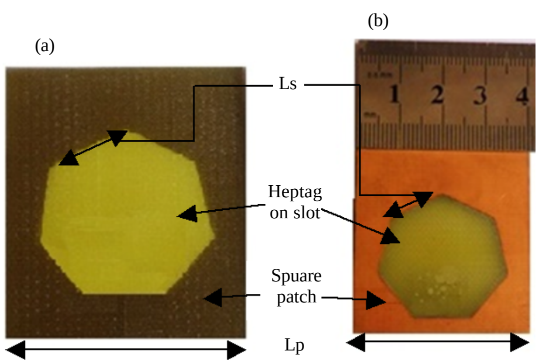

Fig. 4: a) Graphical of the proposed square patch with heptagon slot and b) Picture of the manufactured prototype

especially, a broad range of reflection phase exceeds 360° limit with the presence of relatively low reflection dissipation. A variety of slot lengths are involved to study the reflection responses of the proposed integrated structure. The simulation part of the work which is done with the help of a powerful microwave analysis tool was verified experimentally by the use of the MS4642A Vector Network Analyzer (VNA).

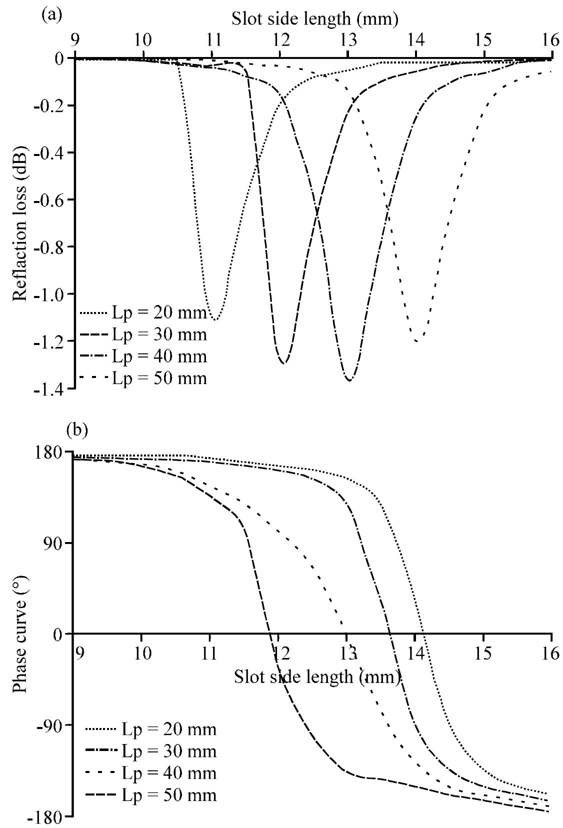

Fig. 5: Effects patch size on the: a) Reflection loss and b) phase-curve of the unit cell

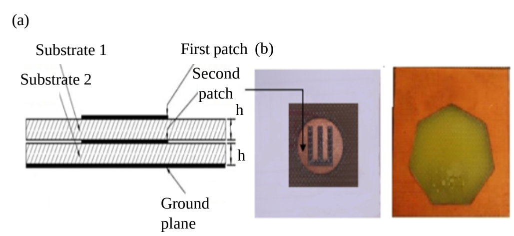

Fig. 6: a) The schematic structure of the proposed double-layered patch element and b) A photograph of the fabricated prototype element

Figuer 6a depict the schematic structure of the proposed double-layered patch element while Fig. 6b shows a photograph of the fabricated prototype element.

Figuer 7 shows the influence of varying the unit cell size in the overall performance of the reflectarray. It's obvious from Fig. 7 that a better reflection characteristic occurs in patch size equal to 40 mm (i.e., Lp = 0.65λ).

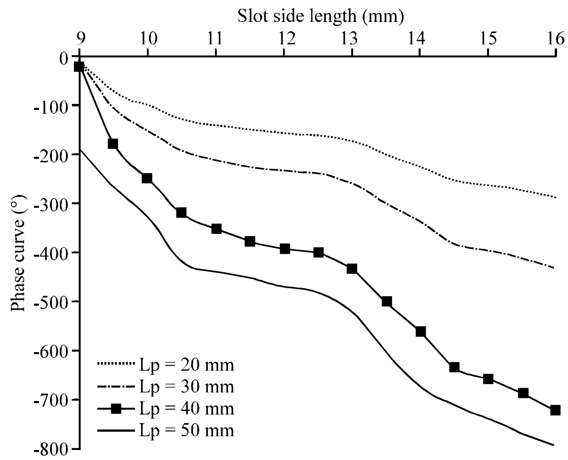

Fig. 7: Phase versus slot side length for a reflectarray with different patch sizes

CONCLUSION

This research is investigating the design methods, simulations, prototypes manufacturing and measurements of double-layer reflectarray elements shapes. At the beginning, reflectarray elements have been investigated and design obstacles have been studied. Variable slot lengths patches are used to supply the required phase shifts of the proposed reflectarray. It is shown that the reflectarray with double-layer structure has a wider phase range than the single-layer frame. It is obvious that using the double-layer leads to smoother S-curve compared to single-layer which simplify the manufacturing process. The construction of the two-layer reflectarray is as follows. The top layer consists of a square patch with heptagonal-slot resonated at 5.5 GHz and the bottom layer consists of several W-slotted circular microstrip patches resonated at 6 GHz. The two layers are integrated together and their closely frequency ranges create a broad C-band range. This composition has a satisfactory performance, particularly when considering the resulted broad reflection phase of about 700° in conjunction with a relatively low reflection loss about 1.5 dB.

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