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Cavity Backed Patch-Slot Antenna for Lower Band 5G Communications

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Abstract

A cavity-backed patch antenna covering two 5G frequency bands under 6 GHz range is proposed. Good performance is obtained by optimizing the geometry of a rectangular slot and the embedded rectangular patch as well as the supporting cavity. The impedance matching between the antenna and the co-planar waveguide excitation feeding line is optimized to cover two 5G bands from 3.38 GHz to 4.35 GHz. The antenna gain is 5.68 dBi at the center frequency 3.95 GHz. A 1×5 linear array of this antenna element yields 12.03 dBi gain at the broadside with uniform excitation and up to 30˚ beam scanning angle with phased excitation. With the additional metal ground plane, the gain of a 1×15 linear array reaches 19.28 dBi. The geometrical properties of this simple antenna structure and its good radiating performance make it a great potential for 5G base station antenna arrays.

1 Introduction

With the growing demands for higher rate of information exchanging, the fourth generation (4G) communication system could no longer meet the needs from personal daily social network to international commodity trading. Thus the fifth generation (5G) network is now under heavy investigations and development which is expected to be 100 times faster than 4G [1]. As a result of the narrow frequency spectrum occupied by 4G, new frequency bands are necessary for 5G. Facing this situation, the Federal Communications Commission (FCC) announced several commercial frequency bands for the United States in 2018 which can be categorized as two parts: one part is the sub-6 bands like 2.496 to 2.69 GHz, 3.55 to 3.7 GHz and 3.7 to 4.2 GHz; another part involves the higher bands like 24 GHz, 28 GHz, 37 GHz and so on [2]. In those bands, the sub-6 bands are getting close attentions in the preliminary stage of 5G considering the significant lower costs and stronger penetration compared to the higher frequencies. Under this background, and as antennas for the indispensable Radio frequency (RF) components for such wireless communication systems, new efficient designs are required, especially for the facing the licensed frequency band 3.7 GHz to 4.2 GHz.

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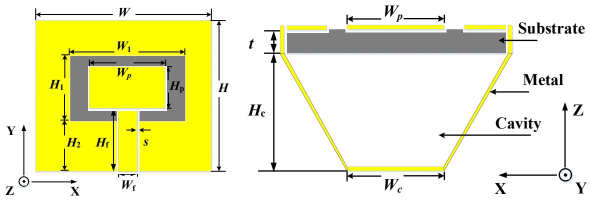
Cavity-backed antenna has always been a research hotspot in the electromagnetic field due to its wider bandwidth compared to the traditional patch antenna [3-5]; flexible control of polarization, like cross-polarization suppressed linear polarization (LP) [6], Dual polarization [7] and circular polarization [8]. Furthermore, Cavity-backed antenna has the natural superiority in the aspect of array antenna design for the purpose of high gain [5, 9] and beam scanning [7]. However, cavity-backed antenna also suffers from the problems like multi-layer structure [3, 4, 9] and complex feeding network design [5, 7, 8]. Hence the simplification of the cavity-backed antenna design has become a direction worth exploring.

In this paper, a slot-patch antenna with a truncated pyramidal backed metal cavity is optimized to present good radiation in two 5G bands: 3.55-3.7 GHz (unlicensed) and 3.7-4.2 GHz (licensed). Modified co-planar waveguide (CPW) excitation and metal cavity under the single-layer substrate make this antenna easy to manufacture. Furthermore, two linear arrays are also discussed to show the simplicity of beam scanning with uniformed spacing and high-gain property.

2 Antenna Design and Structure

The layout configurations and detailed dimensions for the single antenna and the linear array will be demonstrated thoroughly in this section. The top views of the antenna in Fig. 1 (a) shows the proposed slot-patch antenna with the configuration of metal cavity and it should be emphasized that the inclined side walls connecting the four bottom sides of substrate and the bottom square metal to form the metal cavity like a truncated pyramid. The material FR4 with thickness of 1.6 mm, relative permittivity of 4.4 and loss tangent of 0.02 is chosen as the substrate for lower cost consideration. The square footprint size of 35 (W) × 35 (H) mm^2 makes the single unit easy to form the uniform spacing arrangements in different directions for the array design. The cross section in Fig. 1 (b) presents the corresponding position of patch antenna and the cavity. The related dimensions of the cavity-backed antenna in millimeters are: W = 35, H = 35, W_1 = 33.83, H_1 = 14.92, H_2 = 6.8, Wp = 13.69, H_p = 6.52, W_f = 3.6, H_f = 8.07, s = 0.4, Hc = 13.81, Wc = 13.17.



(a) (b)

Figure 1. (a) Top view of the proposed antenna, (b) Cross section in xz plane. (not to scale)

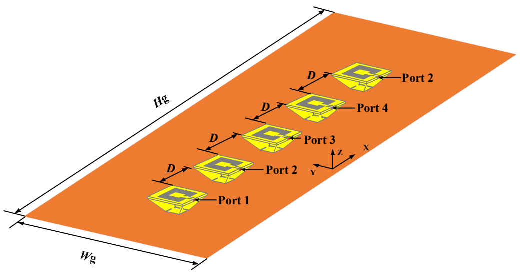
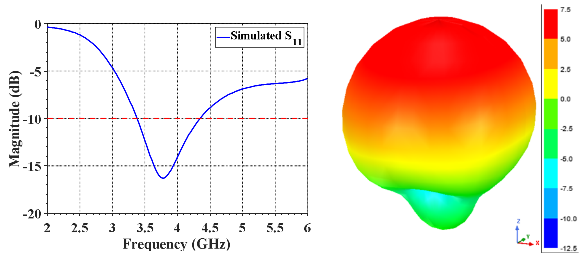


Figure 2. The 1×5 linear array with additional metal ground along x axis. (Added ground)

Fig. 2 shows the 3D view of a 1×5 linear array along the x axis using the element configuration mentioned above with 5 (D) mm uniform spacing between the neighboring elements. Similar configuration of 1×15 linear array is also investigated.

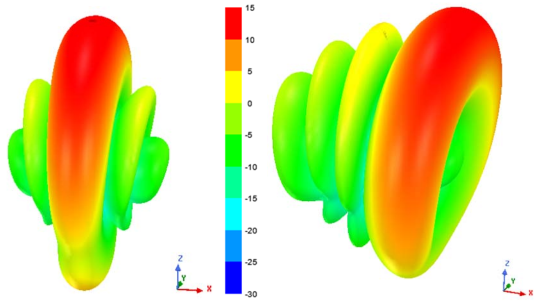
3 Simulated Results

All presented results are generated by the commercial software Ansys High Frequency Structure Simulator (HFSS) and for getting closer to the real testing situation, the losses of conductor and dielectric are both taken into consideration. The -10 dB bandwidth of reflection coefficient (S_{11}) shown in Fig. 3 (a) covers from 3.38 GHz to 4.35 GHz which totally includes two sub-6 bands for 5G: 3.55-3.7 GHz and 3.7-4.5 GHz. The following results will focus on the design performance for the licensed band which has the center frequency of 3.95 GHz. Fig. 3 (b) illustrates the 3D far-field gain pattern for the single cavity backed antenna at 3.95 GHz. It is easy to find that at the broadside ($\theta = 0^{\circ}$) the gain achieves its maximum value of 5.68 dBi with front to back (FB) ratio about 9.95 dBi. This is mainly due to the presence of the cavity which focuses the radiation in the broadside direction compared to traditional grounded patch antenna, and hence this single antenna element is suitable for phased array designs. Without taking additional ground into consideration, Fig. 4 (a) descripts the simulated far-field gain of 1×5 linear array at 3.95 GHz with uniform excitation and a broadside ($\theta = 0^{\circ}$) gain of 12.03 dBi with back beam gain of 3.03 dBi, yielding a FB ration of 9 dBi. A maximum scanning beam for the 1×5 linear array is achieved without beam degradation at 30˚ as shown in Fig. 4 (b).



(a) (b)

Figure 3. (a) Reflection coefficients of single cavity-backed antenna, (b) 3D far-field gain pattern at 3.95 GHz.



(a) (b)

Figure 4. Simulated 3D far-field gian pattern for 1×5 linear array at 3.95 GHz; (a) Based on uniform exciation, (b) Based on the phase distributions for 30˚ beam scanning.

4 Addition of Metal Ground Plane

For the purpose of getting higher gain, more elements are necessary for the array design. However, with these elements increasing in the linear array, more radiations will gather at the back direction of the main beam and that will bring gain reduction and wasting of input power.

The blue dash curve in Fig. 5 shows the far-field radiation pattern in xz plane at 3.95 GHz for 1×15 linear array while all other settings are the same as those of the 1×5 linear array shown in Fig 2. The resulting array gain is enhanced to 16.69 dBi but the backside radiation ($\theta = 180^{\circ}$) also increases to a much higher level as 8.87 dBi. To solve this problem, an additional ground plane touching the bottom of the cavities with optimized dimensions (Wg = 300 mm; Hg = 700 mm) is placed as shown in Fig 2. The corresponding radiation pattern, shown in red color, results a gain of 19.28 dBi at the main beam direction ($\theta = 0^{\circ}$) and an obvious decrease in the backside ($\theta = 180^{\circ}$) to -2.51 dBi which yields a good FB ratio of 21.79 dBi.

Mutual coupling between elements in array designs affects the main beamwidth and the scanning range. Maintaining the coupling in an acceptable low level, yields better array performance. The S-parameters of the middle element of the 1×15 linear array is shown in Fig. 6 illustrating the good performance of this design. The figure shows that the S_{88} has the -10 dB bandwidth from 3.46 GHz to 4.51 GHz, which still covers the desired two 5G bands. As for the closest port to, i.e. 'Port 7' the isolations in terms of S_{78} is at the -18 dB level in the desired bands. All other mutual coupling levels to 'Port 8' are below -20 dB which shows a good performance of isolations in this 1×15 linear array with the ground plane.

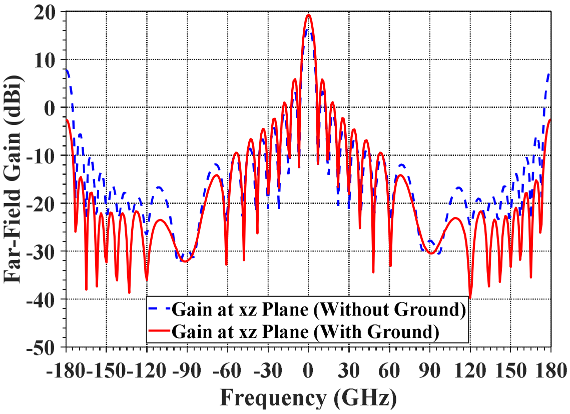


Figure 5. Comparison of far-field radiation pattern with and without metal ground for 1×15 linear array based on uniform excitation in xz cut plane at 3.95 GHz.

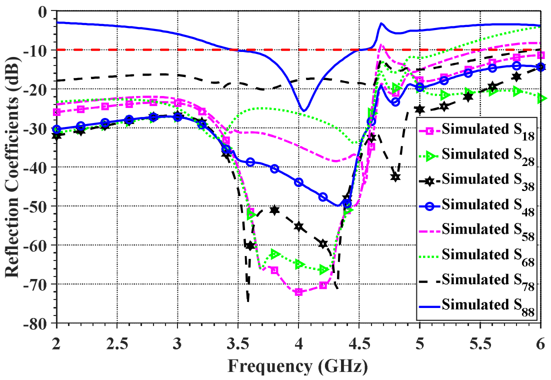


Figure 6. (a) Reflection coefficients at the middle port 8 of the 1×15 linear array.

According to the reasonable performance of this 1×15 linear array, further work will focus on the planar array design with suitable excitation settings, so that the pencil shaped beam with higher gain and wider scanning angle will be discussed.

4 Conclusion

In this paper, a cavity-backed patch antenna with reasonable radiating performance is presented. As for the contribution of cavity structure and CPW excitation, simulated results show a -10 dB S_{11} from 3.38 to 4.35 GHz, which covers two bands: 3.55 to 3.7 GHz and 3.7 GHz to 4.2 GHz for 5G communication. In addition, the cavity back also enhances the antenna's ability to form the array. After optimization, at the center frequency 3.95 GHz for the licensed 5G band, the maximum beam scanning angle can reach to 30° for the 1×5 array and by adding additional ground the 1×15 array achieves 21.7 dBi FB ratio without obvious deteriorations of gain and mutual coupling among the elements.

5 Acknowledgements

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6 References

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