Frequency Reconfigurable Antenna Using Metasurface for Satellite Application

[1]N. Rajakanya , [2]B. Kokila, [3]R. Subraja , [4]Dr.S. Rajakumar
[1,2]PG Student, [3]Assistant Professor, [4] Professor
Department of Electronics and Communication Engineering,
[1,2,4]Panimalar Engineering College, [3]Jeppiaar SRR Engineering College Chennai, India

***Abstract*—A frequency-reconfigurable antenna designed using metasurface (MS) to operate at around 5 GHz is studied and proposed. The frequency-reconfigurable metasurfaced (FRMS) antenna is composed of a simple circular patch antenna and a circular MS with the same diameter of 40 mm and implemented using planar technology. The MS is placed directly atop the patch antenna, making the FRMS antenna very compact and low profile with a thickness of only 3.048 The MS consists of rectangular-loop unit cells placed periodically in the vertical and horizontal directions. Simulation results show that the operating frequency of the antenna can be tuned by physically rotating the MS around the center with respect to the patch antenna. The MS placed atop the patch antenna behaves like a dielectric substrate and rotating the MS changes the equivalent relative permittivity of the substrate and hence the operating frequency of the FRMS antenna. Measured results show that the antenna has a tuning range from 4.76 to 5.51 GHz, a fractional tuning range of 14.6%, radiation efficiency and a realized peak gain of more than 80% and 5 dBi, respectively, across the tuning range.**

Keywords— MS- Meta-Surface; FRMS- Frequency Reconfigurable Meta-Surface; Unit cell.

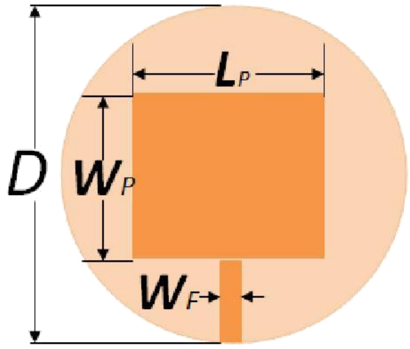
I. INTRODUCTION

Due to the demand for integrating multiple wireless standards into a single wireless platform, reconfigurable antenna, also known as tunable antenna, is attracting much attention. In general, the mechanism used to reconfigure the frequency bands of reconfigurable antennas can be mechanical or electrical. Electrically reconfigurable antennas, which are far more popular, can be classified into band switching and continuous tuning. Band switching can be achieved using PIN-diode switches and the operating frequency band is switched among different frequency bands, depending on the switching states [2]– Continuous tuning can be accomplished using varactor diodes and the antennas can be frequency tuned smoothly within the operating frequency bands [5]. In designing these antennas, direct-current (DC) biasing circuits are needed to bias the PIN or varactor diodes. However, there are drawbacks in electrically reconfigurable antennas. For example, the electronic components and circuits in the biasing circuits may have adverse effects on the antennas performances, DC electrical sources are needed to drive the PIN or varactor diodes, and the antenna operation is depending on the reliability of the electronic components and the DC sources [5]–[13].

In mechanically reconfigurable antennas, the antenna structures consist of movable parts. Frequency tuning is obtained by adjusting the movable parts [14], [15]. The main drawback of such designs was that the overall antenna size required varied with the tuned frequency. Moreover, the actuator used to produce the mechanical movements was very complicated and occupied much space, which led to a bulky and expensive structure. In fact, change of size and/or shape is the common problem for most mechanically tunable antennas.

Metasurface (MS), a two-dimensional equivalent of metamaterial, is essentially a surface distribution of electrically small scatterers [16]. With its succinct planar structure and low cost, MS has wide applications and one of which is on the design of planar antennas. In [17], [18], it was shown that the performance of a patch antenna could be enhanced significantly by placing a MS atop of it. In [18], it was demonstrated that by adding a specially designed MS atop a simple patch/slot antenna, not only the realized gain and return-loss bandwidth (S_{11} <-10dB) would be significantly improved, but also polarization conversion from linear polarization (LP) to circular polarization (CP) could be achieved. The patch/slot antenna (known as the source antenna in such design) together with the MS was called MS antenna. In these designs [17], [18], an air gap was used between the MS and the source antenna, which substantially increased the volume of the MS antenna.

In this paper, a novel frequency-reconfigurable metasurfaced (FRMS) antenna constructed by placing a MS atop a patch antenna is proposed. To make the FRMS antenna more compact and low profile, the patch antenna and MS are placed together in direct contact, eliminating the air gap between them. Thus the proposed design has the apparent advantages of compact size, low cost and simple construction. Results of studies show that the operating frequency of the antenna can be continuously



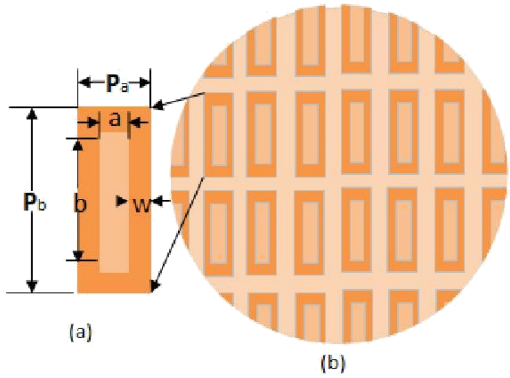


Figure 2. Geometries of (a) Unit cell and (c) Metasurface.

Figure 1. Geometries of Patch Antenna (source antenna).

tuned by rotating the MS around the center and relative to the patch antenna.

For easy mechanical operation, the shapes of the patch antenna and the MS are made circular with identical size. The frequency-reconfigurable property of the FRMS antenna is also analyzed and explained in this paper.

The main difference in the use of MS between the proposed FRMS and our previous design in [18] is that, in the proposed FRMS, the MS is used to tune the frequency and polarization of the antenna remains linear (same as the source antenna), while in design in [18], the MS converts LP from the source antenna to CP. The proposed FRMS antenna is studied and designed to operate at about 5 GHz using the EM simulation tool CST [19].

II. DESIGN OF FREQUENCY RECONFIGURABLE MESTSURFACED ANTENNA

The FRMS antenna proposed here consists of a patch antenna (as the source antenna) and a metasurface (MS). For easy reconfigurable operation of the antenna, the patch antenna and MS are designed to have a circular shape and occupy the same area. The patch antenna is designed in a double sided substrate using planar technology as shown in figure 1, while the MS is designed on a single sided substrate as shown in figure 2c, and composing of a number

of rectangular loop unit cells as shown in figure 1b the unit cells are placed periodically along the x-axis and y-axis directions on the XY plane as shown in figure 1b as will be seen later , frequency reconfigurability of the antenna can be achieved by rotating the MS around the center relative to the patch antenna. The rotation angle θ_R is measured from the Y-axis as shown in figure 1c due to horizontal and vertical symmetries of the MS, θ_R = - θ_R and the maximum rotation angle without repeating is 180^o.

In assembling the FRMS antenna, the non-copper side of the MS is placed in direct contact with the radiator of the patch antenna as shown in. This leads to a very compact and low profile structure. The antenna is microstrip-fed using a 50- feed-line. An SMA connector is fed to the feed-line through the inset feed. The feed will be used to energize the patch alone.

The patch is also made to radiate a fixed frequency and by using the metasurface the frequency reconfigurability can be achieved The FRMS antenna together with the SMA connector is studied and designed on a F-R4 substrates, having a thickness of 1.57 mm and a relative permittivity of ε_r = 4.4. The dimensions are listed in Table I which is used to fabricate the FRMS antenna.

III. ANALYSIS OF FRMS ANTENNA

As will be shown later by the simulated and measured results, rotating the MS with respective to the source antenna will change the resonant frequency of the FRMS substrate antenna. Here we attempt to analyze such frequency-reconfigurable property. The source antenna used in our FRMS antenna is a patch antenna which radiates linearly polarized signal and has a fixed fundamental resonant frequency. Then the metasurface is placed atop of the patch antenna which is printed on single side of the Fr-4 substrate. The FRMS antenna in this design is made without any air gap

Thus the rotation of the metasurface in order to change the frequency can be easily achieved. The metasurface is having same dimension of that of the substrate and it is in circular shape and hence mechanical rotation can be done at ease. The rotation of the antenna is made mechanically and at particular angle we get the maximum radiated frequency and at another angle we get the minimum radiated frequency thus the frequency can be varied within this range with maximum reflection coefficient.

IV. SIMULATION AND MEASUREMENT RESULT

Thus the simulation results of the frequency reconfigurable antenna using meta surface has been designed and simulated

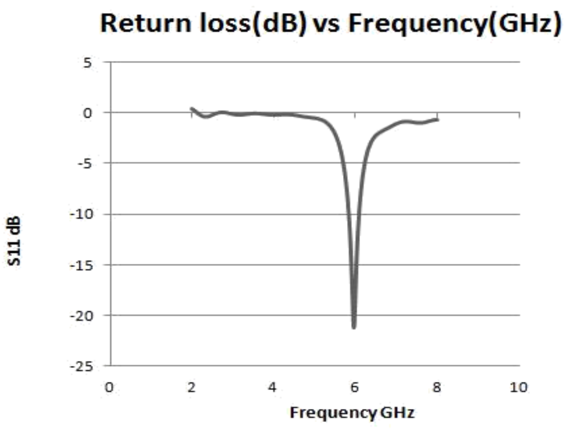


Figure 3. Graph Between Return Loss(dB) Vs Frequency (Ghz)

using the CST software and the results have high correlation with the simulated software module. Here, we have eliminated the air interface and thus we get high tunable range with high return loss. The below figure No. 3 shows the graph of the frequency response Vs retune loss of the antenna at 0 deg of rotation. From figure 3 we can interrupt That the designed antenna has good impedance matching and we get frequency dip at 5.8 GHz and a reflection coefficient of -22.693159 dB.

Here the fixed frequency generated by the patch antenna can be varied using the meta-surface which is placed atop of the patch antenna. The study of the frequency response is carried out form 0^{o} to 180^{o} at the step of 5 degree
The respective rotations and its frequncy response, and its reflection coefficient will be discussed below.

At 0^{o} the resonant frequency is 5.846Ghz and a reflection coefficient of -21.919802 dB this is the lowest frequency response, at 5^{o} the resonant frequency is 5.912 Ghz and a reflection coefficient of -22.631279 dB, at 10^{o} the resonant frequency is 5.894 Ghz and a reflection coefficient of -22.57934 dB, at 15^{o} the resonant frequency is 5.882 Ghz and a reflection coefficient of - 22.631279 dB, at 10^{o} the resonant frequency is 5.882 Ghz and a reflection coefficient of - 23.915474dB, and we get the highest at 85^{o} the resonant frequency is 6 Ghz and a reflection coefficient of -23.421682 dB, the highest return loss of -36.830482 dB occurs at 130^{o} with a frequency response of 5.912 Ghz. The analysis form [1] shows that the frequency response we got from rotating the metasurface of the designed antenna is similar to that of the frequency response of the antenna by changing its substrate.

This shows that changes in the rotation are similar to that of the changes we get by changing the relative permittivity of the substrate materials we use. This allows us to get the similar results which we can obtain my changing the substrate materials which is practical impossible with a

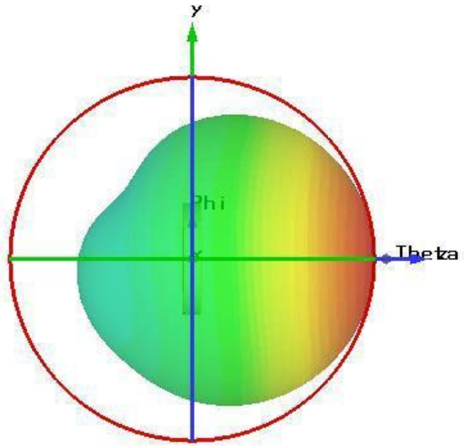


Figure 4. Far Field Radiation in Phi Direction.

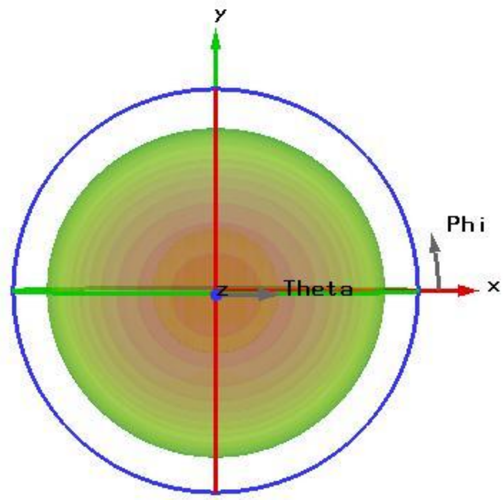


Figure 5. Far Field Radiation in Theta Direction.

fabricated antenna but we can change the rotation angle to get the similar results. The figure 4, figure 5 and figure 6 shows the far field radiation in Phi and Theta direction and the surface current.

In the MS the unit cell have a rectangular shape and they are place periodically along the X-axis and Y-axis. In the co-polarization direction of the patch antenna the unit cells has the lowest periodicity at $\theta_E = 0^{o}$ and the highest periodicity at $\theta_E = 180^{o}$. As the rotation angle θ_E changes from 0^{o} to 180^{o} the periodicity changes form lowest to highest which correspond to change the permittivity from maximum to minimum. As a result the resonant frequency of the FRMS antenna is proportional to that of the rotation angle θ_R.

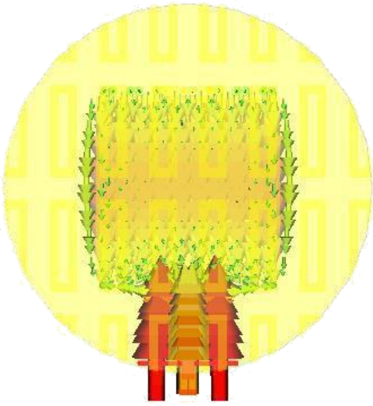


Figure 6. Surface Current of the Antenna with Metasurface.

V. CONCLUSION

The antenna designed here has been designed by using Fr-4 material and this substrate is having a permittivity 4.4 and this is manufactured with a height of 1.57. This design is very compact comparing to the proposed design of FRMS antenna. This will resonate at different frequencies from 5.46 GHz to 5.97 GHz. The S11 will b having the maximum of -31 dB at 5.9 GHz.

A FRMS antenna designed using a patch antenna and a MS has been presented. The resonant frequency of the antenna can be mechanically reconfigure by rotating the MS around the center with respect to the patch. The frequency-reconfigurable property has been analyzed and explained. This can be further extended by increasing the size and increasing the reconfigurability of the antenna further more with increased return loss.

REFERENCES

[1] H. L. Zhu, X. H. Liu, S.W. Cheung., "Frequency recongigurable antenna using metasurface," IEEE Transactions Antennas and Propagation, VOL. 62, pp. 80-85, 2014.
[2] H. F. AbuTarboush et al., "A reconfigurable wideband and multiband antenna using dual-patch elements for compact wireless devices," IEEE Trans. Antennas Propag., vol. 60, pp. 36–43, 2012.
[3] Z. J. Jin, J. H. Lim, and T. Y. Yun, "Frequency reconfigurable mul- tiple-input multiple-output antenna with high isolation," IET Microw., Antennas Propag., vol. 6, pp. 1095–1101, 2012.
[4] A. Sheta and S. F. Mahmoud, "A widely tunable compact patch an- tenna," IEEE Antennas Wireless Propag. Lett., vol. 7, pp. 40–42, 2008.
[5] X. L. Sun, S. W. Cheung, and T. I. Yuk, "Dual-band monopole an- tenna with frequency-tunable feature for WiMAX applications," IEEE
[6] Antennas Wireless Propag. Lett., vol. 12, pp. 100–103, 2013.
[7] M. Abdallah, L. Le Coq, F. Colombel, G. Le Ray, and M. Himdi, "Fre- quency tunable monopole coupled loop antenna with broadside radia- tion pattern," Electron. Lett., vol. 45, pp. 1149–1151, 2009.
[8] H. F. AbuTarboush, R. Nilavalan, S. W. Cheung, and K. M. Nasr, "Compact printed multiband antenna with independent setting suitable for fixed and reconfigurable wireless communication systems," IEEE Trans. Antennas Propag., vol. 60, pp. 3867–3874, 2012.
[9] C. Pei-Ling, R. Waterhouse, and T. Itoh, "Compact and tunable slot-loop antenna," IEEE Trans. Antennas Propag., vol. 59, pp. 1394–1397, 2011.
[10] O. Se-keun, S. Yong-Sun, and P. Seong-Ook, "A novel PIFA type var- actor tunable antenna with U-shaped slot," in Proc. 7th Int. Symp. on Antennas, Propag. & EM Theory, 2006, pp. 1–3.
[11] N. Viet-Anh, R. A. Bhatti, and P. Seong-Ook, "A simple PIFA-based tunable internal antenna for personal communication handsets," IEEE Antennas Wireless Propag. Lett., vol. 7, pp. 130–133, 2008.
[12] C. Yong, Y. J. Guo, and A. R. Weily, "A frequency-reconfigurable Quasi-Yagi dipole antenna," IEEE Antennas Wireless Propag. Lett., vol. 9, pp. 883–886, 2010.
[13] B. A. Cetiner, G. R. Crusats, L. Jofre, and N. Biyikli, "RF MEMS in- tegrated frequency reconfigurable annular slot antenna," IEEE Trans. Antennas Propag., vol. 58, pp. 626–632, 2010.
[14] C. Chi-Yuk, L. Jichao, S. Sichao, and R. D. Murch, "Frequency-recon- figurable pixel slot antenna," IEEE Trans. Antennas Propag., vol. 60, pp. 4921–4924, 2012.
[15] R. Al-Dahleh, L. Shafai, and C. Shafai, "A frequency-tunable mechan- ically actuated microstrip patch antenna," in Proc. IEEE Antennas and Propag. Soc. Int. Symp., 2003, vol. 4, pp. 548–551.
[16] J. T. Bernhard, E. Kiely, and G. Washington, "A smart mechanically ac- tuated two-layer electromagnetically coupled microstrip antenna with variable frequency, bandwidth, and antenna gain," IEEE Trans. An- tennas Propag., vol. 49, pp. 597–601, 2001.
[17] C. L. Holloway, E. F. Kuester, J. A. Gordon, J. O'Hara, J. Booth, and D.R. Smith, "An overview of the theory and applications of metasurfaces: The two-dimensional equivalents of metamaterials," IEEE Antennas Propag. Mag., vol. 54, pp. 10–35, 2012.
[18] K. L. Chung and S. Chaimool, "Diamagnetic metasurfaces for perfor- mance enhancement of microstrip patch antennas," in Proc. 5th Eur. Conf. on Antennas and Propag. (EUCAP), 2011, pp. 48–52.
[19] H. L. Zhu, K. L. Chung, X. L. Sun, S. W. Cheung, and T. I. Yuk, "CP metasurfaced antennas excited by LP sources," in Proc. IEEE Antennas and Propag. Soc. Int. Symp. (APSURSI), 2012, pp. 1–2.
[20] [Online]. Available: https://www.cst.com/
[21] [Online]. Available: http://www.satimo.com/
[22] X. Chen, T. M. Grzegorczyk, B.-I. Wu, J. Pacheco, Jr., and J. A. Kong, "Robust method to retrieve the constitutive effective parameters of metamaterials," Phys. Rev. E, vol. 70, p. 016608, Jul. 2004.
[23] P. Markos and C. Soukoulis, "Transmission properties and effective electromagnetic parameters of double negative metamaterials," Opt. Expr., vol. 11, pp. 649–661, Apr. 2003.
[24] D. R. Smith, S. Schultz, P. Markoš, and C. M. Soukoulis, "Deter- mination of effective permittivity and permeability of metamaterials from reflection and transmission coefficients," Phys. Rev. B, vol. 65, p. 195104, Apr. 2002.
[25] F. C. Seman, R. Cahill, V. F. Fusco, and G. Goussetis, "Design of a Sal- isbury screen absorber using frequency selective surfaces to improve bandwidth and angular stability performance," IET Microw., Antennas Propag., vol. 5, pp. 149–156, 2011.