Design of 4 Elements MIMO Antennas at 24GHz, 26GHz and 28GHz for B5G Mobile Handset Applications

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Abstract. The design of these antennas is in line with the specifications for the futuristic 5G and beyond technologies. The antenna type used for this design is a microstrip patch array antenna with four radiating elements at resonating frequencies of 24GHz, 26GHz, and 28GHz respectively. At these high frequencies, the substrate used is FR4_epoxy, a ceramic material that aids in minimizing mutual coupling effects and has a dielectric constant of $E_r = 4.4$. The resonating frequencies enable the antennas to operate on the millimeter wave band with an enhancement to the throughput, multiplexing abilities, and bandwidth of the antenna. The results obtained at these frequencies peaked at an antenna gain of about 8dB, 3GHz bandwidth, and a return loss of -30dB. These results were then compared to those of earlier works for which microstrip patch antennas were designed.

Keywords: Multiple In Multiple Out (MIMO), Beyond 5G (B5G), Internet of Things (IoT), Millimeter wave (mm-wave).

1 Introduction

The world we live in today has seen fast-paced improvement in many sectors. Most paradigms with which humans relate are seeing steady development and telecommunications is not left out. To meet the networking and miscellaneous demands of the ever-growing human population, ideas for new technologies have been sought and brought forward. For the general telecommunications system of the world to function effectively, several devices have to come into play. Amongst these devices is the antenna.

In simple terms, the antenna performs the function of sending and receiving signals which carry information over a determined distance [3]. For each of the generations of networking; First Generation (1G), Second Generation (2G), Third Generation (3G), Fourth Generation (4G), and the recently introduced Fifth Generation (5G) [4]; the performing power of antennas vary either by very little or by so much. The same is the case in the yet-to-be-introduced sixth generation of networking (6G). It is important to mention that the 5G networking technology brought with

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it great improvements over its predecessor networks. Some might even argue that it has reached a critical level of service which cancels out the need for newer generations of networks. Regardless, the 6G and most likely future frameworks yet to be introduced will aim at further improving upon the past generations of networks. Present sources show that generations beyond 5G are targeted at improving upon important factors such as security, speed, coverage area, bandwidth, and a great reduction in network latency or lags [5]. To achieve these standards, techniques such as massive MIMO, as well as beamforming will be applied in designing suitable antennas.

This project will center around the design of 4-element array antennas at high frequencies; 24GHz, 26GHz, and 28GHz respectively; to test their capabilities in meeting the standards of 5G and beyond networks.

2 Design

Microstrip patch antennas are comprised of some main parts; the ground, feed and substrate, and the patch elements, in that order from bottom to top. Three array antennas were designed here using resonant frequencies of 24GHz, 26GHz, and 28GHz at an impedance of 50 ohms and a dielectric constant of 4.4. FR4_epoxy, a ceramic material, was used as the material for the substrate due to its conducting capabilities, a lumped port was used to serve the feed, and both the ground and patch elements utilized the Perfect E boundary configuration for their conductivities.

To make sure that estimated results were achieved, the most fitting dimensions were calculated and simulated. Furthermore, the challenging task of adjusting dimensions was undertaken to obtain the best results. To facilitate the design process, basic parameters such as the length and width for each of the three antennas were obtained using the formular below;

$$\mathrm{L} = \frac{C}{2Fr\sqrt{Ee}} - 2\Delta l \qquad (1)$$

$$\mathrm{W} = \frac{C}{2Fr\sqrt{(Er+1/2)}} \qquad (2)$$

Where; C = speed of light (3.0×10^8 m/s)

F_r = Resonant frequency

E_r = dielectric constant

E_e = Effective dielectric constant

The diagram of a 4-element microstrip patch antenna is shown in **Figure 1** below. Alternatively, the obtained values for the dimensions of each antenna are summarized in **Table 1** that follows.

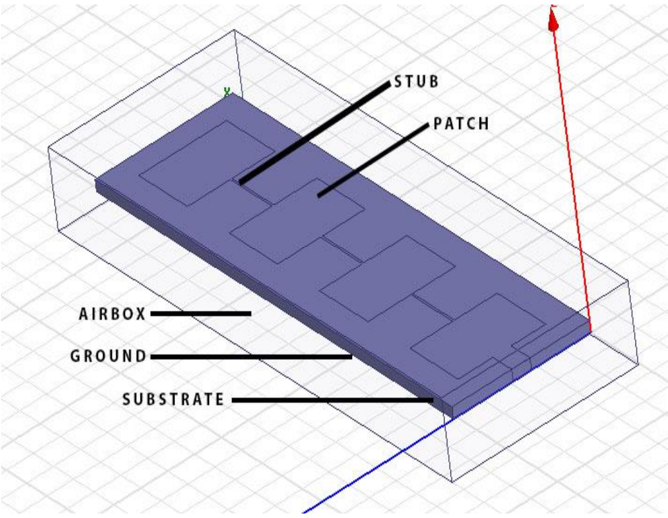


Fig. 1. Snapshot of 4-element Microstrip Patch Antenna in Three Axes

Table 1. Summary of Calculated Antenna Dimensions at each Resonant Frequency

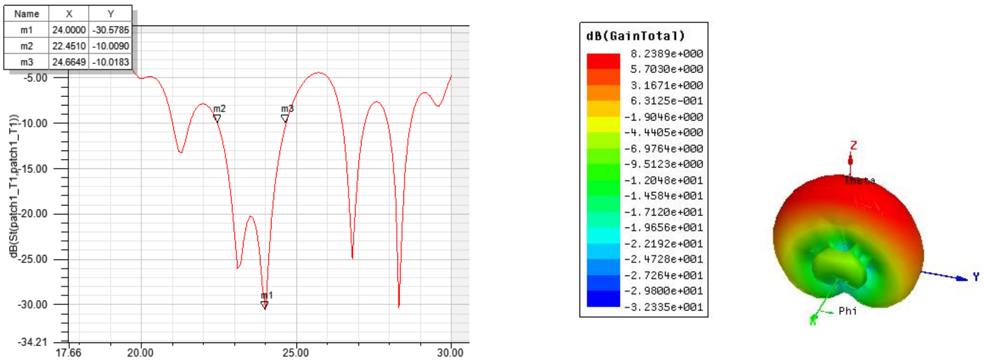
	24GHz	**26GHz**	**28GHz**
$L_g \times W_g$	22.5985 x 5.96	18.602 x 5.49	17.68 x 5.12
L × W	2.8 x 3.8	2.6 × 3.51	2.404 x 3.26
H	0.36	0.33	0.31
$L_f \times W_f$	1.59 x 0.795	1.47 × 0.74	1.36 x 0.68
$L_{st} \times W_{st}$	3.0795 x 0.0795	0.99 × 0.074	2.068 x 0.068

NOTE: All parameters are in millimeters (mm)

Where; L_g = Length of Ground
W_g = Width of Ground
L = Length of Patch
W = Width of Patch
H = Height of Substrate

3 Results (Return loss, Bandwidth, and Gain)

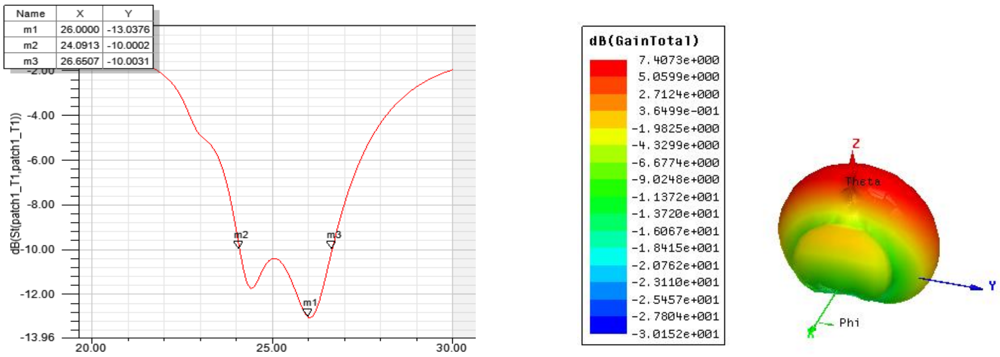
The HFSS environment was utilized to generate results for the return losses (S11), the bandwidths, as well as the gains (S21) of each array antenna. The figures below illustrate these results for each antenna resonating at their different frequencies. Thereafter, **Table 2** that follows gives a comprehensive summary of the results.



Name	X	Y
m1	24.0000	-30.5785
m2	22.4510	-10.0090
m3	24.6649	-10.0183

(a) **(b)**

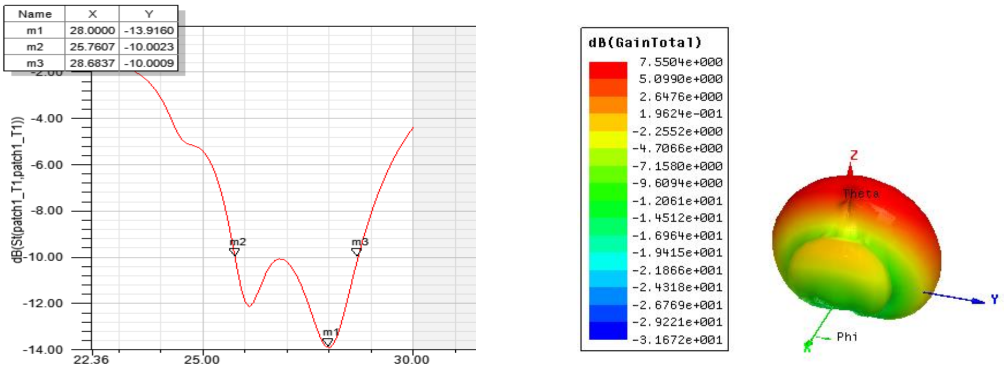
Fig. 2. S11 and S21 for 24GHz respectively



Name	X	Y
m1	26.0000	-13.0376
m2	24.0913	-10.0002
m3	26.6507	-10.0031

(a) **(b)**

Fig. 3. S11 and S21 for 26GHz respectively



(a) **(b)**

Fig. 4. S11 and S21 for 28GHz respectively

Table 2. Summary of Return Loss, Bandwidth, and Gain Results

Frequency	**Return Loss**	**Bandwidth**	**Gain**
24GHz	-31dB	2GHz	8dBi
26GHz	-13dB	3GHz	7dBi
28GHz	-14dB	3GHz	8dBi

4 MIMO

MIMO is the acronym for Multiple In Multiple Out [6] and is a popular form of multiplexing. It is a technique which involves the use of antenna arrays with elements synchronized to use a particular decided frequency for the propagation and receipt of signals carrying information. Typically, signals are sent simultaneously from multiple input sources through a transmitting channel and are multiplexed to carry a variety of data through to the output of the channel [6]. The MIMO technique is subdivided into precoding, spatial multiplexing, as well as diversity coding. In the case of the 5G family of networks, spatial multiplexing is used [3], and will most likely be adopted for future frameworks. This technique of multiplexing has already seen several applications of its use in wireless communications. It comes highly recommended for its capabilities in the increments of data rate during transmission in a channel [3]. From his studies, Shannon expressed that data should not be transmitted beyond its transmitting channel capabilities if not, data would be prone to errors. Without affecting the power of a multiplexing channel, spatial multiplexing increases data rate in contrast to when using a single channel. When applying the MIMO technique, the number of antennas at the transmitting side must be equal to the number of antennas at the receiving side, based on the fact that the transmission channel is split into streams of varying data types. A system of linear equations exists to show the connection between transmitted and received signals during the process of spatial multiplexing. **Figure 5** is an illustration of how data moves around during spatial multiplexing, and Equation **(1)** is the system of equations just mentioned;

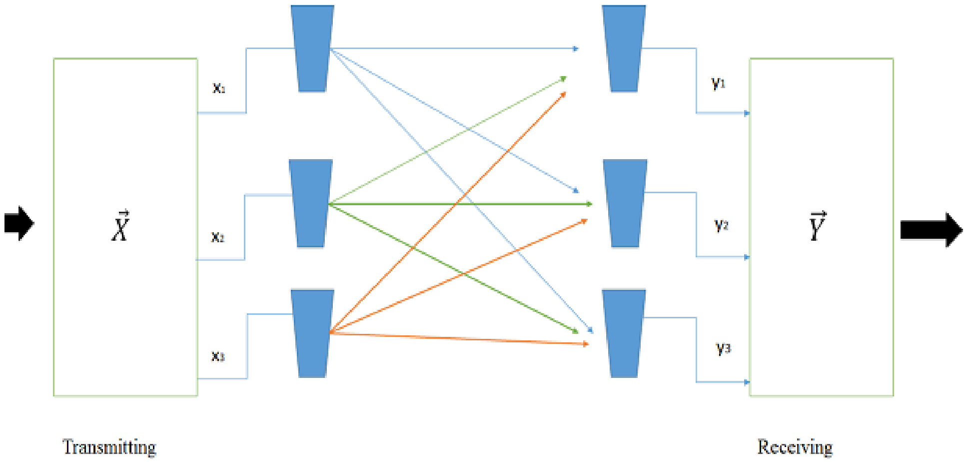


Fig. 5. Spatial Multiplexing

$$\vec{Y} = \begin{bmatrix} h11 & \cdots & h31 \\ \vdots & \ddots & \vdots \\ h31 & \cdots & h33 \end{bmatrix} \vec{X} \tag{1}$$

Where $\vec{Y}$ = received signal
$\vec{X}$ = Transmitted signal
h = data

5 Beamforming

The most effective antennas will utilize the beamforming technique [1]. This technique helps to make antennas ‘smart’. Antennas that utilize the process of beamforming during their operations make use of elements that enable them to be controlled electronically rather than mechanically [7]. This implies that they can receive or transmit signals more effectively from or to the targeted direction. The switch beam and the adaptive antenna are the two types of smart antennas. The former functions by directing a signal toward a moving device which hops from cell to cell [8], while the latter positions its main lobe toward a device while moving from cell to cell through its discarding of the Signal Not of Interest (SNOI). The adaptive smart antenna is considered the better type through its performance in interference reduction [2]. Through the introduction of a digital signal processor, the array antennas discussed here can also be made adaptive.

6 Conclusion

From observed trends, it is safe to project that wireless mobile communication is here to stay. Hence it will be valid to mention that newer technologies will be invented in a quest for man to quench his insatiable craving for satisfaction. Each generation of mobile communication that has existed has posed as a stepping stone for the realization of the next. This trend is bound to continue as current techniques become outdated with time. 5G technologies have paved the way for the revolutionization of concepts such as the Internet of Things (IoT) and machine-to-machine automated communication. They have also sparked a great interest in the development of components aimed at actualizing the creation of future networks. With these and more in mind, this research was carried out. It will suffice to conclude that the antennas realized here obtained a larger proportion of objectives set out for them.

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