Main Beam Manipulation of Patch Antenna Using Non-uniform Meta-surface

H. L. Zhu1, Y. X. Cao1, Can Ding2, Gao Wei1, and Y. Jay Guo2
1Northwestern Polytechnical University, Xi'an, Shaanxi, People's Republic of China
2Global Big Data Technologies Center, University of Technology Sydney, Australia

***Abstract* - A method to manipulate the main beam of patch antenna using non-uniform meta-surface (MS) is proposed in this paper. The proposed antenna is composed of a non-uniform MS placed directly atop of a patch antenna with an area of 100*100 mm^2 (0.82 λ_0 * 0.82 λ_0), making it compact and low profile. After adding the MS to the patch antenna, the main-beam direction can be tilted by an angle of 30°from the boresight direction. The proposed antenna is studied and designed to operate around 2.45 GHz. Simulated results show that the antenna has an operating bandwidth from 2.37-2.51GHz and peak realized gain of 7.3dBi.**

***Index Terms* — Meta-surface, main beam manipulation, patch antenna**

1. Introduction

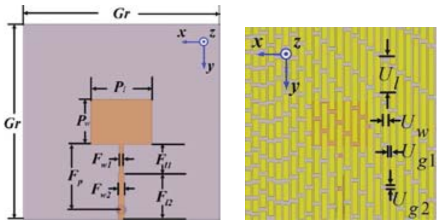
Nowadays antenna has played an increasingly significant role in modern wireless communication systems. In general, we need to point the main beam of an antenna in a specific direction to achieve highly efficient transmission of electromagnetic (EM) energy into a given area. One straightforward solution to accomplish the beam pointing is adjusting the attitude of the antenna itself. This method is certainly the simplest but not feasible always, since the adjustment of antenna's attitude would require more mounting space in most cases. Moreover, if the antenna was conformally mounted on the surface of aircrafts or some other mobile platforms, it would be impossible to change the antenna's attitude arbitrarily. Phased array (PA) offers another solution [1, 2], however, a large number of phase shifters are needed as well as control circuitry, making the PA a solution with high cost and complex structure. For the reasons mentioned above, a solution with low cost and simple structure, which is capable of manipulating the antenna main beam without adjusting the attitude of the antenna itself, is highly desirable for modern wireless communication systems.

The meta-surface lens working at microwave frequency band is a potential solution for antenna beam manipulation. There has been a wealth of research outcome in terms of meta-surface lens over the past years. Through proper design of the unit cells' dimensions and layout on meta-surface, characteristics of the EM wave going through it such as propagation direction and polarization could be manipulated [3]. The meta-surface lens antennas (MLA) is thus formed with a source antenna and meta-surface lens, where the source antenna refers to the antenna used to illuminate the meta-surface lens. For most of current MLAs, the design strategy is based on fundamental theory of optical lens. The meta-surface lens needs to be placed in Fresnel zone accordingly, which means the distance between source antenna and lens is required to be at least quarter wavelength or even longer. Consequently, the total size of the antenna is increased significantly after adding the meta-surface lens. In fact, the bulky size of the MLA is a major factor restricting its application in practice. Therefore, it is necessary to further miniaturize the MLA to make it more desirable in practical applications. To this end, we propose to place the meta-surface lens in the reactive near-field region of the source antenna, where the lens could be placed very close to the source antenna, making the MLA much more compact.

In this paper, a lens working at the reactive near-field region of the source antenna is proposed, the distance between the source antenna and lens is merely 0.013λ_0, where λ_0 is wavelength of operating frequency in free space. The main beam of the source antenna can be deflected after going through the meta-surface lens. The deflection angle can also be manipulated through properly designing the sizes and layout of the unit cells on meta-surface lens. The sizes and layout of the unit cells on meta-surface are optimized to change the electric field distribution near the source antenna and then the radiation pattern at far-field region. Therefore, the geometry of the meta-surface lens proposed in this paper is directly determined by the form of the source antenna. To verify the effectiveness of the lens working at reactive near-field zone, we use patch antenna as source antenna and add meta-surface on it. The meta-surface is printed on one side of substrate and the other side has nothing on it. The final MLA has a very compact structure since the substrate of the meta-surface lens is in direct contact with the source antenna. The simulated results show that the main beam can be manipulated with a tilted range up to 30° from the boresight direction by properly designing the dimensions and layout of the unit cells on meta-surface.

2. Designs of Antenna:

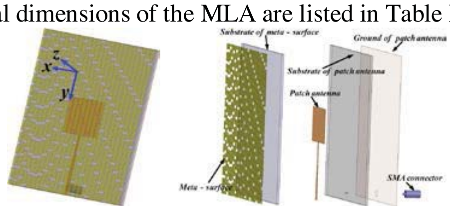
The meta-surface lens antenna (MLA) proposed here is composed of a non-uniform meta-surface (MS) lens and a patch antenna, both designed using planar technology, as shown in Figs. 1. The patch antenna is designed on a double-sided substrate, with one side being the ground plane and the other side a patch as shown in Fig. 1(a). The MS as shown in Fig. 1(b) is designed on a single-sided substrate, composing of a number of rectangular-strip unit cells with different lengths.



(a) (b)

Fig. 1 Top view of (a) patch antenna and (b) MS.

The unit cells are placed periodically along the x-axis but non-uniformly along the y-axis directions on the substrate. The complete antenna structure and the assembly schematic are shown in Figs. 2. The proposed antenna is fed using a SMA connector going through the ground plane as shown in Fig. 2(b). The non-copper side of the MS is placed on the top of and in direct contact with the patch antenna as shown in Figs. 2(a) and (b). It will be shown later the main beam of the patch antenna can be tilted from z-axis in x-z plane by adding the MS. The tilted angle can be tuned by adjusting the layout of the unit cells on meta-surface. The FR-4 substrate, with a thickness of 1.6 mm and a dielectric constant of εr =4.4, is used for the designs of the patch antenna and the MS. The final dimensions of the MLA are listed in Table I.



(a) (b)

Fig. 2 (a) Perspective view and (b) assembly schematic of proposed MLA antenna

Table I

Dimensions of proposed antenna (Unit: mm)

P_l	P_w	F_{l1}	F_{l2}	F_{w1}	F_{w2}	F_p	U_l	U_w	U_{g1}	U_{g2}	G_r
31	23	15	23.5	2	3	33.5	4-25	3	1	2	100

3. Results and Discussions

The simulated results of S11 are shown in Fig. 3. The antenna has a simulated impedance bandwidth from 2.37 to 2.51 GHz, for S11 less than -10dB.

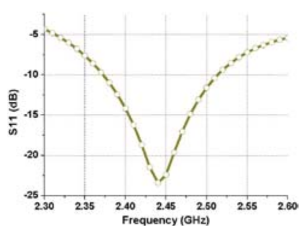


Fig. 3 S11 of proposed antenna

As for radiation pattern, after adding the MS lens, the antenna main beam is tilted in x-z plane as expected. To show the relationship between the tilted angle and the variation range of the unit cell length, simulated results for unit cells varied from 5mm to 35mm and from 3mm to 15mm are also shown in the same figure for comparison. It can be seen from Fig. 4 that with the increase of the variation range of unit cell length, the tiled angle can be further increased to -55°which is indicated by red line in the same figure when the range is set to be from 5mm to 35 mm, however, unacceptable side lobe will appear around +57°.

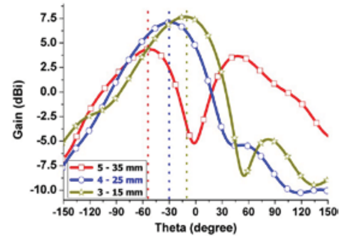
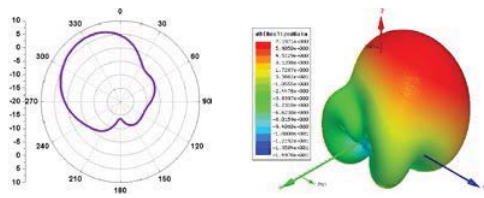


Fig. 4 Main beam directions in x-z plane for different variation range of the unit cell length.

The polar plots of radiation patterns are shown in Fig. 5(a), where it can be seen that the realized gain reaches a peak of 7.3dBi at 2.45 GHz. The half power beam-width （HPBW） is 66° （-2° to 64° ）.The cross-polarizations are too small to be shown in the same figure and so omitted. It should be pointed out that the co-polarization of the antenna is still linear and along y-axis. Result of simulated 3D radiation plot is shown in Figs. 5(b).



(a) (b)

Fig. 5 (a) Polar plots of radiation patterns and (b) 3D Radiation plot at 2.45GHz.

4. Conclusion

A MLA antenna designed using a patch antenna and a non-uniform MS has been proposed. The main beam of patch antenna can be tilted by adjusting the layout of unit cells on MS. The beam tilting feature has been verified using simulated results. Results have shown that the peak realized gain of the main beam can reach up to 7.3dBi with a half power beam width of 66°..

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