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Metasurface argumented high gain 28 GHz microstrip antenna for mm-wave 5G application

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Abstract

This paper presents the design of a linearly polarized metasurface (MTS) at 28 GHz frequency band for mm-wave 5G application. The designed metasurface, when loaded on a suitable radiator kept at the focus of the MTS, provides a substantially improved gain. The MTS is designed by obtaining its phase profile using the phase compensation method. The metasurface comprises multiple layers (four metallic layers over three cascaded dielectric substrates) with each layer having 15×15 elements of circular patches surrounded by square loops. The MTS is loaded on a linearly polarized co-axially fed microstrip patch antenna (MPA) operating at 28 GHz. The MTS loaded MPA contributes to 16.7 dBi of peak in the boresight direction with HPBW of 15^o making it a suitable element for 5G mm wave applications.

1 Introduction

High gain antennas are the key elements for mm-wave communication system to tackle practical and unavoidable constrain in the form of significant atmospheric absorption, rain attenuation and path loss etc. [1]. Among several mm-wave bands, 28- and 38- GHz bands, thanks to comparatively low loss and reduced atmospheric impact, has been touted as possible 5G bands by several surveys, industry and cellular operators. Various conventional and easy to realize antennas, such as, SIW based antennas, slot antennas and defect ground slot (DGS) antennas are reported in [2] for 28 GHz band. However, these antennas surfers from its lower gain with typical value of around 7 dBi. The antenna gain can be enhanced by using the array concepts and/or mm wave lenses. However, such techniques are limited by fabrication difficulties, larger size and weight for several applications. In this article, design of metasurface lense is proposed to enhance the gain of mm-wave antennas. Metasurface lens, being low profile and easy to fabricate, offers an interesting alternative in realizing high gain mm-wave antennas for 5G base station applications

Metasurface (MTS), an engineered quasi 2-D structure with desired surface characteristics, can tailor the transmitted or reflected wave properties through/on it. MTS, of late are extensively used in gain enhancement, polarization conversion and RCS reduction [3, 4, 5, 6]. This paper presents the design of MTS for gain enhancement at 28 GHz. The designed MTS when loaded on a suitable microstrip antenna, the overall system contributes to a high gain at 28 GHz. Proposed metasurface augmented high gain antenna can be used for mm-wave 5G application. This paper is organized as follows: Section 2 presents the unitcell design and analysis. The MTS design and analysis with patch antenna is presented in section 3. Finally, the conclusions are drawn in section 4

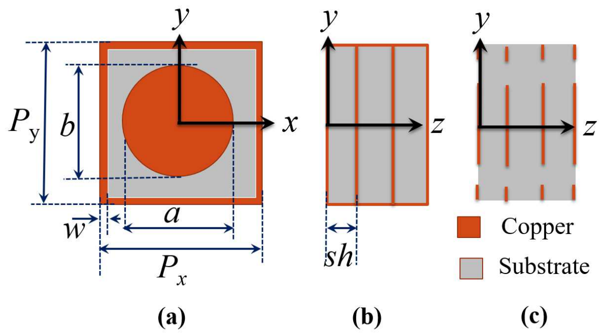


Figure 1. Unitcell Details (a) top view, (b) side view, (c) cross sectional view at $x = 0$ (Unitcell dimensions (mm): $Px = Py = 4$, $a = b = 3.6$, $w = 0.1$, $sh = 0.8$)

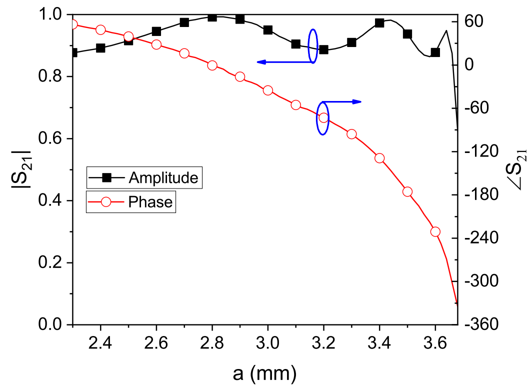


Figure 2. Variation of transmission parameters at 28 GHz

2 Unitcell design and analysis

For gain enhancement application MTS requires unit cells having 360^o phase coverage with high transmission coefficient($|S_{21}| \approx 1$). Hence, the MTS is designed on the commercially available low loss substrate Rogers RT/duroid 5880 (ϵ_r=2.2, $\tan\delta = 0.0003$). The unitcell in present work consists of square loop encircled four metallic patches accommodated over three cascaded dielectric substrates each having thickness of 0.8 mm. Figure 1 shows the geometry of the proposed MTS unitcell . The unitcell is analyzed using CST Microwave studio with periodic boundary conditions and excited with floquet ports along $\pm z$ direction. To realize 360^o phase variation, the dimension of the circular patch (a=b) are varied from 2.2 mm to 3.8 mm. The transmission properties of the unitcells at 28 GHz are shown in figure 2. It is evident from the figure that the unitcell offers high transmission coefficient $|S_{21}| > 0.85$ and broad phase variation from 60^o to -330^o with 390^o phase coverage.

3 Metasurface design and analysis

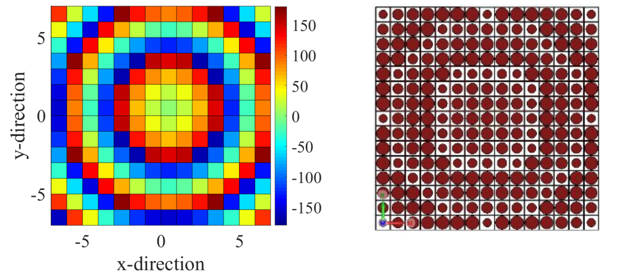
The phase profile on the MTS is governed by the phase compensation method [4],

$$\psi_{mn} = -jk(R_{mn} - \overline{r}_{mn}.\hat{u}_o) + \psi_0 \tag{1}$$

where, ψ_{mn} is phase at mn^{th} position on the MTS, k is the wave number, R_{mn} is the distance form the feed to the mn^{th} position, $\overline{r}_{mn}$ is the position vector the mn^{th} element from the center of the MTS and ψ_0 is the reference phase at the center of the MTS. Considering the periodicity of the unitcell and focal point at (0,0,15 mm), phase profile on the MTS has been calculated at 28 GHz. Figure 3a shows the required phase profile of the MTS obtained from 1. Based on the the derived phase profile, the dimension (a=b) of the MTS unitcells are determined by one to one phase mapping of the unitcells. Figure. 3b shows the top view of the designed multilayered MTS. To demonstrate the gain enhancement functionality of the proposed MTS, it is further loaded on a co-ax fed rectangular microstrip patch antenna operating at 28 GHz. The antenna is printed on a 62 mil thick dielectric laminate (ϵ_r=2.2, $\tan\delta = 0.0003$) with dimensions indicated in caption of Fig. 4

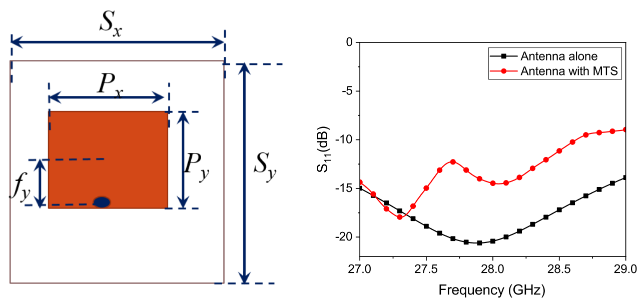
Figure 4b plots reflection coefficient(S_{11}) of the proposed antenna with and without the MTS revealing a good matching at the design frequency of 28 GHz and gain of the antenna with and without the MTS, respectively. Figure 5a plots the maximum realized gain of the antenna with and without the proposed MTS. As revealed from the plot, while the standalone patch antenna exhibits a gain of 7.1 dBi, the MTS antenna with optimal positioning (15 mm away from the MTS), yiels a maximum realized gain of 16.5 dBi at 28 GHz with average gain enhancement of 9 dB from 27 GHz to 29 GHz. Figure. 5b shows the radiation pattern of the proposed MTS augmented patch antenna at 28 GHz. It is observed that in $\phi = 0^{\text{o}}$ plane, the pattern is symmetric with side lobe levels of -21 dB. In $\phi = 90^{\text{o}}$ plane, the pattern is slightly tilted by 2^{o} with first side lobe levels of -15 dB.

It is evident that the antenna is operating from 27 GHz to



(a) **(b)**

Figure 3. MTS at 28 GHz: (a) Phase profile, (b) Designed Metasurface



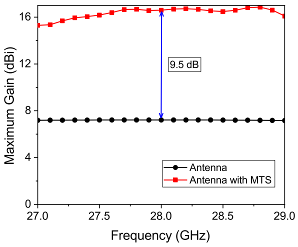
(a) Geometry **(b)** S-Parameters

Figure 4. Antenna (dimensions are in mm: $Sx = Sy = 10$, $Px = 3.5$, $Py = 2.62$, $fy = 0.76$)

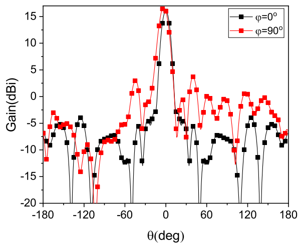
29 GHz with a consistent gain of 7.1 dB. To enhance the gain. As the MTS placed at a 15 mm distance from the antenna center. The $|S_{11}|$ shows a slight deviation from the original, however, $S_{11} < -10$ dB in the frequency range of 27 GHz to 28.5 GHz. The simulation results shows an average gain enhancement of 9 dB from 27 GHz to 29 GHz. Figure 5b shows the radiation pattern of the antenna with MTS. It is observed that in $\phi = 0^o$ plane, the pattern is symmetric with side lobe levels of -21 dB. However, in $\phi = 90^o$ the pattern is tilted by 2^o with first SLL of -15 dB, which is due to the antenna pattern in $\phi = 90^o$ plane. A cross pol of -10 dB and -60 dB has been observed in $\phi = 0^o$ and $\phi = 90^o$ plane, respectively.

4 Conclusion

This paper presents design of a MTS at 28 GHz for gain enhancement of a mm-wave microstrip antenna operating at 28 GHz. The proposed concept of MTS design is independent of feeding antenna type, and hence can be extended for gain enhancement of any other linearly polarized radiators with boresight radiation. This design concept being very generic, can be extended to any other frequency band by tuning the parameters. Hence, The MTS loaded high gain antenna are the potential candidates for point to point communication for 5G mm wave applications. Proposed antenna can be used as unit element for mm-wave based 5G MIMO and massive MIMO systems.



(a) Maximum gain



(b) Radiation pattern

Figure 5. Antenna with MTS: (a) Gain comparison with and without MTS (b) Radiation pattern with MTS at 28GHz

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References

[1] A. Ghosh, T. A. Thomas, M. C. Cudak, R. Ratasuk, P. Moorut, F. W. Vook, T. S. Rappaport, G. R. MacCartney, S. Sun, and S. Nie, "Millimeter-wave enhanced local area systems: A high-data-rate approach for future wireless networks," *IEEE Journal on Selected Areas in Communications*, vol. 32, no. 6, pp. 1152–1163, 2014.

[2] M. Sangwan, G. Panda, and P. Yadav, "A literature survey on different mimo patch antenna," in *2020 International Conference on Inventive Computation Technologies (ICICT)*. IEEE, 2020, pp. 912–918.

[3] A. K. Singh, M. P. Abegaonkar, and S. K. Koul, "Wide angle beam steerable high gain flat top beam antenna using graded index metasurface lens," *IEEE Transactions on Antennas and Propagation*, vol. 67, no. 10, pp. 6334–6343, 2019.

[4] P. V. Kumar and B. Ghosh, "A dual-band multi-layer metasurface lens," in *2018 IEEE Indian Conference on Antennas and Propogation (InCAP)*. IEEE, 2018, pp. 1–4.

[5] K. Kannan, E. George, K. Surendran, and C. Saha, "Boresight gain enhancement of a dielectric resonator antenna using a metasurface lens," in *2017 IEEE International Conference on Antenna Innovations & Modern Technologies for Ground, Aircraft and Satellite Applications (iAIM)*. IEEE, 2017, pp. 1–3.

[6] H. Zhu, S. W. Cheung, and T. I. Yuk, "Enhancing antenna boresight gain using a small metasurface lens: Reduction in half-power beamwidth." *IEEE Antennas and Propagation Magazine*, vol. 58, no. 1, pp. 35–44, 2016.