International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-7 Issue-6, August 2018

Design of 4×4 Microstrip Quasi-Yagi Beam-Steering Antenna Array Operation at 3.5GHz for Future 5G Vehicle Applications

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***Abstract:** In this paper, a novel design of 4×4 microstrip Quasi-Yagi beam-steering antenna array operation at 3.5GHz for future 5G vehicle applications is proposed. This array consists of sixteen element antennas with dimension of 374×374×1.15mm3, which exhibits good bandwidth (impedance bandwidth of single antenna element about 440MHz for S11 less than -10dB at the center frequency of 3.5GHz) and high gain (for single antenna about 7dBi and for antenna array about 5.8~8.76dBi). The beam-steering characteristics in the operation band can nearly achieve omni-directional radiation.*

***Keywords:** 5G; Quasi-Yagi Antenna Array; Beam-Steering; Omni-Directional Radiation*

I. INTRODUCTION

As the development of electronic technology and road data traffic, more and more electronic equipments are used in automobiles. Automobile-mounted monitoring system [1] and Bluetooth or WiFi is widely used nowadays [2]. The next generation of wireless communication technology-the fifth generation, or 5G, is a critical milestone for 21st century's opportunities related to economic growth, education, employment, transportation and beyond. These new networks and technologies will enable new high speed and low latency for various wireless broadband applications like the internet of things and other innovations not even created [3]. Among all the discussed frequency bands for 5G applications, 3.4~3.8GHz is the band that probably will be first deployed for the wireless communication at the vehicle environment. How to design the antenna array with small size, high gain and broad beam width coverage for this application becomes one of the key technologies to achieve fast and sustainable data and voice communication quality.

We know that the path loss from transmitter to receiver is proportional to the antenna operation frequency [4]. In order to overcome the attenuation influences, employing an antenna array could be a solution to enhance antenna gain as well as the physical aperture. The good beam-steering characteristics of the phased array increase the received signal strength and provide large spatial coverage [4][9].

The Yagi antenna is one of the most common directional antennas with simple structure, high directivity and high gain, so it is widely used in many kinds of wireless communication system. But the traditional Yagi antenna's shortcomings are obvious: the antenna's size is too big, and cannot be con-formal with other carriers because of the metal rod-shaped structure, which limits its application in some application situations. However, with the many advantages of the microstrip antennas, such as small size, light weight and ease of combining with other devices, the microstrip Quasi-Yagi antenna is the combination of the microstrip antenna and Yagi antenna, which also possesses the characteristics of high gain and directivity as the traditional Yagi antenna, meanwhile, it has the advantages of wide bandwidth, low cost and ease of fabrication [5]. In this paper, our proposed design is based on the microstrip Quasi-Yagi antenna and designed to be suited for 5G applications [6][7]. This array consists of sixteen element antennas positioned at the edge of the square - shape structure where each side has 4 Quasi-Yagi elements to obtain high gain and omni-directional radiations. The simulation results show that microstrip Quasi-Yagi antenna array has acceptable performance and good beam-steering functionality.

II. SINGLE ELEMENT MICROSTRIP QUASI-YAGI ANTENNA

The Geometry and detailed dimensions of the proposed antenna element is shown in Fig.1. Unlike traditional Yagi-Uda antenna [8], the proposed Quasi-Yagi antenna is printed on the FR4 substrate with dielectric constant of 4.4, conductor loss (tan /) of 0.02 and thickness of 1.15 mm. The antenna is matched with 50 Ÿinput impedance. It consists of three main components, a dipole driver, the parasitic directors and the reflector element. The ground plane acts as a reflector to achieve a directive radiation pattern. To further improve the directivity, four parasitic directors are designed and optimized at the operating frequency of 3.5GHz. This antenna has advantages of small size and simple structure for fabrication. In this design, the antenna has been simulated using the full-wave electromagnetic field simulator Ansoft HFSS version 13. As shown in Fig.2, it presents the simulated return loss of the proposed single microstrip Quasi-Yagi antenna. The operating bandwidth (about 440MHz for S11 less than - 10dB at the center frequency of 3.5GHz) of the antenna can be suitable for array design. As shown in Fig.3, the far-field radiation pattern of E and H plane of the single antenna element is computed at 3.5GHz. It can be seen that the antenna's peak gain up to about 7dBi with wide main beamwidth (Half Power Beamwidth is about 78º).

Manuscript published on 30 August 2018.
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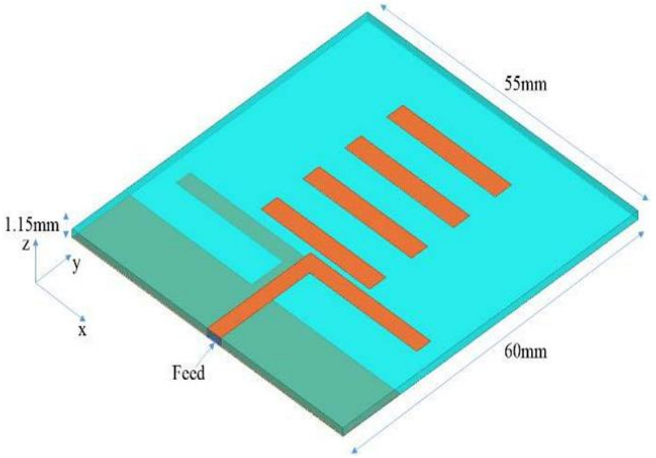
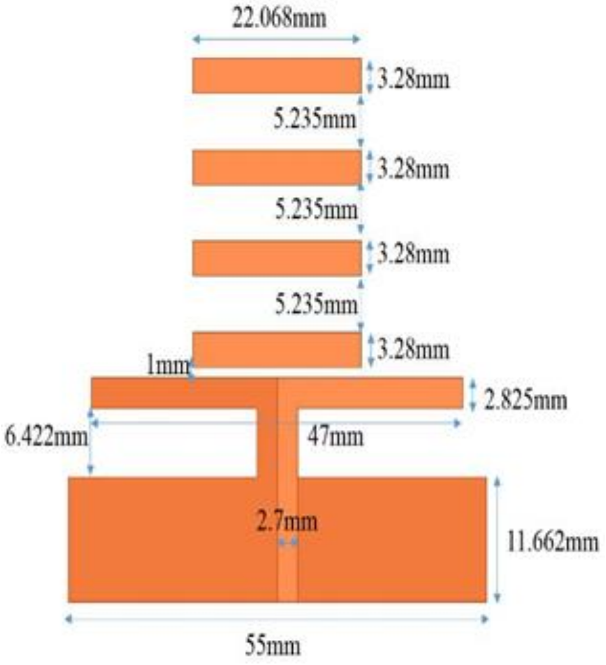


(a) 3D View



(b) Top View

Fig. 1. Geometry of Microstrip Quasi-Yagi Antenna. (a) 3D View (b) Top View.

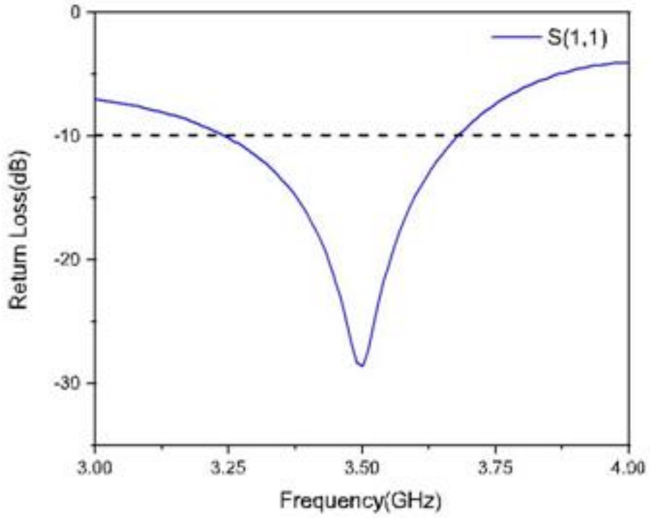


Fig. 2. Simulated Return Loss of the Proposed Antenna Element.

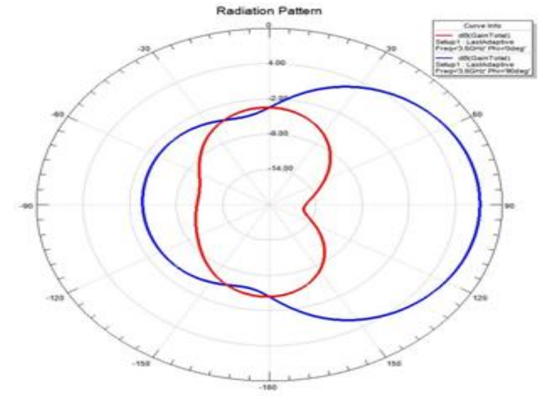
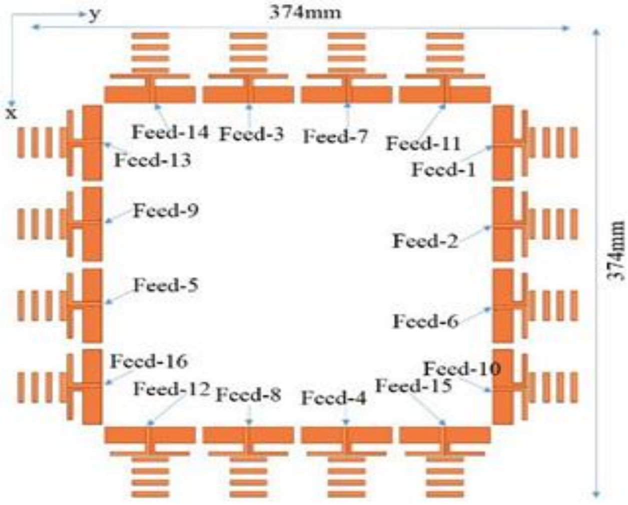


Fig. 3. Computed Radiation Pattern of E and H Plane of The Single Antenna Element at The Operating Frequency of 3.5GHz.

III. PROPOSED 4×4 MICROSTRIP QUASI-YAGI ANTENNA ARRAY

The schematic of the 4×4 array with sixteen elements of the microstrip Quasi-Yagi antenna is shown in Fig.4 and the feed network and phase shifters for simulation of the proposed phased array antenna is illustrated in Fig.5. In this design, four 1×4 uniform linear array (subarray) antennas have been used, where each radiating element of them is excited by signals with equal magnitude. Actually it is important for us to design a feed network such as Wilkinson power divider, but it is quite expensive for us to employ traditional phase shifters for measurement. So, the Butler Matrix could be the further research work to achieve the functional array antennas.

The simulated S-parameters of the proposed phased array antenna structure is illustrated in Fig.6. And Fig.7 shows the radiation pattern of the proposed antenna array. As shown in Fig.6, all the 16 antenna elements perform very consistently with almost identical S11 with sufficient bandwidth to cover 3.5 GHz. Also, the isolation between the each linearly arranged antenna element's feeding point is more than 27dB which can meet the antenna array's requirements.



(a) Array Structure and Feed Position.

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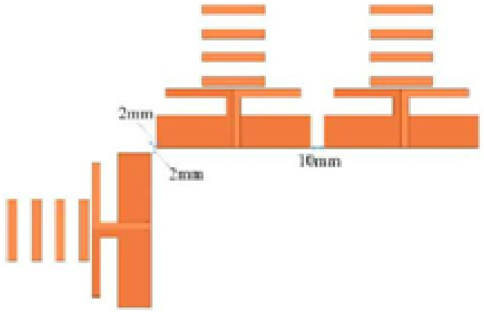


(b) Element Spacing of The Array.

Fig. 4. Geometry of The Proposed Antenna Array. (a) Array Structure and Feed Position (b) Element Spacing of The Array.

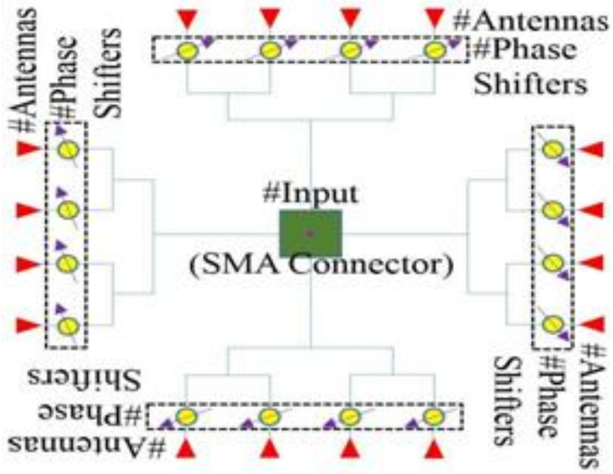


Fig.5. Phased Array Architecture for the Proposed Phased Array Antenna (Feed Network and Phase Shifters).

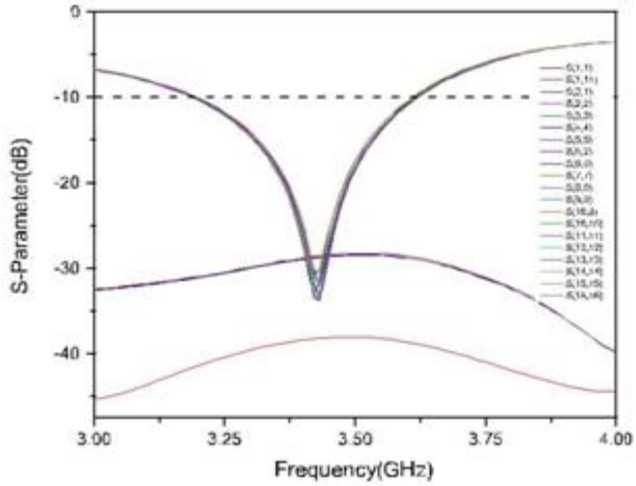
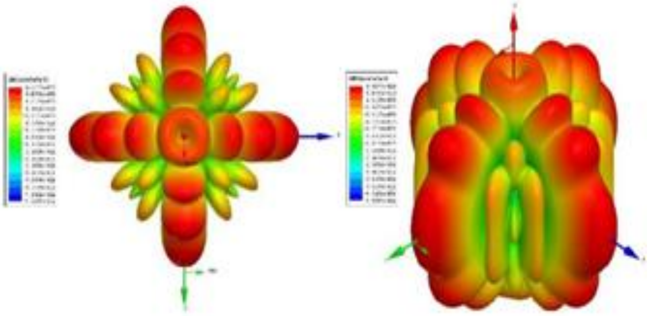
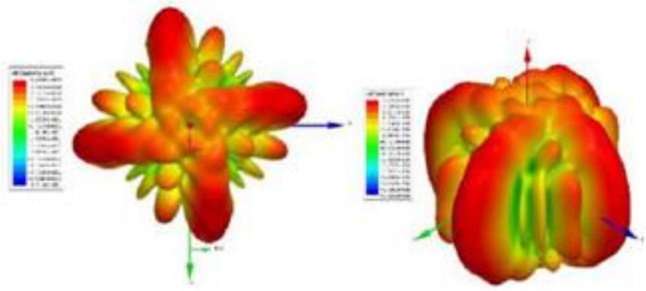


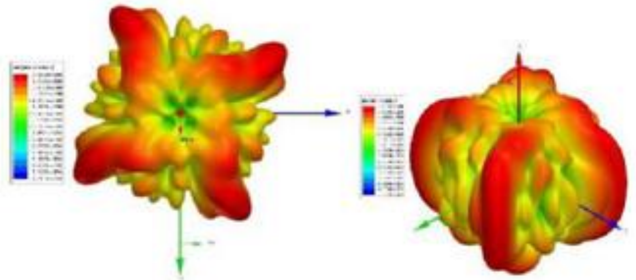
Fig. 6. Simulated S-Parameters of The Microstrip Quasi-Yagi Antenna Array.



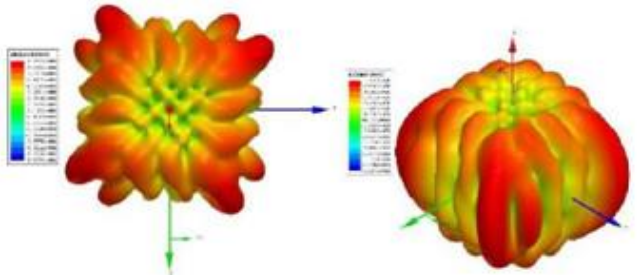
(a) 0° (Top View and Oblique View)



(b) 60° (Top View and Oblique View)



(c) 120° (Top View and Oblique View)



(d) 160° (Top View and Oblique View)

Fig. 7. Beam-Steering Radiation Pattern in 3D view of the Array at Different Offset Phase. (a) 0°- Offset Phase, (b) 60°- Offset Phase, (c) 120°- Offset Phase, (d) 160°- Offset Phase.

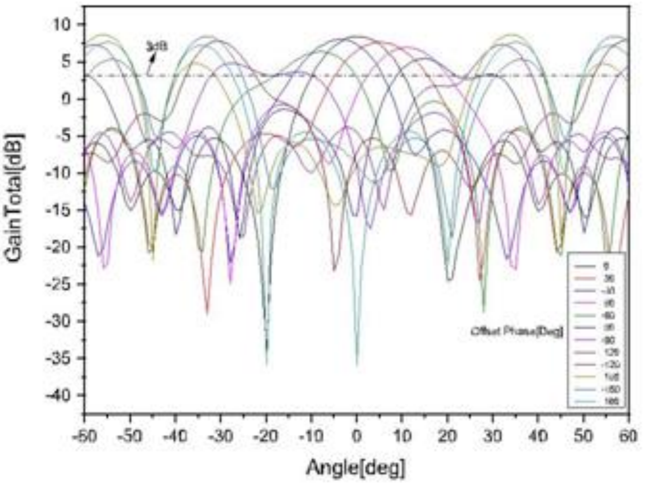


Fig. 8. Scanning Angle of a Linear Subarray with 3dB Main Lobe Width.

As shown in Fig.7, it presents four of a series of radiation pattern of the array at different offset phase. It can be seen that the array has sufficient gain (about 8.54 dBi, 6.88dBi, 7.67dBi, 8.76dBi, respectively) at different scanning angle. As the offset phase increases,

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The radiation pattern of the subarray will have a main lobe and a sidelobe with analogous gain which narrows the half power beamwidth of the main lobe. This sidelobe can be superimposed with the sidelobes of the adjacent subarray which forms two main lobes as shown in Fig.7(d).

As shown in Fig.8, it presents the scanning angle of a linear subarray with 3dB main lobe width corresponding to the results of Fig.7. The every 1×4 subarray beam can be gradually steered up to about 45º with the variation of offset phase. In the same way, the every 1×4 subarray beam can be gradually steered up to about - 45º with the variation of offset phase. Theoretically, as long as the subarray can achieve scanning range of -45º to 45º, which means that the whole antenna array can obtain omni-directional radiation. However, strictly speaking, the radiation pattern is low gain when scanning angle is 45 degrees. But the total scanning angle can achieve more than 85 degrees and the purpose of this paper is also to present a architecture of high-gain beam-steering antenna array with nearly omni-directional radiation. The detailed control mechanism of offset phase of above-mentioned four radiation patterns is shown in the Table I.

Table I. Different Offset Phase (Degree)

Feed State	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
(a)	0	0	0	0	0	0	0	0
(b)	0	60	60	60	60	120	120	120
(c)	0	120	120	120	120	240	240	240
(d)	0	160	160	160	160	320	320	320
Feed State	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
(a)	0	0	0	0	0	0	0	0
(b)	120	180	180	180	180	0	0	0
(c)	240	360	360	360	360	0	0	0
(d)	320	480	480	480	480	0	0	0

IV. CONCLUSIONS

In this paper, we introduced a novel wireless communication phased array antenna, which is composed of sixteen microstrip Quasi-Yagi antenna elements and forms a 4×4 square structure with center frequency operating in the 5G low-band at 3.5 GHz. The simulation results show that the antenna array has high gain (peak value about 8.76dBi), wide bandwidth (about 440MHz at the center frequency of 3.5GHz) and can approximately achieve omni-directional radiation. Detailed performance of this antenna array mounted on the vehicle will be reported during the conference.

ACKNOWLEDGMENT

The authors want to thank the research funding support from “Shanghai 1000 plan” and graphic editing from the teammate Mr. Yibo Wang.

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