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MIMO Planar Quasi Yagi Antenna for 5G Mobile Applications

H. M.R. Nurul[#1], Z Mansor[#2], M. K. A. Rahim[*3]
[#1]*Communication Technology Section,*
[#2]*Research and Innovation Section,*
Universiti Kuala Lumpur British Malaysian Institute,
Batu 8, Jalan Sungai Pusu,
53100 Gombak, Selangor.
[1]nurulhusnamr@unikl.edu.my, [2]zuhanis@unikl.edu.my,
[*3]*Advanced RF & Microwave Research School of Electrical Engineering,*
Faculty of Electrical Engineering,
Universiti Teknologi Malaysia, UTM JB 81310 Skudai, Johor.
[3]mdkamal@utm.my

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Abstract:

This paper presents planar quasi Yagi antenna for 5G mobile applications with 28 GHz operating frequency. The proposed quasi Yagi antenna fed by microstrip feed and consist of dipole driver, threedirectors and truncated ground plane as reflector. The single planar quasi Yagi antenna achieved 8.15 dB realized gain. The MIMO configuration of the proposed antenna is also investigated. It consistsof two sets of array located orthogonal side of each other. Realized gain of the two element of planar quasi MIMO antenna achieved up to 11.63 dB. The simple design of the MIMO planar quasi Yagi antenna offers ease to be implemented for 5G mobile phone antenna.
***Keywords:** 5G technology, millimeter wave, quasi Yagi,MIMO antenna*

I. INTRODUCTION

The rapid growth in mobile communication has encouraged the International Telecommunication Union (ITU) to utilize Fifth Generation (5G) of the mobile wireless network for future. The existing network technology, 4G-LTE already packed and cannot fulfill network capacity demand for user nowadays.One of allocated frequency use for 5G technology proposed by the Federal Communications Commission (FCC) is 27.5 - 28.35 GHz[1].Larger bandwidth allocations with the utilization of millimeter-wave carrier frequency enable the increases of data transfer rate.

Investigation in [2]stated that the antenna for 5G requiresthe utilization of multiple input multiple output (MIMO) antenna and directional beam pattern antenna.A directional antenna is an antenna which radiates greater power in one or more direction, focusing transmit and receive at desired directions and reduced interference from unwanted sources [3]. One of the bestcandidates for directional antennas is Yagi-Uda antenna. Yagi-Uda antenna has gone through an evolution since it first invented in 1928 when Yagi published for the first time in English languages and named the antenna with his name[4].

The first printed Yagi-Uda antenna introduced in [5] comprises a reflector, a driver and several directors. The truncated ground plane of the antennas acts as a reflector for the transverse electric surface wave [6]. The evolution of conventional Yagi-Uda antenna called as quasi Yagi as the design concept is almost the same with conventional Yagi-Uda. Quasi Yagi basically designed in planar design and apply the different feeding technique to enhance the antenna performance[7]–[9].

Quasi Yagi-Uda designed concept was used for the proposed antenna since it can exhibit a directional radiation pattern [10]. The proposed antenna has been designed and optimized using Computer Simulation Technology (CST)

May – June 2020
ISSN: 0193-4120 Page No. 1935 - 1940

electromagnetic software. The single element of the proposed antenna produces 8.15 dB gain. Increment of 3 dB gain resulted with linear array arrangement of the two antenna elements. Analysis of the designed antenna done with the simulation of the antenna with a large ground plane indicates the size of the mobile phone. The objectives of this workis to propose a planar quasi Yagi antenna for 28 GHz frequency and produce two element MIMO antenna array design. This work also investigates the MIMO antenna array configurations with the size of mobile phone printed circuit board (PCB).

This paper organized as follows. Section I introduce about millimeter wave network technology and reliability of Yagi-Uda asthe antenna for 5G. Section II presents the design methodology of the single element and the MIMO antenna design. Section III discusses the result for the single element, two antenna element and the MIMO configuration of planar quasi Yagi with the size of mobile phone printed circuit board (PCB).

II. DESIGN METHODOLOGY

A. *Planar Quasi Yagi Antenna*

The proposed planar quasi Yagi antenna has been designed on Rogers 5880 substrate having 2.2 permittivity and 0.0009 conductor loss with 0.254 mm thickness. The planar quasi Yagi antenna consists of a dipole driver and three director elements. The antenna fed by microstrip feed line with 4.8 mmlength (L_f) and 0.72 mm width (W_f) match with 50Ω input impedance. Partial ground plane with 3 mm height withparasitic element act as a reflector to reflect the electromagnetic waves to produce directional beam pattern[11]. The geometry of the proposed antenna is shown in Fig. 1 and dimension of the antenna is detailed in Table 1. Dimension of the single planar quasi Yagi is 20 mm × 15 mm for the length (L) and width (W)respectively. L_g and W_g are length and width of the ground plane.

TABLE 1. ANTENNA DIMENSIONS IN MM

L	**W**	**L_f**	**W_f**	**L_g**	**W_g**	**L_1**	**L_2**
20	15	4	0.72	3	20	4.8	3.6

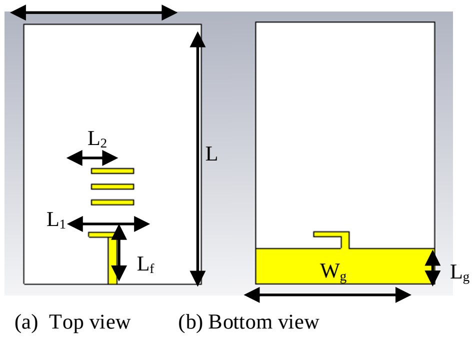


Fig. 1. Geometry of proposed antenna (a) Top view (b) Bottom view

For the proposed quasi Yagi calculation done for the length of the driver (L_1) and director (L_2) for the antenna. The equation for the length of the driver is $0.5\lambda_g$ and the length of the director is $0.45\lambda_g$[12], where the effective wavelength (λ_g) of the antenna can be calculated by using equation as follows:

$$\lambda_g = \frac{c}{f_r\sqrt{\varepsilon_{r+1}}} \quad (1)$$

Where c is the velocity of light and ε_r is the permittivity of the substrate and $f_r$is the resonant frequency of the antenna. The calculated length is optimized thought the simulation. The optimized length of L_1 and L_2 is 4.8 mm and 3.6 mm respectively.

III. RESULTS AND DISCUSSION

This section presents the simulated results of the single element, two elements and MIMO configuration of the proposed planar quasi Yagi antenna. Results presented are reflection coefficient, 3D radiation pattern, gain, directivity and envelope correlation coefficient (ECC).

A. *Single Element Planar Quasi Yagi Uda*

The simulated refection coefficient (S_{11}) is as shown in Fig. 2. As shown in the result the proposed antenna provides wide frequency bandwidth of 4.37 GHz covering the 24.76 – 29.13 GHz frequency. The single element of the antenna performs well with 8.15 dB realized gain. 3D radiation pattern in Fig. 3 shows that the proposed antenna has directional radiation pattern along the xy plane. Polar plot for the radiation pattern can be seen in Fig.4. The 3 dB beam width along the E-plane is 46.9^0 while for the H-plane is 59.2^0. The

May – June 2020
ISSN: 0193-4120 Page No. 1935 - 1940

beam width of antenna shows how directive antenna to the main direction.

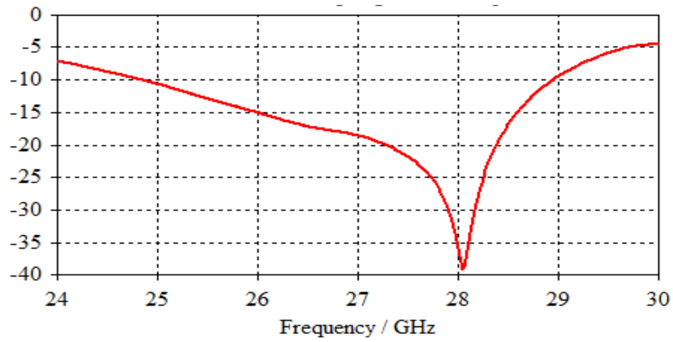


Fig. 2. Simulated reflection coefficient (S_{11}) of the single element planarquasi Yagi antenna.

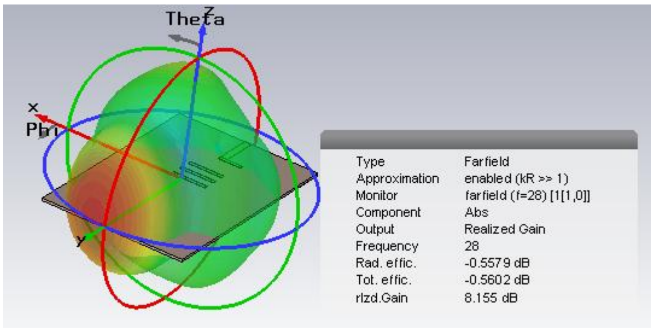
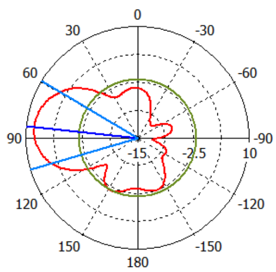
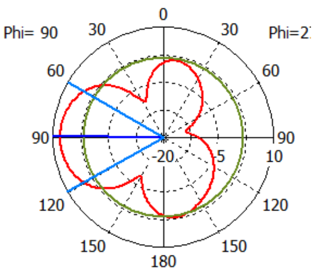


Fig. 3. 3D Radiation Pattern of the proposed antenna.



(a)



(b)

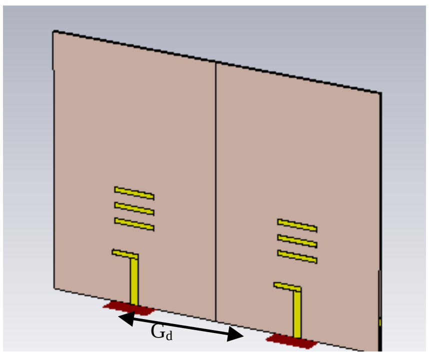
Fig. 4. Polar plot for the (a) E-plane (xy plane) and (b) H-plane (xz.-plane) of the proposed antenna.

B. Two Element Planar Quasiagi

The array configuration of the proposed antenna designed with linear array arrangement as shown in Fig. 5. The investigation is carried out by varying the gap distance between the element. The gap distance considered from the middle edge of the first element to the middle edge of the second element as indicated in the figure. Fig. 6 shows the reflection coefficient of the proposed two elementsplanar quasi Yagi antenna with 20 mm gap distance between the antenna element.

The S_{11} and S_{22} of the antenna performed wide frequency bandwidth which is 4.56 GHz (24.84 – 29.10 GHz).It can be seen from the S_{12} and S_{21}that the antenna performed good performance with low mutual coupling within the frequency range 24 – 30 GHz. Referring to Table 2, 20 mm gap distance is the best as ityields the highest gain, 11.08 dB compared to others. The differences value of the gain can be depicted from the achieved 3 dB angular width. 3 dB angular width is a measure to define the directivity of the antenna [13]. The lower value of angular width indicates that the antenna is more focus in a certain direction and resulted in the increasing value of gain.

Value of envelope correlation coefficient (ECC) also presented in Table 2. The ECC is used to verify the diversity of multi-antenna configuration. Low ECC value means higher isolation and contributes to large diversity gain[14], [15]. Fig. 7 presents the simulated 3D radiation pattern of the two element antenna array while Fig. 8 shows the simulated ECC for the antenna. The antenna array connected to each other by sharing the same ground planeThe ECC result as depicted in Fig. 8 prove that the radiation pattern for both antenna is almost uncorrelated as the value approaching zero. This is due to the direction of the radiation isthe same direction and not correlate each other.



May – June 2020
ISSN: 0193-4120 Page No. 1935 - 1940

Fig. 5. Two element linear array quasi Yagi antenna.

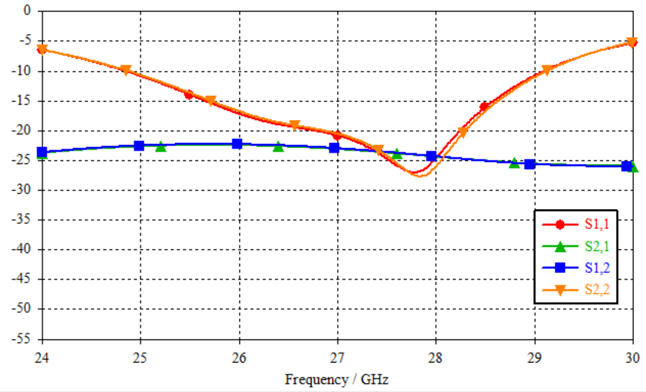


Fig.6. Simulated reflection coefficient of two element planar quasi Yagi antenna.

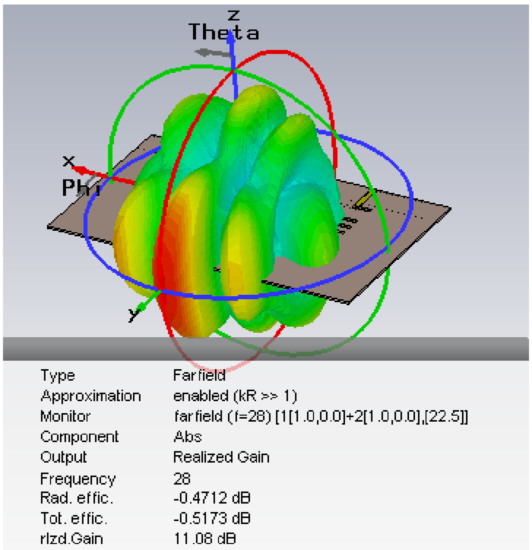


Fig. 7. 3D radiation pattern for the two element will all port excite.

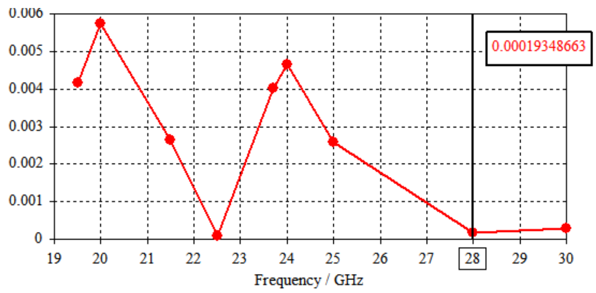


Fig. 8. Simulated Envelope Correlation Coefficient for the proposed antenna with 20 mm gap distance between antenna element.

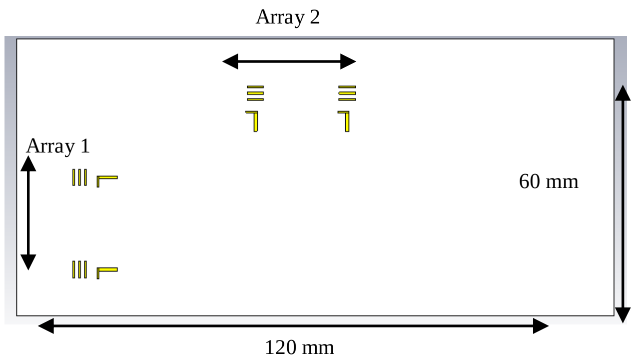


Fig. 9. Array displacement of the proposed antenna with mobile phone CB.

C. MIMO Configuration on Mobile Phone PCB

Fig. 9illustrates the MIMO configuration of the proposed 5G antenna on the mobile phone printed circuit board (PCB). The mobile phone PCB designed with 120 × 60 mm for the length and width respectively. Two sets of linear array placed on different sides of the mobile phone PCB, to exploit the performance in the horizontal and vertical position.

As presented in [16] the investigation done with two antenna displacement in the vertical and horizontal position. The proposed design used two antenna element to obtain higher gain and more directive radiation pattern. The employed arrays have the same dimension and performance as presented in the previous section. As shown in the figure, the ground plane for the proposed MIMO configuration is the whole size of the mobile phone PCB.

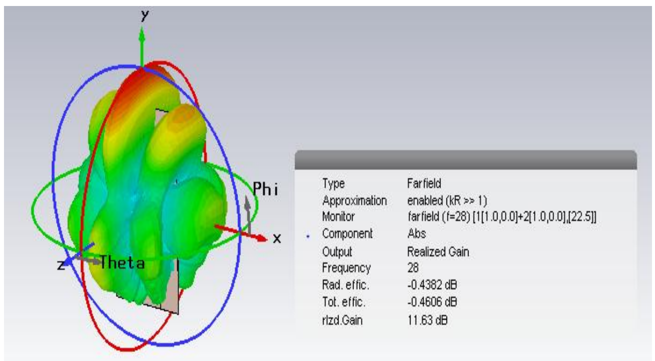


Fig. 10. Simulated 3D Radiation pattern of the proposed MIMO configuration of Array 1.

May – June 2020
ISSN: 0193-4120 Page No. 1935 - 1940

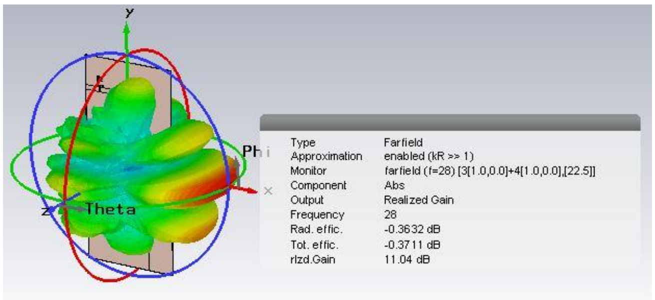


Fig. 11. Simulated 3D Radiation pattern of the proposed MIMO configuration of Array 2.

Simulation of the array 1 and array 2 was done separately, where for array 1, indicate by port 1 and port 2 was done will both port excite to see the combined result of the radiation pattern for array 1. Simulation for array 2 representsbythe combination of both port excite for port 3 and port 4. The beam pattern for array 1 focus to the top of the mobile phone as the antenna radiate upwards along the direction of the antenna as shown in Fig. 10. The simulated 3D radiation pattern for array 2 located at the side of the mobile phone PCB presented in Fig. 11. the beam pattern focus to the orthogonal direction to array 1. The allocation for both array position is to provide beam pattern even the mobile phone is vertical or horizontal position.

Table 3 summarizes the results for the MIMO configuration on mobile phone PCB. The gain achieved by array 1 is 11.63 dB with 89% total efficiency and 90% radiation efficiency. The gain achieved by array 2 having e 0.59 dB decrement which decreases to 11.04 dB. The gain decrement caused by the increment value of ECC for port 2 and 3, which is 0.25. However, this value is still acceptable as it is not exceeding 0.5[17]. The MIMO configuration of quasi Yagi resulted more directive antenna pattern indicate by the value of 3 dB angular width. The 3 dB angular width achieved by array 1 is 14.2° and 15.1° for array 2. Based on the results, the existence of the large ground plane does not degradethe antenna performance and shows that the proposed antenna suitable to be used as 5G mobile phone antenna.

TABLE 3. RESULT SUMMARY FOR MIMO CONFIGURATION

MIMO Antenna		**Array 1**	**Array 2**
Gain(dB)		11.63	11.04
Total Efficiency(%)		89	87.8
Radiation Efficiency (%)		90	88.1
Angular Width (3dB)	**Theta Cut (90^0)**	14.2	15.1
	Phi Cut (90^0)	89	59.8

CONCLUSION

Planar quasi Yagi antenna has been proposed and investigated. The gain of the two elementsquasi Yagi antenna increases compares to single element from 8.15 dB to 11.08 dB. The proposed antenna implements for MIMO array configuration for mobile phone PCB. The proposed antenna maintains good radiation behavior even mounted on mobile phone PCB with a large size of ground plane. The simulation yields good result as the proposed MIMO configuration performs well with 11.63 dB for array 1 and 11.04 dB for array 2. The proposed MIMO quasi Yagiantennais suitable for 5G mobile applications.

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