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60 GHz Multi-Sector Antenna Array with Switchable Radiation-Beams for Small Cell 5G Networks

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***Abstract*—**A compact design of multi-sector patch antenna array for 60 GHz applications is presented and discussed in details. The proposed design combines five 1×8 linear patch antenna arrays, referred to as sectors, in a multi-sector configuration. The coaxial-fed radiation elements of the multi-sector array are designed on 0.2 mm Rogers RT5880 dielectrics. The array operates in the frequency range of 58-62 GHz and provides switchable directional/omnidirectional radiation beams with high gain and high directivity characteristics. The designed multi-sector array exhibits good performances and could be used in the fifth generation (5G) cellular networks.

***Keywords*—**MM-wave communications, multi-sector array, patch antenna, small cell networks.

I. Introduction

THE multi-sector antenna array is a type of microwave antennas with sector-shaped radiation sections and could be used for specific operational needs such as mobile communications [1]-[5]. Its main advantage is that the antenna beams can be reconfigured to cover everywhere and can provide high gains for stationary and/or moving stations. Since MM-Wave communications have a harder time traveling through the obstacles, a sort of relay team for signal transmitting is needed [6]-[12]. By using this technique, as illustrated in Fig. 1, the smartphones can be switched to a new mini base station to keep the connections all the time.

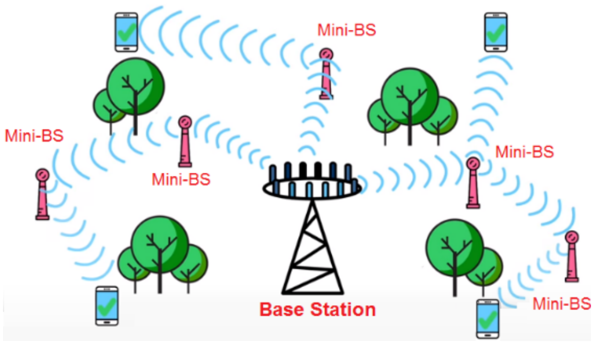


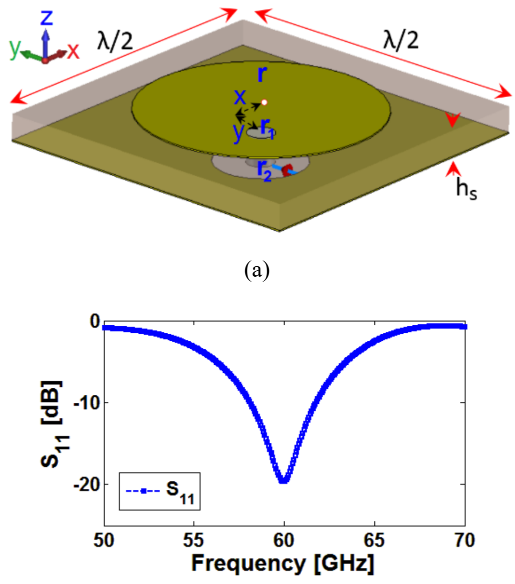
Fig. 1 Small cell network for 5G communications

Different kinds of antennas could be used as the radiation elements of the multi-sector antennas [13]-[18]. The printed patch antenna is very popular in arrays due to their attractive characteristics such as compact-size, high gain, and etc. [19]-[25].

The main objective of this study is to demonstrate a very compact design of multi-sector patch antenna array for future cellular applications. The multi-sector antenna array is designed to use in mm-Wave 5G wireless networks [26]-[30]. The design is composed of five 1×8 linear arrays arranged in a conformal form. The antenna provides 4 GHz bandwidth with high-gain and switchable directional/omnidirectional patterns. Fundamental properties of the multi-sector array have been studied and good results are achieved.

II. 60 GHz Patch Antenna

Fig. 2 (a) illustrates the schematic of the single element 60 GHz circular patch antenna.



(a)

(b)

Fig. 2 (a) 60 GHz patch antenna and (b) its reflection coefficient

It is designed on a Rogers RT5880 dielectric with an overall dimension of $\lambda/2\times\lambda/2\times hS$ = 2.5×2.5×0.2 mm^3. As illustrated, the antenna has been fed by bringing the inner conductor of a coaxial cable through the substrate and connecting it to the circular patch surface. The parameter values of the antennas are as follow: r = 0.92 mm, r1 = 0.1 mm, r2 = 0.35 mm, x = 0.35 mm. Fig. 2 (b) shows the reflection-coefficient (S11) of the coaxial-fed antenna versus frequency. It can be observed that the antenna has a good response around 60 GHz with 4

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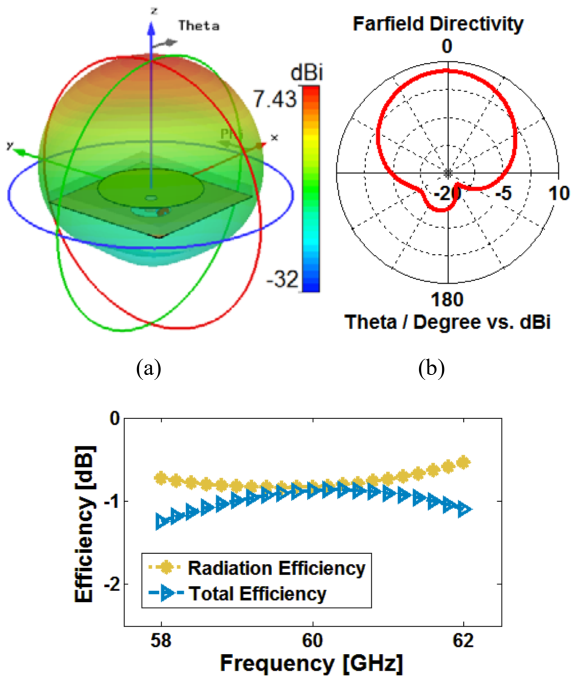
GHz bandwidth [31]-[35].



(a) (b)

(c)

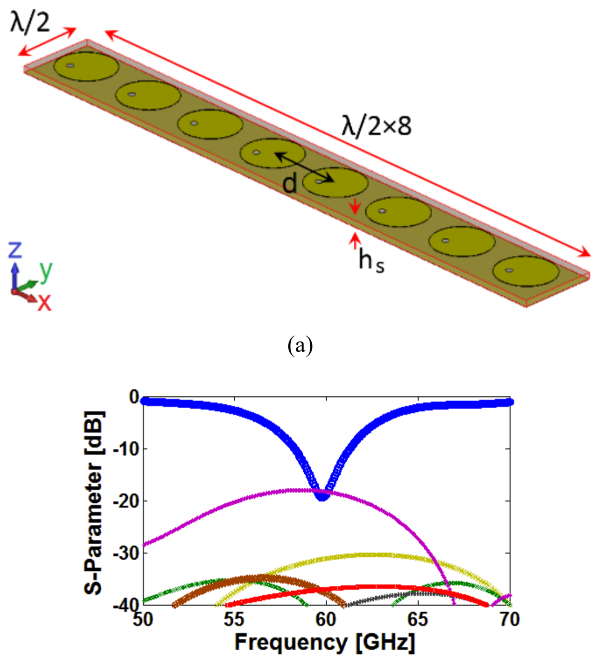
Fig. 3 (a) 3D (b) 2D radiation patterns at 60 GHz, and (c) the antenna efficiencies

The simulated 3-D and 2-D radiation patterns of the antenna are depicted in Fig. 3(a) and Fig. 3(b). The designed antenna has 7.43 dBi directivity with low back-lobes at 60 GHz. Simulated antenna efficiencies in the frequency range of 58 GHz to 62 GHz are shown in Fig. 3 (c). More than -1 dB (80%) and -1.25 (70%) radiation and total efficiencies are obtained for the designed single-element coaxial-fed antenna [36]-[38].

III. 1×8 Linear Antenna Array

Using eight elements of the 60 GHz patch antenna, a 1×8 linear array is designed as illustrated in Fig. 4 (a). The antenna elements have been arranged with a distance of d = λ/2 = 2.5 mm. The overall dimension of the array is 2.5×20 mm^2. Fig. 4 b) depicts the simulated S parameter results. As shown, the array has a good frequency response with a maximum -18 dB mutual coupling characteristics at 60 GHz.

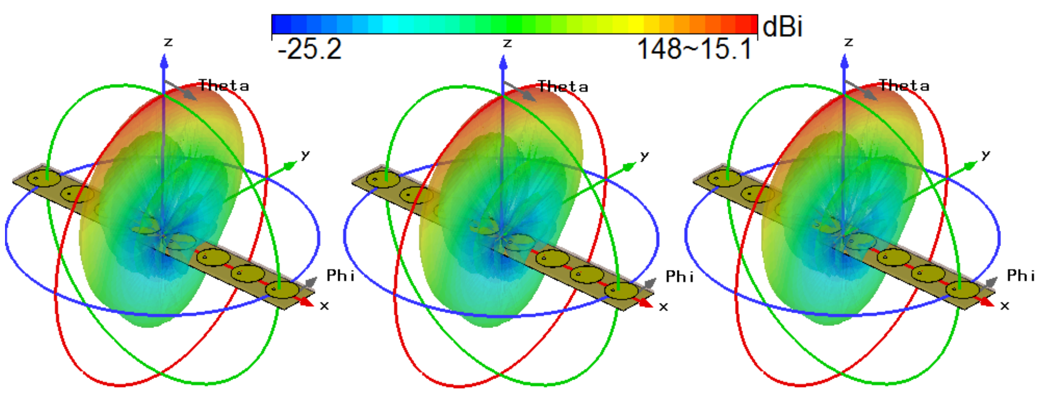
3-D view of the array antenna beams (0°) at different frequencies of the antenna operation range (59 GHz, 60 GHz, and 61 GHz, respectively) are shown in Fig. 5: the designed antenna array has good radiation beams versus its operation frequency. It provides high-directivity/directional beams with low back/side lobes [39]-[42].



(a)

(b)

Fig. 4 (a) Structure of the linear array and (b) the array S parameter results



(a) (b) (c)

Fig. 5 3D views of the array radiation beams at (a) 59 GHz, (b) 60 GHz, and (c) 61 GHz

IV. The Proposed Multi-Sector Antenna Array

The schematic of the multi-sector array is illustrtaed in Fig. 6. The design is composed of five 1×8 linear patch antenna arrays, referred to as sectors, in a multi-sector configuration.

The overall dimension of the antenna is 8λ/2×L= 20×4.5 mm^2. Simulated S_{11} characteristics of the employed linear arrays as sectors are represented in Fig. 7. As shown, the sectors have good frequency responses around 60 GHz. Fig. 8 illustrates the directivity characteristics of the single element and the linear array at 60 GHz: symmetrical radiation patterns with low side lobes are achieved.

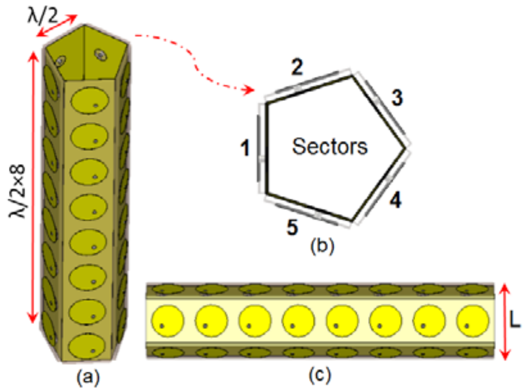


Fig. 6 (a) Side, (b) top, and (c) front views of the multi-sector design

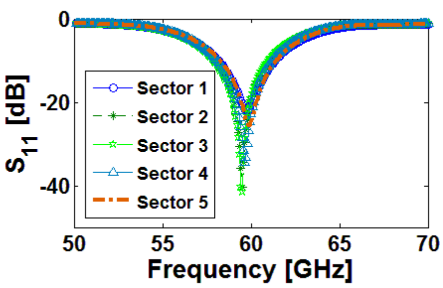


Fig. 7 S_{11} results of the antenna array sectors

The 2D-polar radiation beams of the proposed multi-sector patch antenna array fed singly at different frequencies (59 GHz, 60 GHz, and 61 GHz) have been illustrated in Fig. 9. As can be observed, each sector of the proposed array can cover a different area of the required radiation coverage [43]-[45]. Apart from the directional beams of the multi-sector array, as shown in Fig. 10, the proposed design can also provide omnidirectional radiation patterns with sufficient directivity values everywhere when it is fed singly (all the ports are excited simultaneously).

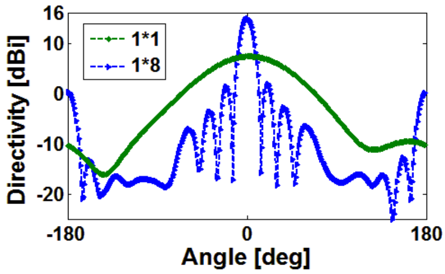
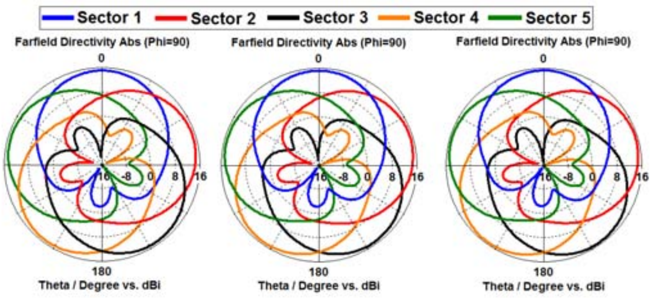


Fig. 8 Directivities of the single element and each secto

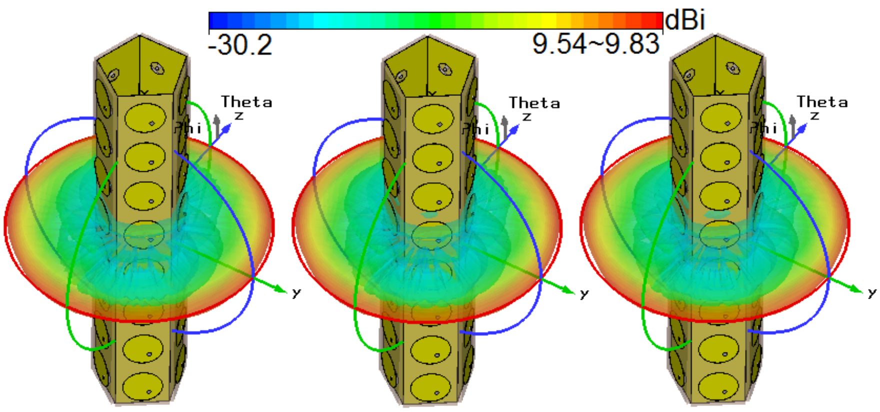


(a) (b) (c)

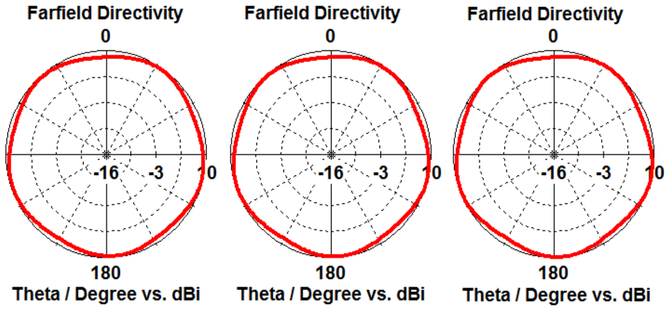
Fig. 9 2D views of the individual fed arrays at (a) 59 GHz, (b) 60 GHz, and (c) 61 GHz

V. Conclusion

This manuscript presented the design and characteristic analysis of a very compact multi-sector patch antenna array for 5G cellular applications. The design contains five linear patch antenna arrays, referred to as sectors, to form a multi-sector antenna array. The radiation elements of the arrays are designed to operate at 60 GHz with 4 GHz impedance bandwidth. Fundamental properties of the design are discussed and sufficient results are achieved. The multi-sector array design has a compact size and is suitable to be used in 5G cellular networks.



(a)



(b)

Fig. 10 (a) 3-D and (b) 2-D radiation beams of the single-fed array at 59, 60, and 61 GHz, respectively

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