Compact MIMO antenna using dual-band for fifth-generation mobile communication system

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Article Info

Article history:

Received Jan 24, 2021
Revised Sep 4, 2021
Accepted Sep 9, 2021

Keywords:

5G communication
CST microwave studio
Dual-band antenna
Impedance matching
MIMO antenna
Smartphones

ABSTRACT

This paper presents the design of a multiple-input and multiple-output (MIMO) antenna for a fifth-generation (5G) smartphone that will work in dual-band. The antenna proposed in this work operates at 2 frequency ranges, i.e., (3300-3600) MHz and (4800-5000) MHz. The antenna design consists of four antennas that are placed perpendicular to the edge of the system and this makes it different from the traditional 5G antennas. The area of each antenna on the side frames is (3.9×17 mm), and hence can be used in ultra-thin smartphones for 5G applications. The reflection coefficient obtained in the simulations is less than -6 dB for the required band, which suggests that the required impedance matching is obtained. The antenna proposed is designed by using central time zone (CST) microwave studio.

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1. INTRODUCTION

The popularity of mobile communication networks has increased rapidly within the last few years. Initially, it was used to support communication via calls and texts, but over time, now data transmission is also possible. With the introduction of a new generation, the data rate is increasing and there is also the addition of more features. The previous generations were designed keeping in mind the need for high data rates to be used by few devices simultaneously, but with the introduction of machine-to-machine (M2M) communication, many small devices are becoming an important part of the network [1]. Hence, the 5th generation is expected to be more reliable, to have more data rate that is at least 1 Gbps, should not have latency and along with this it should be able to address the above problem as well, that is allowing M2M communication [2].

With the development of modern 5G wireless communication systems, the user's demand for high speed has also increased tremendously. So, to meet this increasing demand, the research and development of the fifth-generation (5G) antenna are being carried out [3], [4]. In reference [5], 4G/5G multi-antenna that can be used in smartphones in the range of (3400-3600) MHz was proposed. Again, radio access technologies have also developed to a large extent in recent years due to which diverse types of networks are being merged with wireless communication networks. This has led to the rise of mobile terminals with multi-mode in the field of wireless communication. 5G antenna, multiband antenna, multi-mode antenna, and smart antennas are the antennas whose demands have increased rapidly because they can be used in these terminals [6], [7].

Miniaturization of antenna and use of array antennas can lead to high-speed data transmission. Due to this among all these antennas, the one that is especially employed in smartphones is multiple input multiple output that is a multiple-input and multiple-output (MIMO) antenna [8]. This means that a large number of antennas can be placed within the mobile phone's limited space. But due to the limited size, the antennas with strong mutual coupling cannot be used as it affects the efficiency of the antenna and also its correlation. So, implementing MIMO in the design of smartphone antennas is very challenging as in increasing the number of antennas, the isolation between each of them will reduce and this will result in a decrease in their efficiency. Hence achieving high efficiency as well as good isolation in the MIMO antenna is a very critical challenge. So, there is a need to decouple the elements of the antenna to improve the isolation. In [9], an 8-element PIFA-based MIMO antenna system was proposed but it can cover only a single band of 3.5GHz and the minimum isolation possible between the antenna's elements was 7.4 dB.

Some more research is done that provides good solutions for even 8×8 MIMO systems [10]-[15]. But these are all for a single band of frequency and hence cannot be used in 5G communications. 5G communication needs to address a lot many new applications and needs to meet the new standards of communication. So, it needs multiple frequency ranges. Due to this, it needs multiple antennas that are working in different frequency bands. So, the antennas which can work in multiple bands will be more preferable in smartphones. In this paper, a MIMO antenna consisting of four antennas is proposed. The proposed antenna can work in a dual-frequency range, that is, it not only operates in the frequency range of 3300-3600 MHz but also in the range of (4800-5000) MHz. Again, in this model, the four antennas are along two side edges of the smartphone and hence it can also provide 12 dB of isolation and can be used in the design of a full-screen smartphone antenna, which can be implemented in the full-screen smartphone.

2. RESEARCH METHOD

The design of the MIMO antenna in CST microwave studio [16], [17] for dual-band is divided into the designs of the following subdivisions. In this paper, a MIMO antenna consisting of four antennas is proposed. The proposed antenna can work in a dual-frequency range, that is, it not only operates in the frequency range of 3300-3600 MHz but also in the range of (4800-5000) MHz.

2.1. Design of substrate

The substrate is fabricated first using FR4 substrate [18]. This material has a relative permittivity (ε_r) of 4.3 and electric loss tangent of 0.025. Its dimensions are (130×74×0.8 mm) [19], and it is shown in Figure 1(a).

2.2. Design of ground on substrate's backside

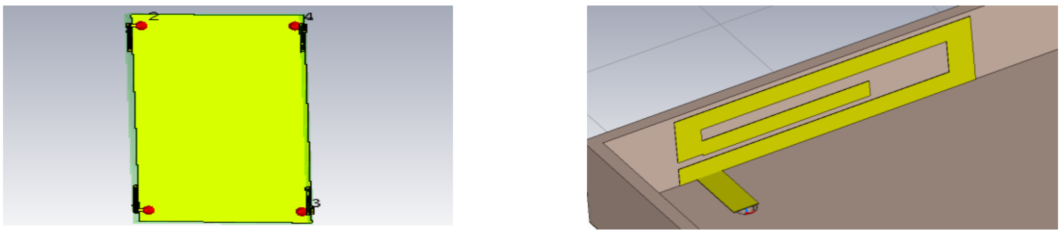
The ground is fabricated using copper and is placed at the back of the substrate [20], [21]. Its dimensions are the same as that of the substrate but with a thickness of 0.035 mm, i.e., (130×74×0.8 mm).

2.3. Design of side frames of PCB

One vertical side frame of printed circuit board (PCB) is fabricated first of dimensions, (0.8×130×4.2 mm). It is then copied to the other side at 74.08 mm [22]. Then the horizontal side substrate is designed of dimensions (74 ×0.8×4.2 mm). This is then copied to the other side at 130.08 mm [23].

2.4. Design of front part of antenna on side frames

The front part of the antenna consists of several bricks, which are designed one after another using copper as material and then are added to give a complete picture as shown in Figure 1(b). The dimensions of each parts are: (0.035×17.7×1 mm); (0.035×1.5×1.5 mm); (0.035×10×0.9 mm); (0.035×1.5×2.9 mm); (0.035×16.2×1 mm) [24].



(a) (b)

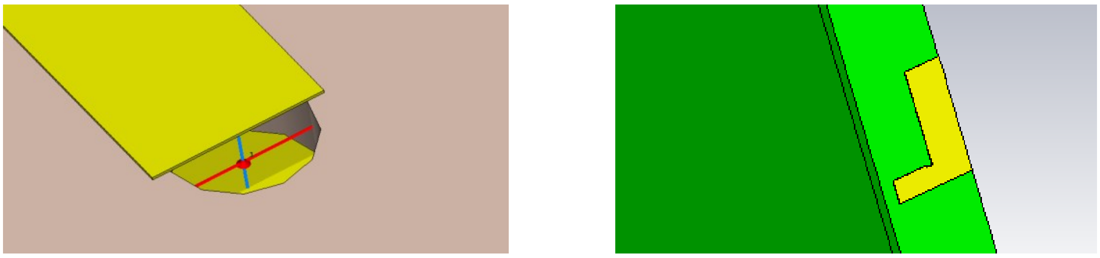
Figure 1. (a) The main substrate of the antenna and (b) Front view of the antenna

2.5. Feeding process

The bend line in Figure 1(b) shows the feed. Its dimensions are (4×1.5×0.035 mm). We will use a cylinder for feeding on the main ground whose outer radius is 0.1 mm [25], [26], and is made of vacuum material as shown in Figure 2(a). The antenna is fed by the main ground.

2.6. Design of back part of antenna on side frames

The back part of the antenna consists of 2 bricks, which are designed and then added as shown in Figure 2(b). The dimensions of each part are [27]: (0.035×1×4.2 mm), and (0.035×4.4×2 mm).



(a) (b)

Figure 2. (a) Feeding part of the antenna and (b) Back part of the antenna

2.7. Transforming the antenna to the remaining 3 sides and aligning

After the fabrication of one antenna, it is copied to the other 3 edges of the substrate and is aligned such that the feeding part is facing inside [28], and it is shown in Figure 3. This completes the fabrication. The PCB fabricated is of size (130×74 mm) which is approximately the same as that of a smartphone of 5 inches. Then the 4 antennas having the same structure and dimensions, (3.9×17 mm) are fabricated on it such that they are along two side edges of the smartphone and hence the isolation between each of them will be more and their efficiency is not affected.

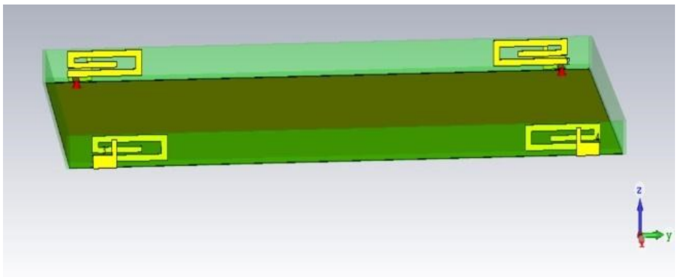


Figure 3. Antenna array structure

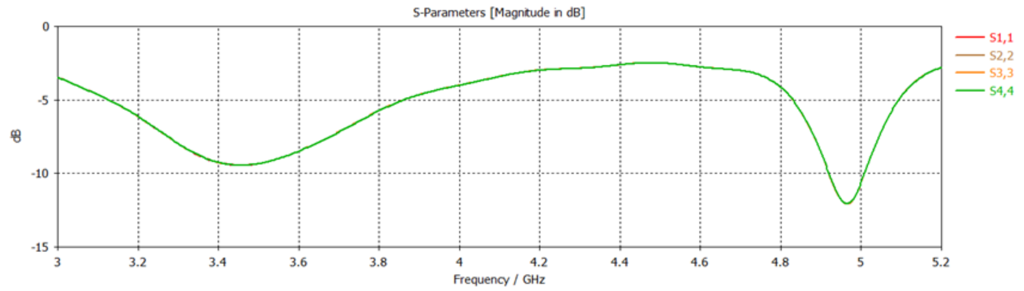
2.8. Start simulation

After the completion of fabrication, the simulation is done and variations in the parameters like S-parameters, gain and efficiency are observed. The antenna is designed to work in two frequency bands, 3.3 to 3.6 MHz and 4.8 to 5 MHz. The antenna has two parts that are responsible for radiation. The feed part of the monopole with a bent shape as shown in Figure 2 is responsible for radiation from the front part and the L-shaped structure as shown in Figure 2(b) is responsible for radiation from the back part. The capacitance due to coupling between these two radiation parts is mainly responsible for the impedance matching in two frequency bands and hence results in dual-band working [29], [30]. The capacitance generated due to coupling between monopole and the L-shaped structure at back leads to impedance matching at low frequency and hence in the band of 3.3 to 3.6 GHz. The length of monopole and feed part resonates around 4.9 MHz and the capacitance generated due to coupling between feed part and the L-shaped structure at back leads to impedance matching at high frequency and hence in the band of 4.8 to 5 GHz.

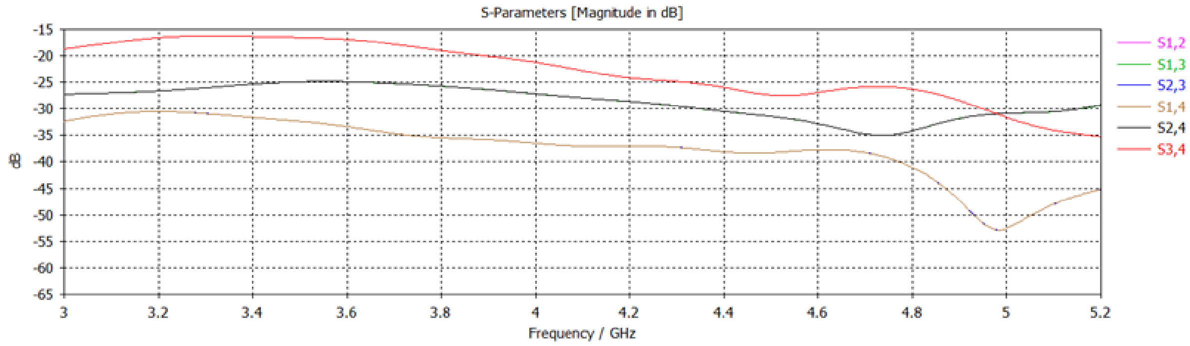
3. RESULTS AND ANALYSIS

The simulations were carried out using central time zone (CST) microwave studio. The antenna proposed is designed on the side of the PCB to meet the modern technology of smartphones as shown in Figure 3. The S-parameters for the antenna which include both reflection coefficient and transmission coefficient are given in Figure 4. The reflection coefficient of an antenna is desired to have less value because it refers to the power which is reflected without getting transmitted. Similarly, we need to have proper impedance matching so that the signal gets transmitted without any reflection. The reflection coefficients of all four antennas are less than 8dB for the given band of frequencies as seen in Figure 4(a), which is as per the requirement. The transmission coefficient at 3.4 GHz is about -12 dB and at 4.8 GHz it is less than -10 dB, which is according to the expected results for smartphone application and can be seen in Figure 4(b).

Voltage standing wave ratio (VSWR) refers to how efficiently the power is transmitted through a transmission line to the load point. If the reflection coefficient and VSWR are less, it indicates that the antenna is matched. Here, the VSWR value is less than 3 as shown in Figure 5 indicating that the antenna is nicely matched and reflection losses are minimized. As all four antennas have the same structure and are simulated under ideal conditions, the VSWR values completely overlap. The antenna efficiency should be as high as possible. Here, the efficiency is around 85% for the lower band and it is between (50-60%) for the higher band of frequency which is shown in Figure 6.



(a)



(b)

Figure 4. (a) Reflection coefficient and (b) Transmission coefficient of the simulated antenna

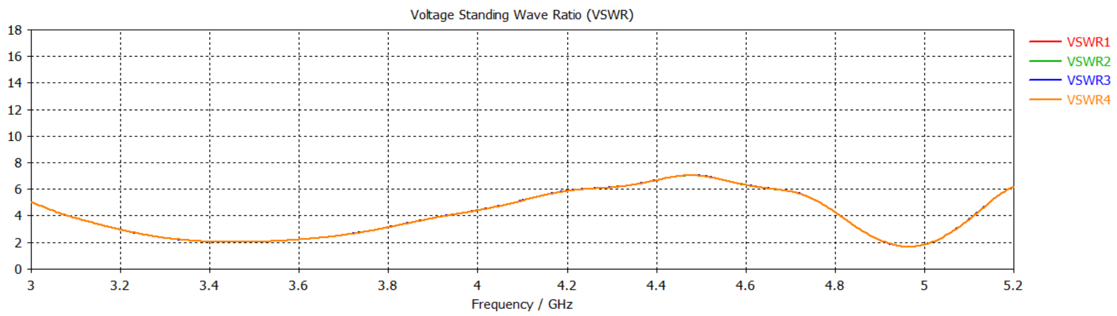


Figure 5. Obtained voltage standing wave ratio (VSWR)

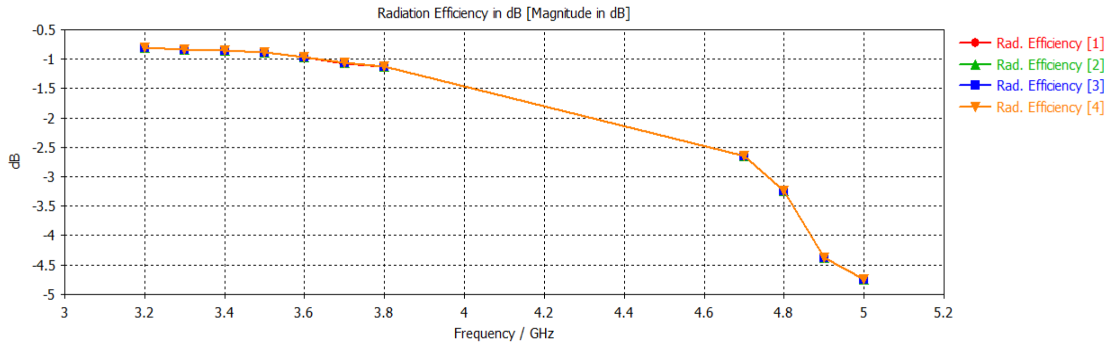


Figure 6. Antenna efficiency

The antenna gain describes how much power is transmitted in the direction of peak radiation to that of an isotropic source. Antenna gain is more commonly quoted than directivity in an antenna's specification sheet because it takes into account the actual losses that occur. The gain should be as high as possible for better power transmission. Here, the gain for the lower frequency band will be around 4 dB and around 3 dB for the higher frequency band which is the required gain and can be seen in Figure 7. Figures 7(a) to 7(d) (see Apendix) depicts the farfield gain simulated for 3.4 GHz band, whereas Figures 7(e) to 7(h) (see Apendix).depicts the farfield gain simulated for 4.8 GHz band.

Radiation pattern refers to the way radiated power is varied with respect to the direction away from the antenna. It is the function of the angle of arrival. Hence, the variation in the power radiation is also a function of phi and theta. At phi =90, the position of nulls and maxima of all the antennas can be observed from the radiation pattern shown in Figure 8. Directivity measures the pattern of antenna radiation in a specified direction in space In this figure the directivity of all the four antennas in both lower and higher frequency bands has been demonstrated.

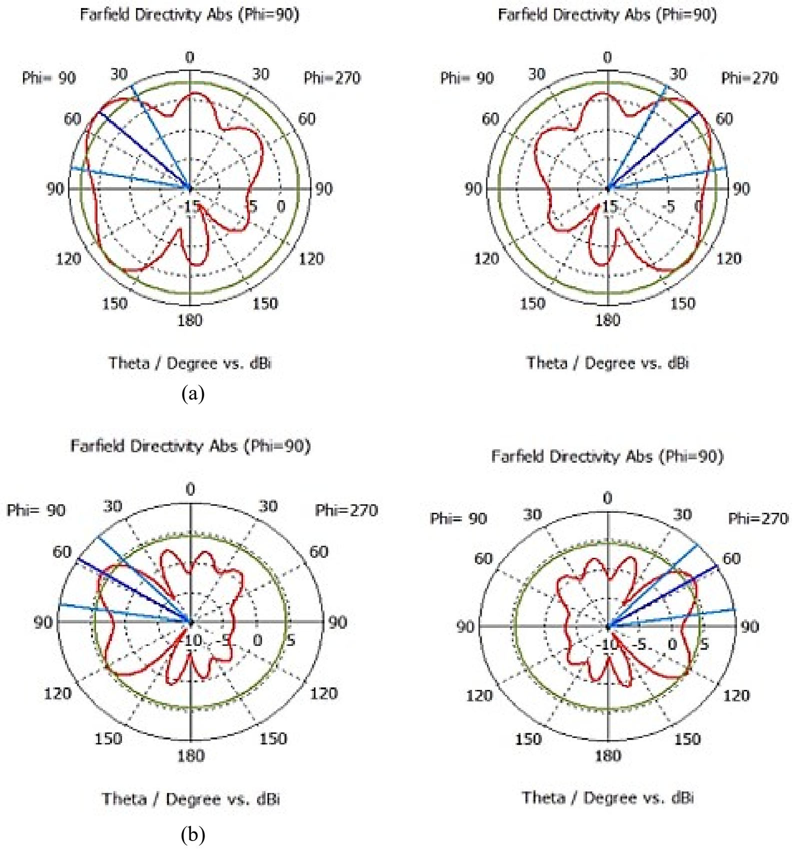
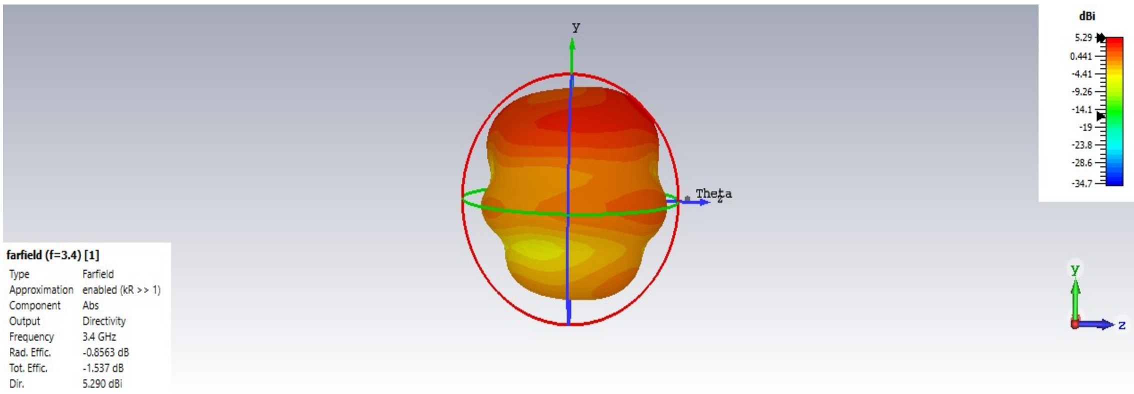


Figure 8. Directivity of (a) 3.4 GHz band in polar form and (b) 4.8 GHz band in polar form

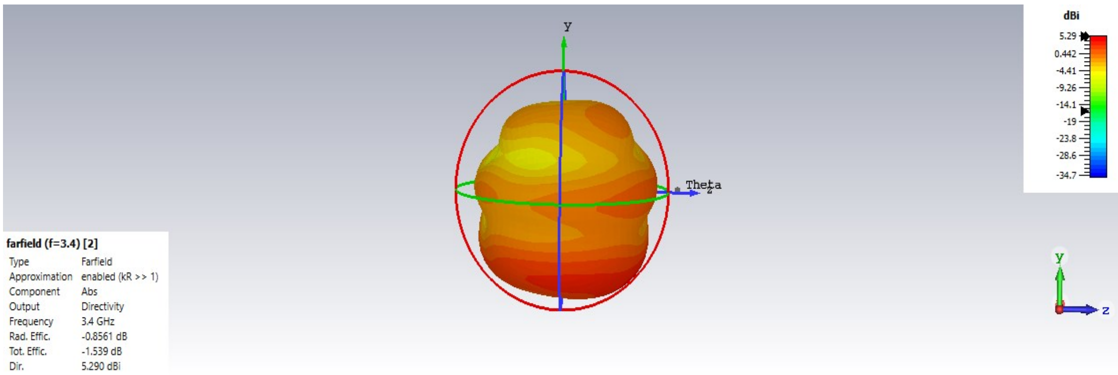
4. CONCLUSIONS

A MIMO antenna with a dual-band feature that can work in both (3.3-3.6) MHz frequency range and (4.8-5) MHz frequency range has been designed successfully using CST microwave studio. The proposed antenna has two frequency bands of operation and hence can be used to enhance 5G communication which needs to work in multiple frequency ranges to address a lot many new applications and to meet the new standards of communication. This will also help in providing a stable wireless connection is often difficult to reach locations. Knowing the requirements of 5G supporting smartphones, this antenna is designed to have a comparatively small size, better impedance matching, less reflection coefficient, more transmission coefficient, more VSWR, and relatively higher isolation. In the near future, one can proceed with a similar type of framework with more number antennas and hence can further increase the data rate and the converging area.

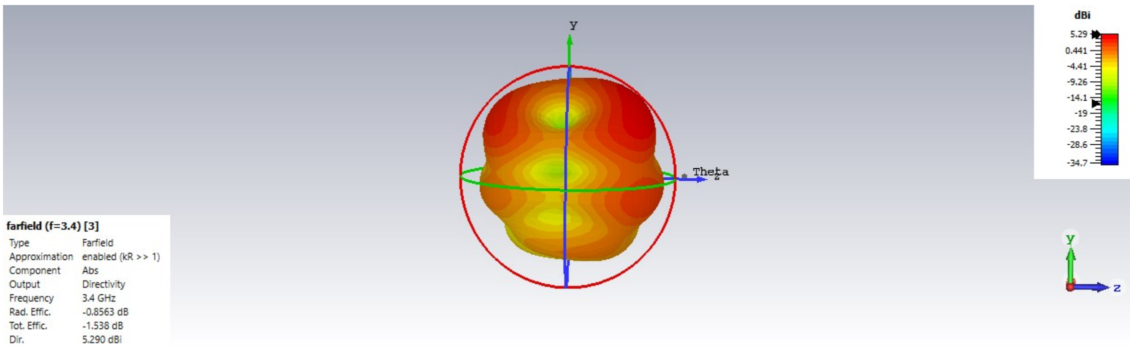
APENDIX



(a)

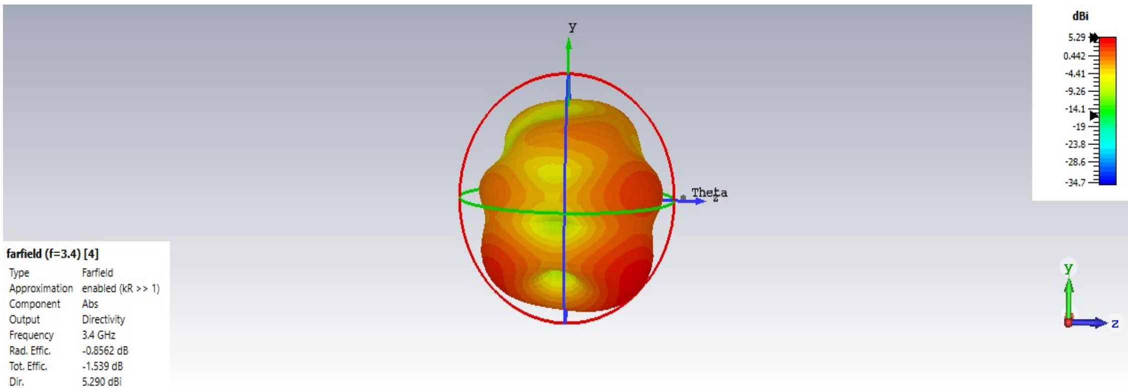


(b)

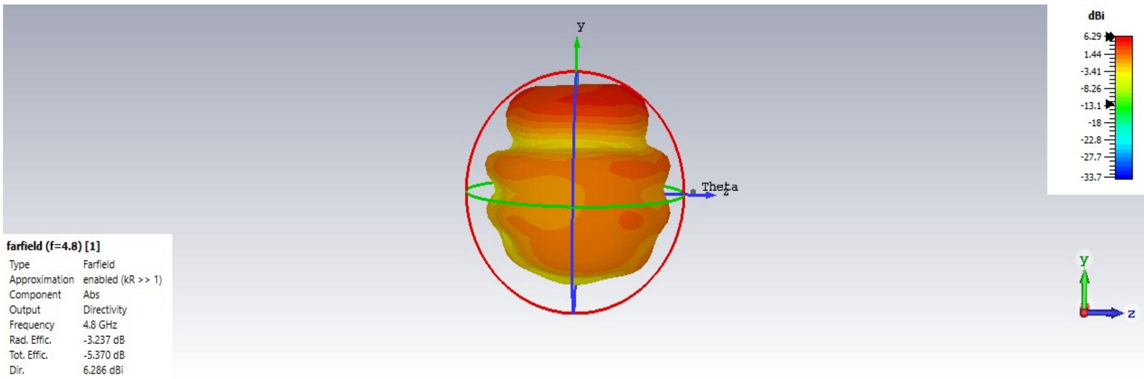


(c)

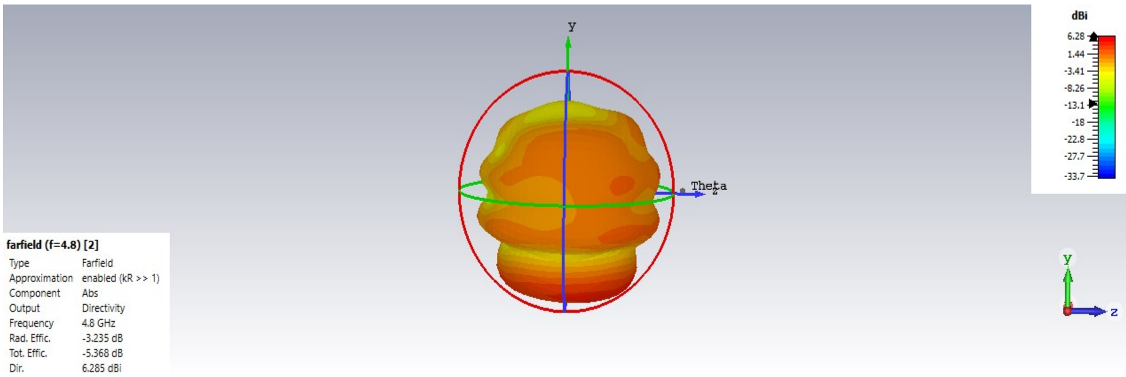
Figure 7. Farfield gain simulation: (a) for 3.4 GHz band and total efficiency of -1.537 dB, (b) for 3.4 GHz band and total efficiency of -1.539 dB, (c) for 3.4 GHz band and total efficiency of -1.538 dB



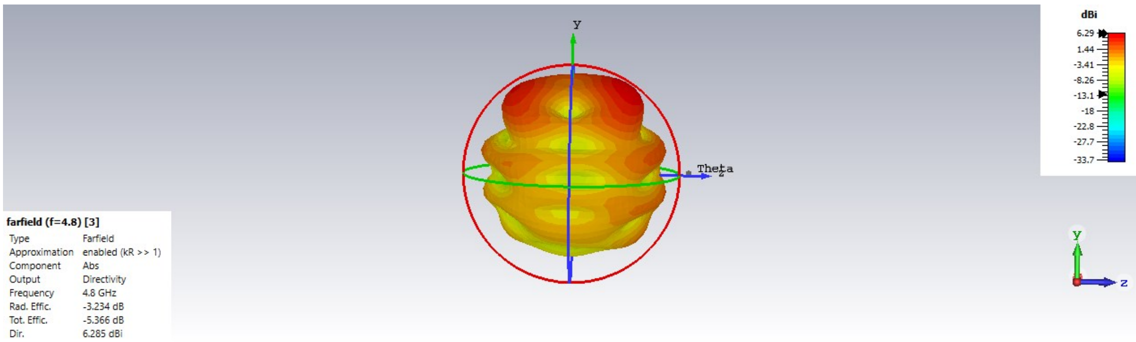
(d)



(e)

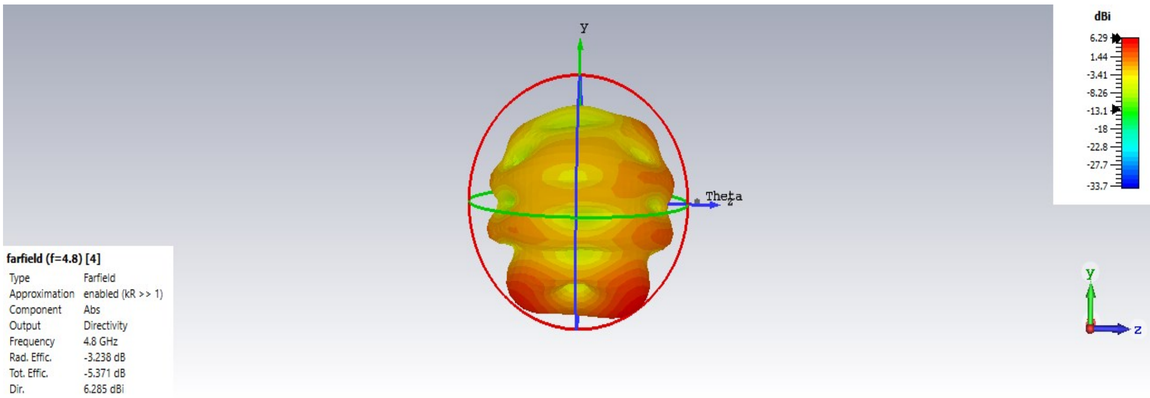


(f)



(g)

Figure 7. Farfield gain simulation, (d) for 3.4 GHz band and radiation efficiency of -0.8562 dB, (e) for 4.8 GHz band and total efficiency of -5.370 dB, (f). for 4.8 GHz band and total efficiency of -5.368 dB, (g) for 4.8 GHz band and total efficiency of -5.366 dB (continue)



(h)

Figure 7. Farfield gain simulation; (h) for 4.8 GHz band and total efficiency of -5.371 Db (continue)

ACKNOWLEDGEMENTS

This research work was funded by "Woosong University's Academic Research Funding - 2021".

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