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

Vinod Kumar P(1), Basudeb Ghosh(1) and Chinmoy Saha(1),
(1) Department of Avionics, Indian Institute of Space Science and Technology, Kerala, India, 695547

Abstract

This paper presents the design of a linearly polarized meta-
surface (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, pro-
vides a substantially improved gain. The MTS is designed
by obtaining its phase profile using the phase compensa-
tion method. The metasurface comprises multiple layers
(four metallic layers over three cascaded dielectric sub-
strates) 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 an-
tenna (MPA) operating at 28 GHz. The MTS loaded MPA
contributes to 16.7 dBi of peak in the boresight direction
with HPBW of 15° making it a suitable element for 5G mm
wave applications.

1 Introduction

High gain antennas are the key elements for mm-wave com-
munication system to tackle practical and unavoidable con-
strain 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 anten-
nas, 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 conver-
sion and RCS reduction [3, 4, 5, 6]. This paper presents the
design of MTS for gain enhancement at 28 GHz. The de-
signed 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 anal-
ysis. The MTS design and analysis with patch antenna is
presented in section 3. Finally, the conclusions are drawn
in section 4

2 Unitcell design and analysis

For gain enhancement application MTS requires unit
cells having 360° phase coverage with high transmission
coefficient(\(|S_{21}| \approx 1\)). Hence, the MTS is designed
3 Metasurface design and analysis

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

\[ \psi_{mn} = -jk(R_{mn} - r_{mn}a_o) + \psi_0 \]  \hspace{1cm} (1)

where, \( \psi_{mn} \) is phase at \( mn \)th position on the MTS, \( k \) is the wave number, \( R_{mn} \) is the distance from the feed to the \( mn \)th position, \( r_{mn} \) is the position vector the \( mn \)th element from the center of the MTS and \( \psi_0 \) 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 (\( \varepsilon_r=2.2, \tan \delta = 0.0003 \)) 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 dB, the MTS antenna with optimal positioning (15 mm away from the MTS), yields a maximum realized gain of 16.5 dB 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 \( \phi = 0^\circ \) plane, the pattern is symmetric with side lobe levels of -21 dB. In \( \phi = 90^\circ \) plane, the pattern is slightly tilted by 2\( ^\circ \) with first side lobe levels of -15 dB.

It is evident that the antenna is operating from 27 GHz to 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 \( \phi = 0^\circ \) plane, the pattern is symmetric with side lobe levels of -21 dB. However, in \( \phi = 90^\circ \) the pattern is tilted by 2\( ^\circ \) with first SLL of -15 dB, which is due to the antenna pattern in \( \phi = 90^\circ \) plane. A cross pol of -10 dB and -60 dB has been observed in \( \phi = 0^\circ \) and \( \phi = 90^\circ \) 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.
Figure 5. Antenna with MTS: (a) Gain comparison with and without MTS (b) Radiation pattern with MTS at 28GHz

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References


