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DESIGN OF SUB MILLIMETER-WAVE ANTENNA WITH HIGH GAIN FOR NEXT GENERATION WIRELESS COMMUNICATION (5G)

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ABSTRACT

In this paper, a 1x8 coupled microstrip patch array antenna capable of providing high gain and operating between 24 GHz to 28 GHz is designed for 5G mobile applications. The proposed array antenna consists of eight antenna elements, with each single antenna element achieves simulated average return loss of less than 10 dB from 24.125 GHz to 28.131 GHz. The simulated peak realized gain of the proposed array antenna is 15.6 dBi at 0 degree. In addition, four identical 1x8 subarrays with each providing 90^{0} coverage are arranged in 4 different directions to provide 360° coverage. The single microstrip patch antenna element and four identical 1x8 subarrays antenna are fabricated where the overall size suitable for implementation in 5G smartphone applications.

Keywords: 5G, mm-wave, patch antenna, 5G mobile application.

INTRODUCTION

As the number of mobile phone users increases gradually every year, wireless communication is the key element to enhance the mobility of mobile phones. When the mobile phone user has been increases where it will affect the increase of mobile data traffic over last few years. To guide user demand of high data rate transmission and overcome the shortage of frequency spectrum below 6GHz.Therefore, 5G smartphone application is created. The benefits of millimeter-wave frequency bands include larger bandwidth which can support higher users, where the 5G is 100 times faster than 4G. To support more users and provide the data rate as high as several-gigabits-per-second [1]-[3].

A phased array antenna is proposed in [1] with each sub array consists of 8 array elements arranged at the bottom of the mobile phone. The proposed antenna achieves a 6 GHz bandwidth and maximum gain around 13 dBi but the coverage angle is narrow. In [2], a capacitive coupled patch antenna array with high gain and 360° coverage in the elevation plane is designed. The design of 4 sub-arrays with each array consisting of 12 array elements providing 90° coverage is able to provide a high realized gain around 16.5 dBi. However, the total number of 48 array elements is used required more feeding. The frequency of the capacitive coupled patch antenna operates at 24-28 GHz which is prospective to 5G band. 4 sub-arrays of 12 antenna where it provides 90°, but the antenna has a high gain around 27 dBi but required a larger number of array elements [3].

The millimeter-wave communication techniques that can provide a width bandwidth have received a great deal of attention are used to support tremendous data demands from mobile communication researchers. In [4], a phased array antenna is designed, the frequency ranges from 27.1 GHz to 28.6 GHz. The proposed antenna is typically designed for the whole metal cover handset. It contains 8 rotated slot antenna elements, demonstrates good S-parameter characteristics but the coverage is narrow while the antenna is compact but had strong back radiation and limited angle coverage of approximately 50° and narrow bandwidth [5].

In [6], the hybrid antenna is designed where it combines two existing concepts, which are the Antenna in Package (AiP) and Antenna on Display (AoD), to steer the end-fire and broadside direction at the antenna main lobe. The antenna achieved a high realized gain but narrow bandwidth of 1.67 GHz with a maximum gain of 9.2 dBi. Some alternative solution has been used to reduce the cost of the phased array and achieve high gain without using multiple transceivers [7]. The structure integrated waveguide (SIW) technique is used to fabricate using planar to form a beam-forming network. Hence, the beam-steerable range between two frequencies is narrow than 28 GHz but is still larger than 101°. Therefore, the proposed array only can provide 27 GHz to 29 GHz band in 5G mm-wave communication while the array can cover 38.8% with a gain of 10 dBi but only provide 121° coverage in the upper hemisphere. The plane of phi=90° and 270° represent the scanning plane to observe the intensity when the angle is near the broadside direction. The signal will become weak when it approaches the end-fire direction.

Multiband patch antenna is designed with the frequency operates at 37 GHz and 54 GHz, while maximum bandwidth is 5.5 GHz and 8.67 GHz where the sufficient gain is about 5 dBi and 6 dBi. The antenna is designed using Rogers RT5880 as a substrate with a height of 0.787 mm and a dielectric constant of 2.2. The copper material is used for radiating patch and ground plane where it has good conductivity. It also has a small form factor of 7.2 x 5.0 x 0.787 mm^{3} of antenna. However, it has a low gain [8].

In recent years, the planar printed antenna had attracted interest for millimeter-wave applications because of its wide bandwidth, low cost, ease of fabrication, and potential for high-efficiency operation. The printed-dipole antenna with broadband is designed for millimeter-wave application. The antenna operates at 26.5 GHz to 38.2 GHz provides 45° coverage, but the gain achieved is low, which is 4.9 dBi to 5.9 dBi [9]. A switched folded slot phased array antenna is designed to operate millimeter-wave 5G communication at 28GHz. The beam steering angle is 140° at xy-plane and 60° at yz-plane. Each mode has 10.7 dBi, 10.6 dBi, and 11.7 dBi of maximum gain. It operates at 27 to 28.5 GHz, where the bandwidth is 1.5 GHz. It observes that the array is below -10 dB were it in the range at 27 to 28.5 GHz [10].

In this paper, a microstrip patch array antenna is proposing which operates between 24 to 28 GHz with wide bandwidth and high gain for future 5G mobile applications. The proposed array antenna consists of eight antenna elements in each sub array that are arranged linearly and implement at the top and bottom of the mobile handset. A 360° coverage is achieved by positioned four sets of 1x8 array in four different directions in phone chassis.

ANTENNA DESIGN

Design Specification

A microstrip antenna with couple rectangular patch is chosen to produce a center frequency of 26 GHz due to its advantages such as simplicity and ease of fabrication. Rogers 5880LZ of a relative dielectric constant 2.0, thickness 0.508 mm, and loss tangent 0.0021 is chosen as the substrate materials to fabricate the proposed design. For the specification of the proposed design, which requires operating frequency 24 to 28 GHz, a bandwidth of 4 GHz, realized gain better than 13 dB and 360° coverage is specified based on Qualcomm Global 5G Spectrum standard and comparison between related previous research. The antenna design is built up from 4 arrays, with each array consist of 8 antenna elements that arrange in 4 different directions to produce 360° coverage.

Table-1. Specification of the substrate material.

Substrate Specification	
Substrate materials	Rogers 5880LZ
Thickness (h)	0.508
Dielectric constant, Ɛr	2.00 ± 0.04
Loss tangent	0.0021

Table-2. Specification of the proposed design.

Design Specifications	
Frequency Range	24GHz – 28GHz
Centre Frequency (f_o)	26GHz
Bandwidth (BW)	4GHz
Return Loss	Better than 10dB
Gain	>13dB

Equations and Calculation

The initial dimension of the proposed design is obtained using appropriate equations. Based on the design specification of the proposed design, the width of the patch can be calculated using the equation below:

$$W = \frac{c}{2f_0}\sqrt{\frac{2}{\varepsilon_r + 1}} \qquad (1)$$

where: C = Speed of light
f_0 = Centre frequency of proposed design
ε_r = Dielectric constant of the substrate

Due to the fringing effect which produces a larger fringe field, the effective electrical length, l_{eff}, look greater than the actual length of the patch, L_a, during the resonant condition. In other words, the actual length, L_a, is extended by a distance ΔL ΔL on each end of the patch. The extended distance can be calculated using equations:

$$\Delta L = 0.412\,h\frac{\left(\varepsilon_{eff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_{eff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)} \qquad (2)$$

where h is the substrate thickness and ε_{reff} is the substrate's powerful dielectric constant expressed as:

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W_a}\right]^{-\frac{1}{2}} \qquad (3)$$

Therefore, the actual length La can be calculated as:

$$L_a = L_{eff} - 2\Delta L \qquad (4)$$

where:

$$L_{eff} = \frac{c}{2f_0\sqrt{\varepsilon_{reff}}} \qquad (5)$$

The microstrip patch antenna is typically built with a 50-ohm feedline impedance that is close to the edge of the antenna's radiation resistance. It is necessary to have the impedance matched between the transmission line and the edge of the antenna for a transmission line that has maximum power transfer of radio frequency energy from source to the antenna with minimal power loss. If there is an impedance mismatch in the input, it will affect the output of the antenna as some of the signal power enters the antenna and reflects it. Therefore, to enhance antenna performance, an impedance matching technique known as inset feed is used where the input resistance is defined as:

$$R_{in} = \frac{1}{2(G_1 \pm G_{12})} \qquad (6)$$

where: G_{12} = Mutual conductance
G_1 = Self-conductance

The self-conductance can be calculated using the following equation:

$$G_1 = \frac{I_1}{120\pi^2} \qquad (7)$$

where I_1 is defined as:

$$I_1 = \int_0^{\pi} \left[\frac{\sin\left(\frac{k_0 W_a}{2}\cos\theta\right)}{\cos\theta} \right] \sin^3\theta d\theta \qquad (8)$$

$$= -2 + \cos(X) + XS_i(X) + \frac{\sin(X)}{X} \qquad (9)$$

where: $X = k_0 W_a$
$k_0 = 2\pi / \lambda$
S_i = sin integral

Next, the mutual conductance, G_{12}, is calculated using the following equation:

$$G_{12} = \frac{1}{120\pi^2} \int_0^{\pi} \left[\frac{\sin\left(\frac{k_0 W_a}{2}\cos\theta\right)}{\cos\theta} \right] J_0(k_0 L \sin\theta) \sin^3\theta d\theta$$

(10)

However, the value of G_{12} is very small and assumed 0. Equations (6) to (10) of input resistance for inset feed is simplified as:

$$R_{in}(y = y_0) = \frac{1}{2(G_1 \pm G_{12})} \cos^2\left(\frac{\pi}{L_a} y_0\right) \qquad (11)$$

where: y_0 = inset feed distance

The total length of the feedline can be calculated by using equation:

$$y_{total} = y_0 + y_1 \qquad (12)$$

where:

$$y_1 = \left(\frac{L_a}{2} - y_0\right) + \frac{\lambda_g}{4} \qquad (13)$$

The overall parameter design of the proposed design is summarized in Table-3 and shows in Figure-1.

Table-3. Summary of microstrip patch antenna parameter.

Parameter	Dimensions (mm)
Width of the Patch, W	4.711
Length of the patch, L_a	3.723
Length of feedline, y_0	1.116
Length of feedline, y_1	2.828
Total Length of the feed line, y_{total}	3.994

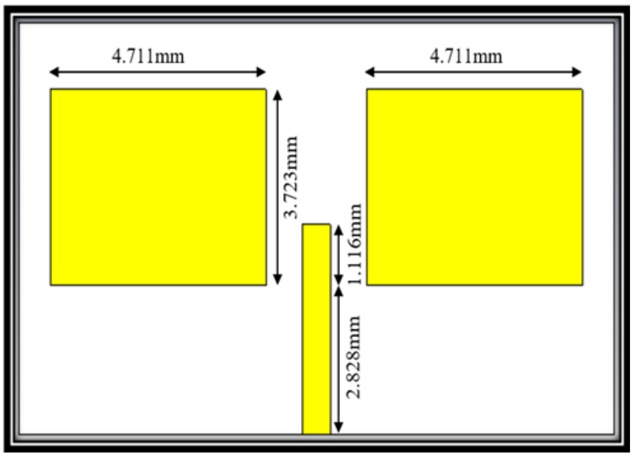

Figure-1. Design structure of microstrip patch antenna.

Design Process

The initial design structure is simulated using Computer Simulation Technology (CST) Studio Suite. The response of the initial design gives a good response for its return loss at the resonance frequency. Nevertheless, the bandwidth is narrow. A rectangular notch and a slanting notch are added at the top of the patch antenna to increase the bandwidth of the antenna.

These parameters are optimized by using a parametric study to obtain the desired response. Figure-2 depicts the 12 considered parameters during the optimization process. The optimized parameters of a single microstrip patch antenna are shown in Table-3.

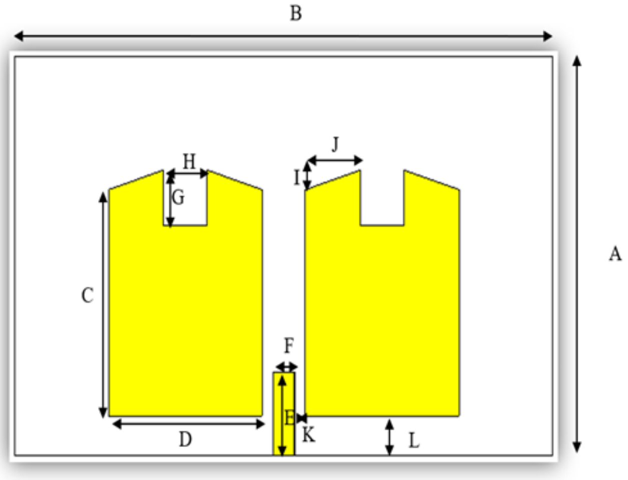

Figure-2. Parameter to consider during optimization.

Table-4. Optimized parameter of microstrip patch antenna.

Label	Parameter	Dimension (mm)
A	Length of substrate	6.00
B	Width of substrate	10.50
C	Length of patch	3.41
D	Width of patch	2.93
E	Length of feedline	1.24
F	Width of feedline	0.36
G	Length of rectangular notch	0.82
H	Width of rectangular notch	0.84
I	Length of slanting notch	0.74
J	Width of slanting notch	2.50
K	Gap between patch and feedline	0.18
L	Gap between patch and bottom	0.50

The optimized design is then duplicated to become a 1x8 array antenna consist of 8 identical antenna elements as shown in Figure-3. The overall size of the 1x8 sub array is 7.6 cm x 0.7 cm.

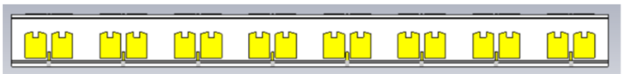

Figure-3. 1x8 array antenna.

Four sets of 1x8 sub array is positioned in 4 different Four sets of 1x8 sub array are positioned in four different directions of the casing to achieve a 360^0 coverage angle. Figure-4 and Figure-5 show the perspective view of the array antenna for three sub array sides and one sub array side, respectively.

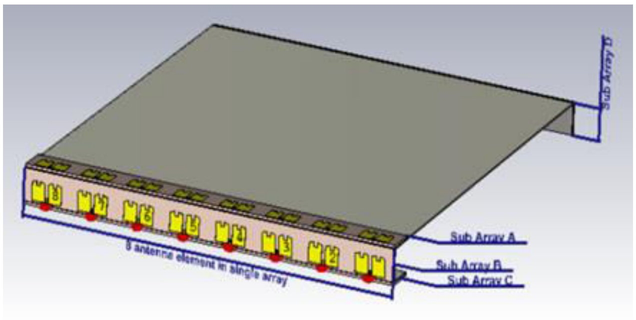

Figure-4. Perspective view A (3 sub array antenna).

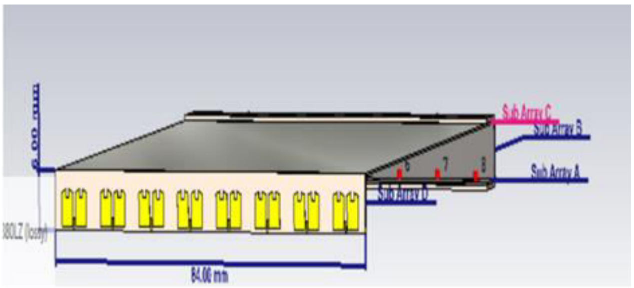

Figure-5. Perspective view B (1 Sub array antenna).

Manufactured Product

The optimized microstrip patch antenna is manufactured through the fabrication process using Rogers 5880LZ as substrate with thickness 0.508 mm, and dielectric constant, ε_r = 2.00. The copper cladding thickness is 0.035 mm, and the loss tangent of the substrate is 0.021. Figure-6 and Figure-7 show the manufactured single microstrip patch antenna with soldered ports for measurement and four sets of microstrip array antenna with a casing, respectively.

Figure-6. Manufactured single microstrip patch antenna.

Figure-7. 4 set of 1x8 array antenna with casing.

PERFORMANCE OF PROPOSED 5G ANTENNA

Return Loss, Operating Frequency and Bandwidth

Figure-8 shows the (S11) graph of the simulated results. For simulated results, a return loss (S11) of 20.21 dB at center frequency 26.128 GHz is obtained. The operating frequency is between 24.125 GHz and 28.131 GHz, which gives a frequency bandwidth of 4.0058 GHz. The desired bandwidth of 4GHz is a trade-off to get better return loss.

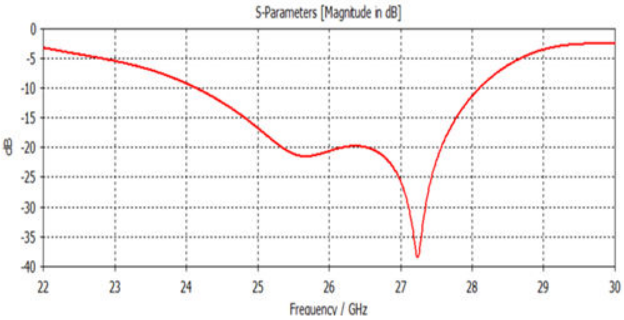

Figure-8. Simulated result.

Realized Gain and Radiation Pattern

The simulated realized gain of a 1x8 sub array was achieved at 15.6 dB. Figure-9 shows the simulated radiation pattern at the E-plane of the single array antenna at the frequency of 25.224 GHz, which the frequency obtained at the peak gain. The radiation pattern represents the main lobe magnitude of 15.6 dB at 0° direction from the origin point.

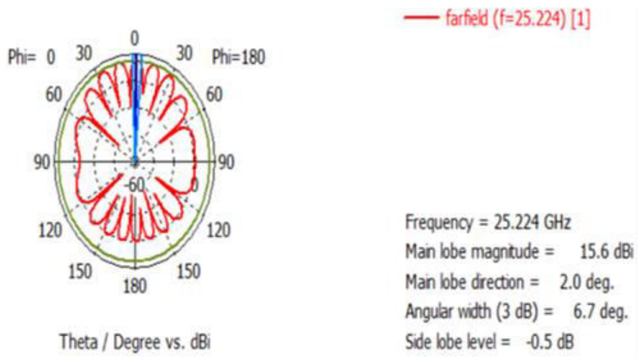

Figure-9. Radiation pattern of single array element at frequency of 25.224GHz.

Figure-10 shows the arrangement and radiation pattern of four identical sub arrays in a casing and radiation pattern. Each sub array consists of eight antenna element that arranged in four different directions to provided 90° coverage.

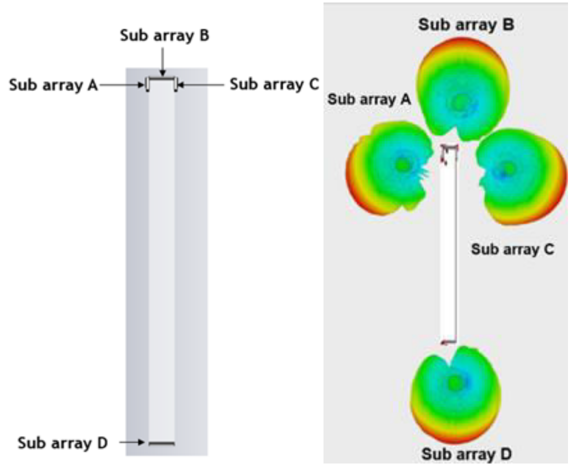

Figure-10. Radiation pattern of 4 set 1x8 array antenna.

CONCLUSIONS

In this paper, a high gain microstrip patch array antenna is suggested and designed for wireless communication of the next generation (5G). The simulated results show that the array antenna operates between 24.125 GHz to 28.131 GHz with a bandwidth of 4.0058 GHz and peak gain up to 15.6 dB. Four identical 1x8 array antennas are arranged in four different directions to provide 360° coverage. The design is manufactured and validated through experiment works in the laboratory. Finally, the objective of this study is achieved.

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