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Directive Antennas for Future 5G Mobile Wireless Communications

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Abstract

In this paper, a single directive antenna for the future 5G mobile wireless communications is proposed. Several gain enhancement techniques including antenna arrays, metallic horn, dielectric horn, superstrate, homogenous hemisphere lens, and convex hyperbolic lens are presented. A realized gain of more than 10 dB with small side lobe level is achieved. The performance of different antennas incorporating different gain improvement techniques is presented.

1. Introduction

The demand for high quality ubiquitous wireless communication systems is more than ever before. This requirement is the driving force towards the rapid research and development in the fields of information and communication technologies worldwide that leads the research community towards the development of next generation of wireless communication.

The planned 5G cellular networks base stations and mobile devices will essentially make use of mm-wave frequency bands to meet consumers' ever growing demand for high data rate and capacity from wireless service providers. Millimeter-wave antenna design is considered as the first step for realizing mm-wave wireless communication systems. Not only improving the highly directional antenna gain but also reducing the size and employing a suitable impedance-matching bandwidth are considered critical design requirements.

The latest published literature shows that for the future 5G mobile communication, the frequency of operation is expected to be around the Ka-band in general, and more precisely at 28/38 GHz. Due to the propagation characteristics of these frequency bands, the cell structure needs to be compact in size that will result in large number of base stations [1], [2].

There is a need for designing antenna with higher gain to overcome the path loss due to the atmospheric absorption of electromagnetic waves at higher frequencies. Some work done by the authors on designing 5G high gain antennas / arrays / reflectarrays have been recently released [3]-[8].

In this article, gain enhancement techniques such as antenna arrays, metallic horn, dielectric horn, superstrate, homogenous hemisphere lens, and convex hyperbolic lens are placed over the patch to achieve a realized gain more than 10 dBi (up to 22 dB) with small side lobe level.

2. Proposed Directive 5G Antennas

2.1 Single Element Antenna configuration

Fig. 1 shows the geometry of the proposed directive antenna. The elliptical patch is printed on a low permittivity "εr2=2.2" grounded substrate with a 0.254-mm-thick where it is fed by a 50Ω microstrip line on the backside of a second thin dielectric layer with a higher permittivity "εr1=10.2" and 0.254-mm-thick through an elliptical aperture etched in the ground plane with a width nearly equals to half wave length of the center frequency "around 28 GHz". Based on several parametric studies and optimization, the optimized parameters are summarized in Table I.

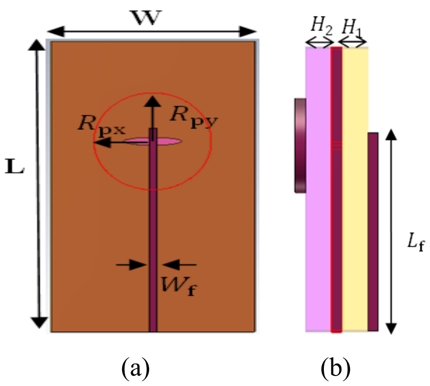


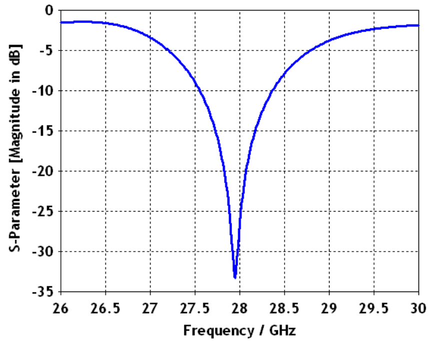
Figure 1. Geometrical configuration of the proposed 5G antenna, (a) top view, and (b) side view.

TABLE I.
The optimized parameters of proposed 5G antenna (All units are in mm)

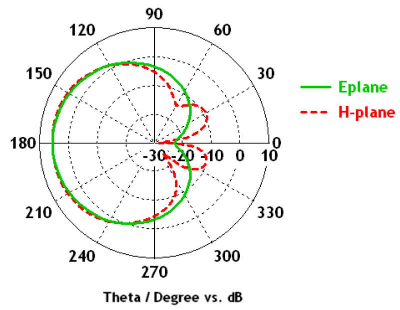
L	W	W_f	L_f	R_{px}	R_{py}	R_{sx}	R_{sy}	H_1	H_2
11	5	0.18	1.	1.44	1.8	0.7	0.1	0.25	0.25

2.2 Results and Discussions

The performance of the proposed antenna is analyzed and optimized using full-wave EM simulator CST MWS [9]. The simulated result of S-parameter for the proposed 5G antenna is shown in Fig. 2. It is obvious that the antenna properly matched at 28 GHz with S11 less than -10 dB and impedance bandwidth of 0.82 GHz. Fig. 2(b) shows the simulated radiation patterns of proposed 5G antenna at frequencies of 28. The figure demonstrates that the antenna is characterized by directional patterns with SLL < -15dB and 5.9dB maximum gain.



(a)

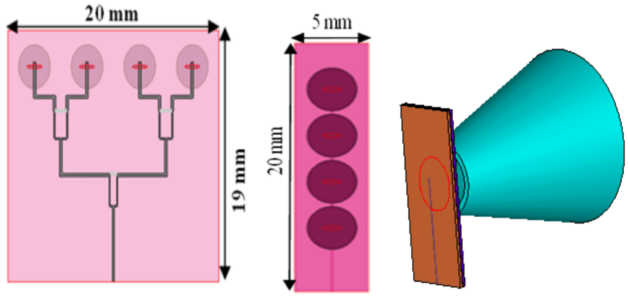


(b)

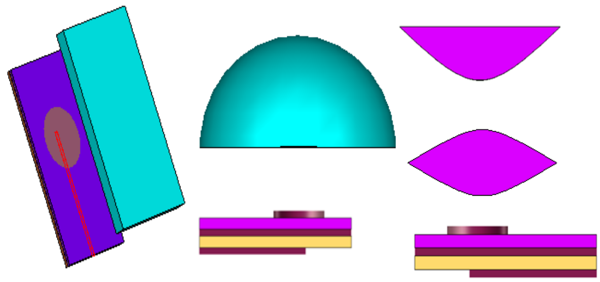
Figure 2. Simulated return loss |S11| versus frequency of proposed Directive 5G antenna, (b) Simulated radiation patterns of proposed 5G antenna 28 GHz.

3. Proposed Gain Enhancements Techniques For 5G Directive Antenna

Fig. 3 presents the geometrical configurations of the proposed gain improvement techniques that including antenna arrays, metallic horn, dielectric horn, superstrate, homogenous hemisphere lens, and convex hyperbolic lenses. Fig. 3(a) illustrates the geometrical configuration of the proposed four-element antenna array. The proposed array is built using a designed 1- to-4 Wilkinson power divider and four identical antenna elements. The spacing among antenna elements is set to be almost a half wavelength at 28 GHz to avoid the grating lobes. The geometrical configuration of the alternative best proposed series fed four-element antenna array is shown in Fig. 3(b). The spacing among radiation elements is optimized at 28 GHz to decreases the side lobe level. This type antenna array does not affect the bandwidth, on the contrary to the traditional antenna array discussed before. Furthermore, it has compact size compare to traditional one, because of the avoidance of feed network. Fig. 3(c) depicts the geometrical configuration of the proposed directive antenna with dielectric horn with $\varepsilon_r = 7.6$ and thickness of 0.4 mm placed over the center of radiating elliptical patch at distance 1.3 mm with height of 14 mm and top radius of 10.3 mm. The dielectric horn can be replaced with metallic horn with thickness of 0.254 mm placed over the center of radiating elliptical patch at distance .017 mm with height of 8 mm and top radius of 8.3 mm to facilitate the fabrication process. The proposed 5G antenna with a superstrate layer with $\varepsilon_r = 7.6$ operating at 28 GHz is introduced. For gain improvement, a superstrate dielectric layer of a thickness 1.9 mm at located at distance 7.3 mm from the top substrate as presented in Fig. 3(d), is applied above the 5G antenna. Fig. 3(e) shows a proposed 5G antenna with a homogenous hemispherical lens with $\varepsilon_r = 2.2$ operating at 28 GHz is presented. For gain improvement, a hemispherical lens with diameter 62 mm at located at distance 22.4 mm from the top substrate. The virtue for the utilization of a hyperbolic lens consists mainly in its simple shape and therefore easier development. Fig. 3(f) shows the side view of the proposed antenna with single and double curve convex hyperbolic lenses. For the subsequent study the designed lens with the diameter of 75 mm and the focal distance equaling 16 mm for single curve Convex hyperbolic lens and lens with the diameter of 76 mm and the focal distance equaling 11 mm for double curve Convex hyperbolic were selected.



(a) (b) (c)



(d) (e) (f)

Figure 3. The geometry of the proposed 5G antenna with gain improvement techniques, (a) Traditional four-element antenna array, (b) Series feed antenna array, (c) DRA horn, (d) Supersubstrate, (e) hemispherical lens, (f) Single and double curve convex hyperbolic lenses.

All of proposed configurations have been designed, optimized and simulated using CST program. The simulated results of the reflection coefficients |S11| for the proposed gain enhancement techniques for the proposed 5G directive antenna are illustrated in Fig. 4. It is apparent that the proposed antenna with these techniques has a good impedance matching at the desired frequency band of 28 GHz for $|S_{11}|$ less than -10 dB. Also, the comparison between the proposed techniques for the simulated radiation patterns is presented in Fig. 5. Table II shows the comparison of the realized gain and side lobe levels of the proposed 5G antenna with the suggested techniques to increase the gain.

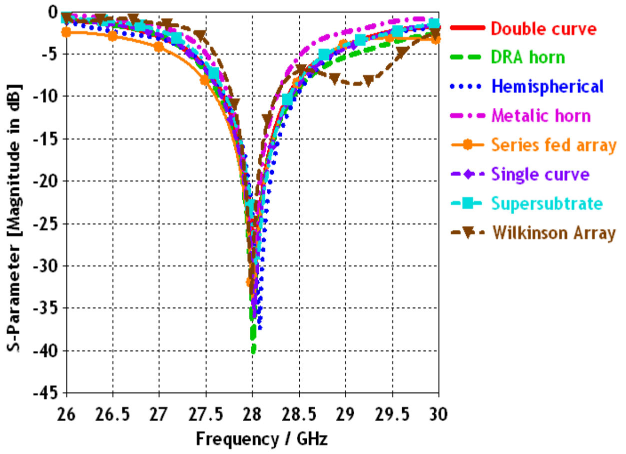


Figure 4. Reflection coefficient |S11| versus frequency of proposed 5G antenna with gain improvement techniques.

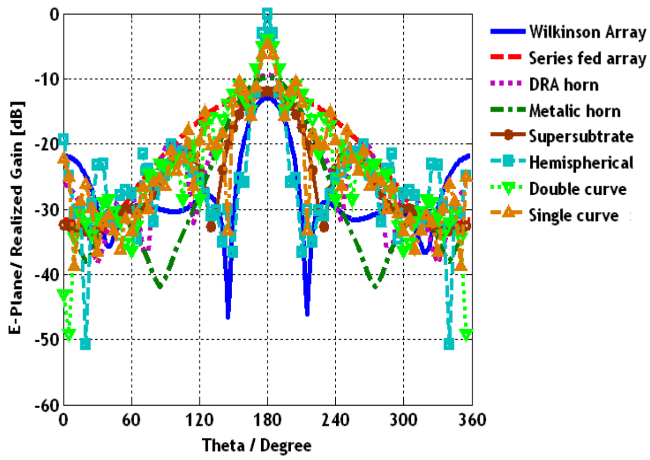
TABLE II.
The comparison of the realized gain and side lobe levels of the proposed 5G antenna.

Gain Enhancements Technique	Gain (dB)	Side lobe level (dB)	
		E-plane	***H-plane***
Proposed 5G antenna	5.9	-15	-
Wilkinson Array	10.58 (+4.68 dB)	-8.9	-6
Series fed array	10.67 (+4.68 dB)	-20	-14
Supersubtrate	10.58 (+4.68 dB)	-9.3	-10.3
DRA horn	12.77(+6.87 dB)	-10.2	- 10.9
Metallic horn	12.51(+6.61 dB)	-21.4	-11.4
Single curve convex hyperbolic lens	17.5 (+11.6 dB)	-6	-8
Double curve convex hyperbolic lens	19 (+13.1dB)	-14.5	-18
Hemispherical lens	22.17(+16.27 dB)	-19.4	–19.4

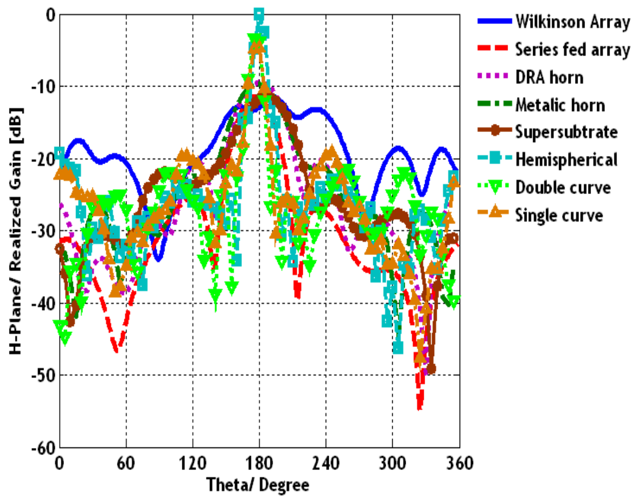
4. Conclusion

A single directive antenna for the future 5G mobile networks has been proposed. Several gain enhancement techniques including antenna arrays, metallic horn, dielectric horn, superstrate, homogenous hemisphere lens, and convex hyperbolic lenses have been presented. A realized gain of more than 10 dB with small side lobe level has been achieved. The proposed antenna element consist of elliptical patch printed on a low permittivity grounded substrate where it is fed by a 50Ω microstrip line on the backside of a second thin dielectric layer with a higher permittivity through an elliptical aperture etched in common the ground plane. The performance of different antennas incorporating different gain improvement techniques has been presented.

5. References



(a)



(b)

Figure 5. Simulated radiation patterns of proposed 5G antenna at 28 GHz with gain improvement techniques. (a) E-plane, (b) H-plane.

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