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A Gain Enhancement of Rectangular Microstrip Patch Antenna, Utilizing Array Structures with Cooperate Feed Technique

Radhi Sehen Issa [1], Ammar Ali SAHRAB[2]

[1,2]Department of Electrical Engineering, College of Engineering (COE),

Mustansiriyah University, Baghdad, Iraq

Corresponding Author: Radhi Sehen Issa

ABSTRACT

The patch antennas are considered as widespread antennas that used in variety applications for their ability to cooperate, integrate with various devices, low weight, and low cost manufacturing. On the other hand, in contrast to these advantages, these antennas are lacked to their narrow bandwidth, low efficiency, and poor gain. The use of 60 GHz high frequencies bandwidth for indoor applications allow users to obtain a high data transfer speed of up to 1 Gbps, but at the expense of losses in this frequency band, which must be rationed as much as possible through the optimum design of antenna. In this article, a rectangular Microstrip Patch (MP) antenna will be simulated and improved to enhance the antenna gain and the other parameters for 1x4 and 1x8 array antennas configuration supported by the cooperate feed technique is practised to feed equal power for each array element. The proposed antennas designed by using the finite integration that is offered by the Computer Simulation Technology (CST) software. The obtained results for the simulated antennas are: 7.07dBi antenna gain with 1.5653GHz bandwidth for single element; 12.3dBi antenna gain with 1.7144GHz bandwidth for the 1x4 array configuration; and finally 15dBi antenna gain with 1.6335GHz bandwidth for the 1x8 array configuration.

Keywords:Patch antennas, Cooperate, Rectangular MP, Antenna Array, CST

1. INTRODUCTION

Over the last three decades, telecommunications had been grown at an exponential rate. Today, the quantity of data used by the end user devices is growing gradually. When studying the progression of wireless communications, this growth is more noticeable as the demand for faster data rates has raised, prompting researchers to look for new ways to increase data rates [1].

The currently utilized wireless mobile communications of the electromagnetic spectrum such as cellular, Wi-Fi, Bluetooth, and so on which works approximately at 0.5-6GHz, which is a little part of the spectrum and extremely congested because of the large amount of the applications that operated in such band. Moreover, with the numerous advancements in spectral efficiency, this is become a limited factor [2].

Developers and researchers are investigating other parts of the frequency spectrum that could be practised to improve the wireless technologies. One of these frequency bands is the licence-free 60GHz band. The aforementioned band was previously only employed for the limited requirements of point-to-point radio links such as the satellite-to-satellite communications and private applications. Now it is employed at the home to a number of short-range high-throughput wireless technologies such as the Wireless HD (also known as UltraGig) and the Wireless Gigabit Alliance (WiGig) [3].

WiGig enables several Gbps communication between the connected devices. The increased number of start-up communication companies by technology behemoths has given it significant commercial aid, while other smaller producers continue to emerge, allowing for a greater variety of communication devices to be suggested.

Many WiGig chipsets are already available for purchase on the internet, then many researches into WiGig systems has exploded in popularity in recent years [4].

In terms of performance and combination, the antenna is one of the most important segments of a wireless communications systems. Also, the designed antennas steelyard of price and performance can achieve a vaster development. Rain attenuation is unusual at the 60GHz band, and the power losses are meaningful. Further importantly, there is a peak in oxygen intake at this precise frequency. At the millimeter-wave frequencies, Figure 1 depicts atmospheric attenuation. As a result, WiGig is used for indoor requirements [5].

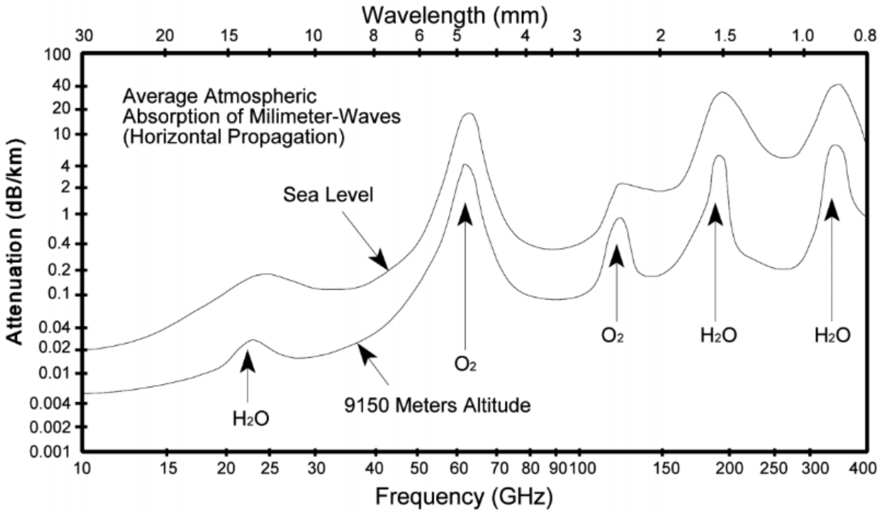


Figure 1. The atmospheric attenuation in the millimeter-waves

According to the countries rules, this licence-free band has a bandwidth of approximately about 9GHz. The 60 GHz band in North America are ranges at 57-64 GHz and differs from the other countries. The suitable antenna for these requirements, must had a reasonable bandwidth and cover the whole WiGig band. Short-range requirements function as point-to-point radio links, which necessitate a high degree of directivity and gain [6].

In this article, a rectangular Microstrip Patch (MP) will be simulated and improved for the WiGig (i.e. 60GHz) applications by using the Computer Simulation Technology (CST) software. The simulated antenna contains a copper patch, a substrate with a 2.2 dielectric constant, a fully copper ground plane, and is fed by an inset line feeding technique. Array structure with corporate feeding techniques are employed to improve the antenna parameters 1x4 and 1x8. The design of the array structures is done within the Antenna Magus simulation software that helps to develop the overall array structure and later export the whole structure to the CST for testing and optimization purposes.

2. RECTANGULAR MP ANTENNA

MP antennas (or utterly "patch" antenna) are a kind of antenna more useful and used because they can be printed immediately onto a substrate. In addition, they offer a benefit of being easily fabricated making them cost-effective. Their small profile design, which is often square or rectangular, permits them to be installed on flat surfaces [7]. The general structure of the rectangular MP antenna contains a copper radiated patch, insulating material often called substrate, ground plane, and feed line, as shown in Figure 2.

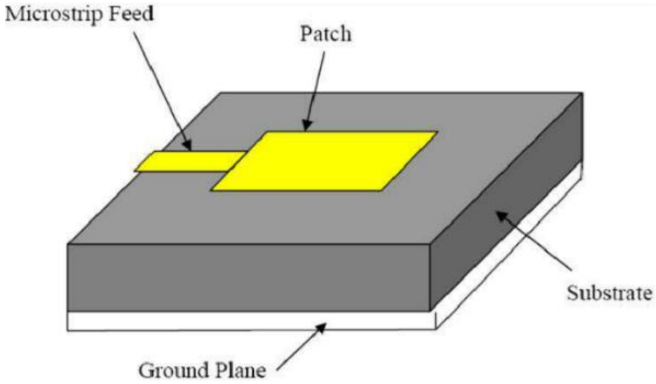


Figure 2. Structure of rectangular MP antenna

3. ANTENNA ARRAY

In order to improve the overall antenna performance, The MP antenna array is utilised which one of the common and popularly known usable antennas structure. The MP antenna array is made up of several separated patch elements combined through, a simple feeding network printed on the substrate, and a ground plane printed on the bottom of the substrate. The MP antenna array has similarly eligible designations as the ordinary MP antenna element such as small size, lightweight, and low cost of manufacturing [8].

4. MP ANTENNA DESIGN AND SIMULATION

In this paper, special simulation software was used called "Antenna Magus" that helps in designing the antenna completely without the need to use mathematical equations. This program can provide the antenna structure only by entering three basic parameters, these are the operating frequency (f_r), the thickness of the dielectric substrate (h), and the dielectric constant of the substrate (ε_r). Then the antenna structure is exported to the CST software for antenna testing and optimization to enhance its performance. In order to test the validity and accuracy of the antenna dimensions obtained from the program, the following set of equations were used, which confirmed the validity of the dimensions [9]:

$$W_p = \frac{c_o}{2f_r\sqrt{\frac{(\varepsilon_r+1)}{2}}}) \quad (1)$$

$$\varepsilon_{r.eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1 + 12\frac{h}{W}\right]^{\frac{-1}{2}}) \quad (2)$$

$$\Delta L = 0.412h\frac{(\varepsilon_{reff}+0.3)\left[\frac{W_p}{h}+0.264\right]}{(\varepsilon_{r.eff}-0.258)\left[\frac{W}{h}+0.8\right]}) \quad (3)$$

$$L_{.eff=}\frac{c}{2f_r\sqrt{\varepsilon_{r.eff}}}) \quad (4)$$

$$L_p = L_{.eff} - 2\Delta L) \quad (5)$$

$$W_{sub} = 2 \times W) \quad (6)$$

$$L_{sub} = 2 \times L) \quad (7)$$

Where W_p is the width of the patch, $\varepsilon_{r.eff}$ is the effective relative permittivity, ΔL is the length expansion, $L._{eff}$ is the effective length of the patch, L_p is the width of the patch, W_{sub} is the width of the substrate, L_{sub} is the length of the substrate, and c_o is the light speed.

In order to facilitate the manufacturing process, obtain the exact return loss value at 60GHz, and improve the gain the optimization process is applied by trial and error mechanism on the antenna dimensions. Table 1 and Figure 3, respectively, illustrates the dimensions of the single rectangular MP antenna and the exported single rectangular MP antenna in the CST software.

Table 1. Single rectangular MP antenna dimensions

Description	Value (mm)	Optimized (mm)
Patch Width (W_p)	1.97505623	2.01
Patch Length (L_p)	1.63014807	1.623
Substrate Width (W_{sub})	3.95011246	4.02
Substrate Length (L_{sub})	3.26029614	3.246
Feed Width (W_f)	0.30811734	0.303
Feed Length (L_f)	1.82632978	1.82
Feed-Patch-Spacing (g)	0.04301480	0.05
Feed inset (f)	0.55641348	0.49

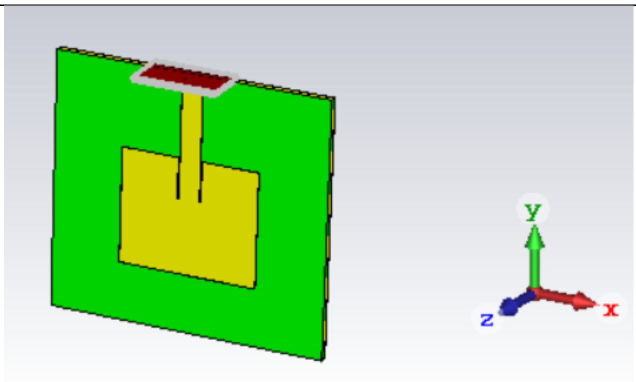


Figure 3. Simulated rectangular MP antenna with ε_r=2.2 and h=0.1mm in CST

5. MP ANTENNA ARRAY SIMULATION

The MP antennas could be practised as individual antennas or as array elements. Through practising the array structures in the wireless communication tools, the overall antenna performance is enhanced such as improving the gain, directivity, efficiency and bandwidth [10]. The rectangular MP antenna array is designed and simulated by using the "Antenna Magus" software by entering the number of the elements, h, ϵ_r and f_r. In order to obtain the optimum performance and improve the designed array the cooperate feed technique is used. In this approach of feeding the supplied power from the feeding port is divided equally to each element in the array structure. Consequently, it contributes a better directivity, the efficiency of the radiation and diminish the beam variations beyond a frequency bands as contrast with the chain feeding. In this paper, two approaches of the rectangular MP antenna arrays are designed and simulated, as presented in Figures 4 and 5.

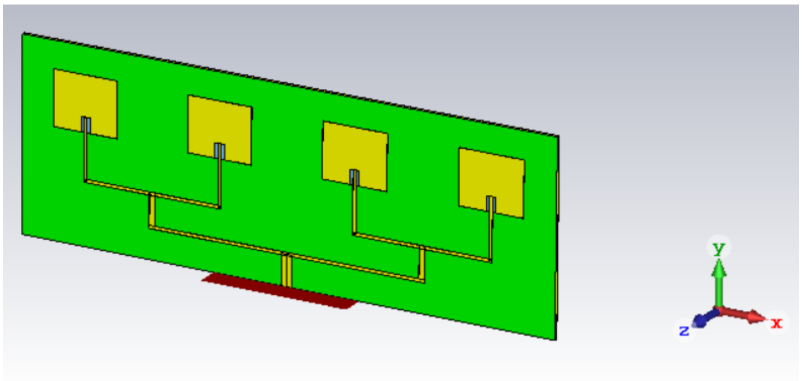


Figure 4. Simulated 1x4 rectangular MP antenna array

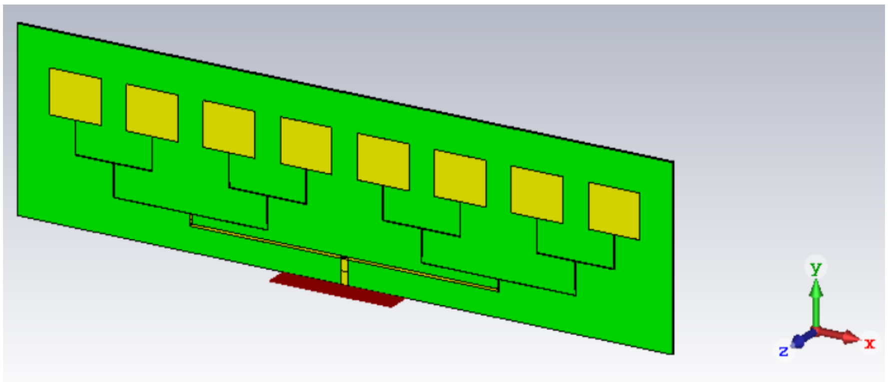


Figure 5. Simulated 1x8 rectangular MP antenna array

For antenna arrays, the spacing distance between the adjacent elements should be selected in a definite manner. Where the large distance leads to the presence of the grating lobes that waste the useful power. While the smaller distance leads to a broader beamwidth which is unacceptable in the popular applications. In addition, the small distance reduces the expense and the volume of the feeding network. (Therefore, the distance separating the elements must be chosen properly, which is usually selected to be about λ/2 [11], [12]. Figure 6 presents the structure for the cooperate feed that used for feeding the proposed array structures and Table 2 demonstrate the dimensions of the simulated rectangular MP structures.

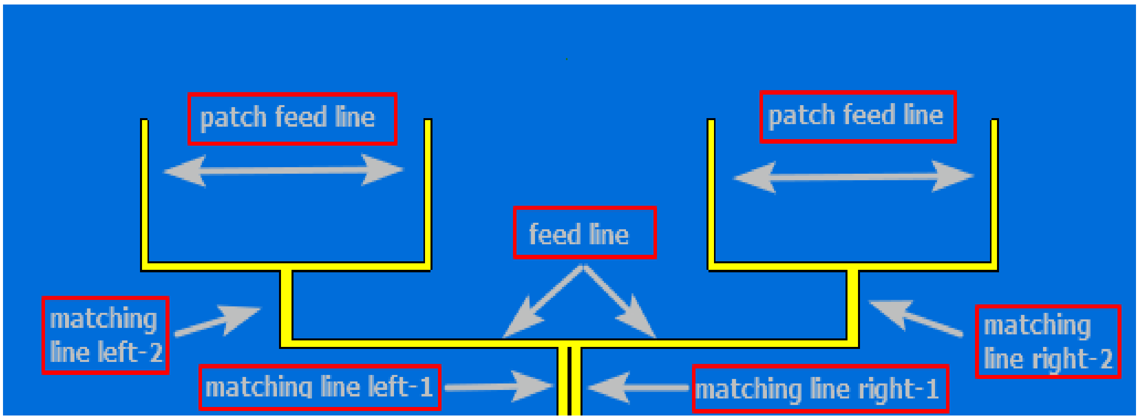


Figure 6. Structure for the corporate [13]

Table 2. Dimensions of the simulated MP antenna array designs

Parameter	1x4 Design Dimensions (mm)	1x8 Design Dimensions (mm)
Substrate Width	15.791	32.812
Substrate length	5.586	8.775
Patch Width	1.9	2
Patch length	1.604	1.6
Patch Spacing	3.997	4.213
Patch Feed Line Width	0.09	0.01
Patch Feed Line Length	1.77	1.16
Matching Line Left#1 Width	0.15	0.31
Matching line Left#1 length	0.91	0.91
Matching Line Left#2 Width	0.18	0.01

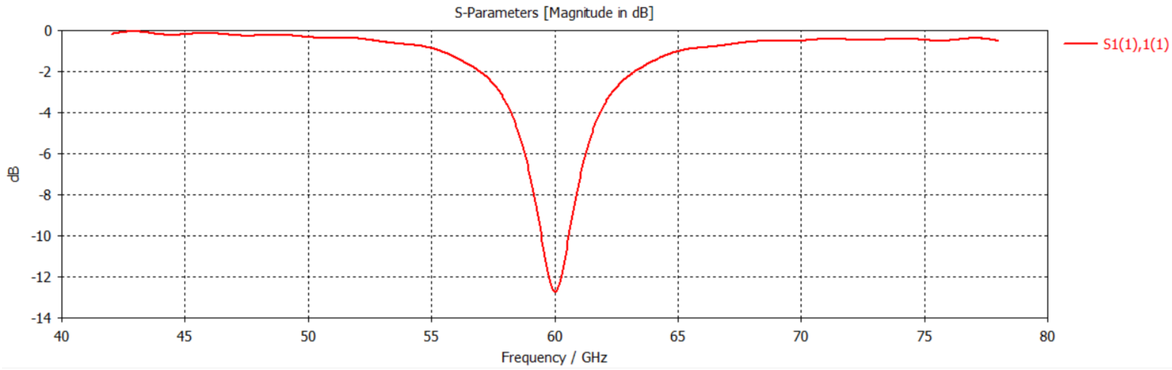
Matching line left#2 Length	0.92	0.921
Matching line right#1 width	0.15	Merged with Matching line Left#1
Matching line right#1 length	0.91	
Matching line right#2 width	0.18	0.01
Matching line right#2 length	0.92	0.983
Feed line width	0.09	0.09
Feed line length	8.17	12.08

6. SIMULATION RESULTS AND DISCUSSION

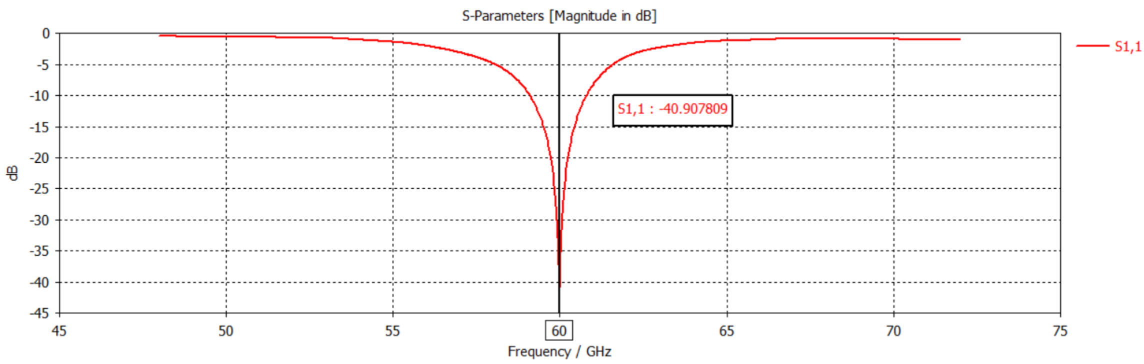
This part of the paper illustrates the results of the simulated antennas like gain, return loss and bandwidth after completed the simulation process.

6.1. Return Loss

The simulation results for the return loss S_{11} at 60GHz of the single rectangular MP antenna from CST software is -12.5dB, -40.9dB for the 1x4 rectangular MP antenna array and -18.7 for the 1x8 rectangular MP antenna array, as presented in Figure 7.



(a)



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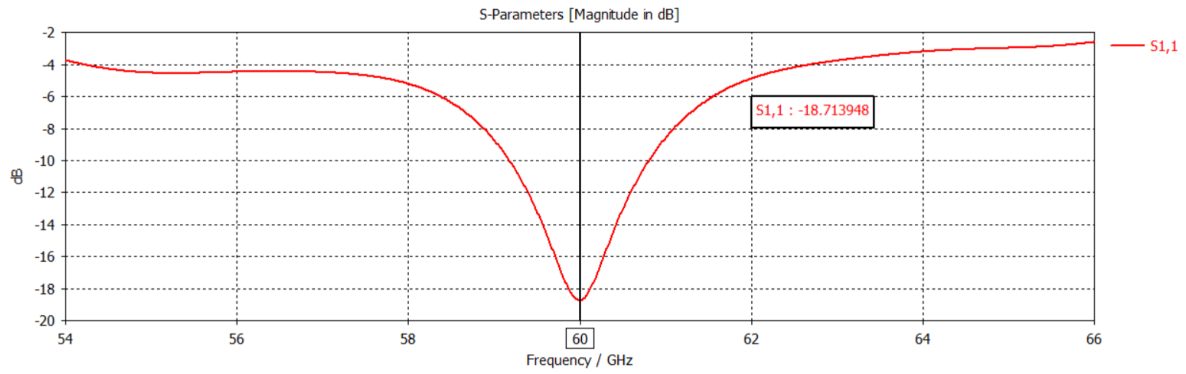
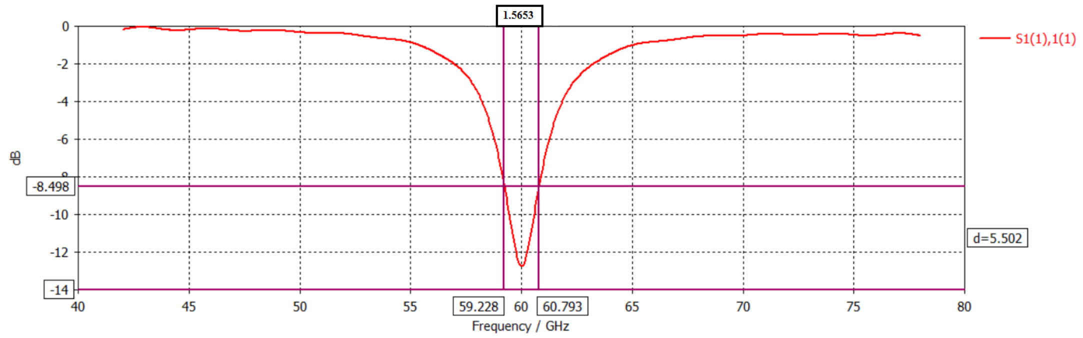


(c)

Figure 7. The S_{11} results for the simulated antennas (a) S_{11} for the single element, (b) S_{11} for 1x4 rectangular MP antenna array and (c) S_{11} for 1x8 rectangular MP antenna array

6.2. Bandwidth Results

The bandwidth of the antenna is the range over which the antenna is operated properly. The bandwidth of the proposed antenna can be estimated from the S_{11} pattern [14]. The bandwidth in the centre frequency of 60GHz of single element is found to be 1.5653GHz, 1.7144GHz for the 1x4 rectangular MP antenna array and 1.6335GHz for the 1x8 rectangular MP antenna array, as shown in Figure 8.



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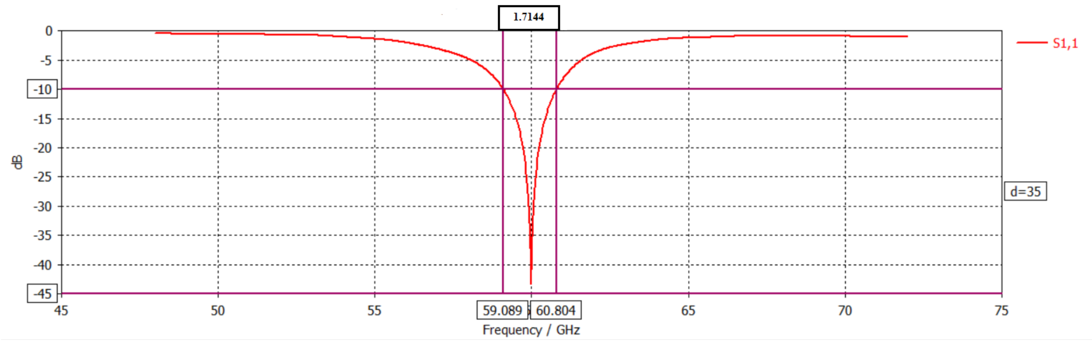

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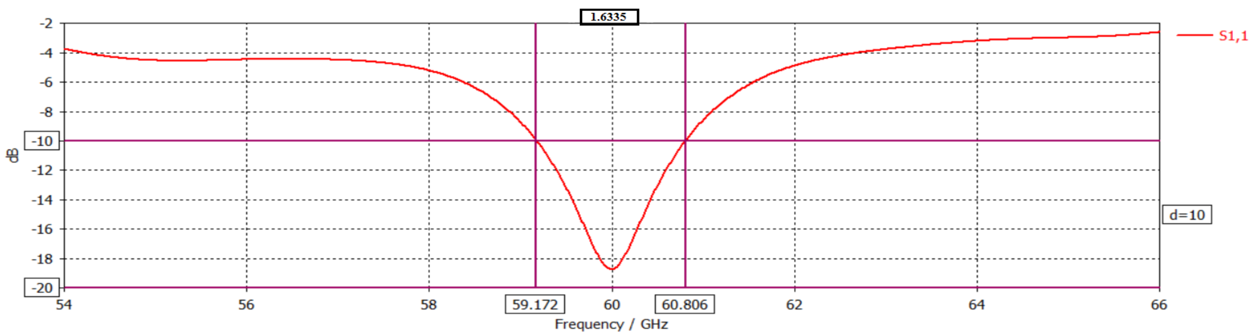

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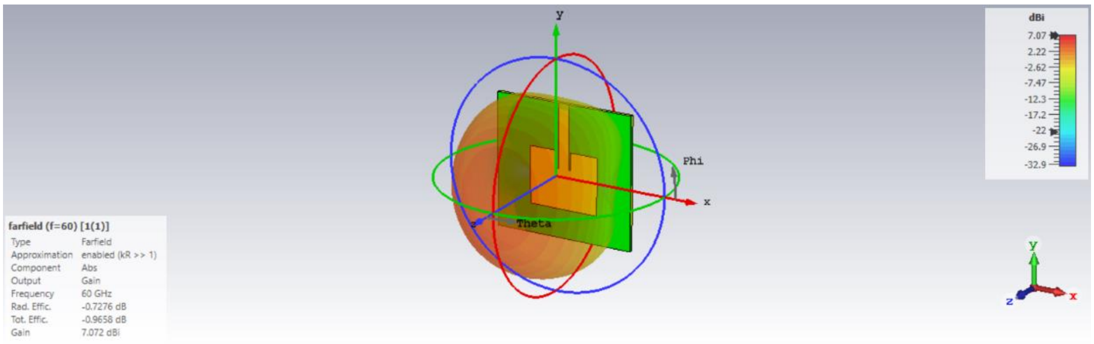
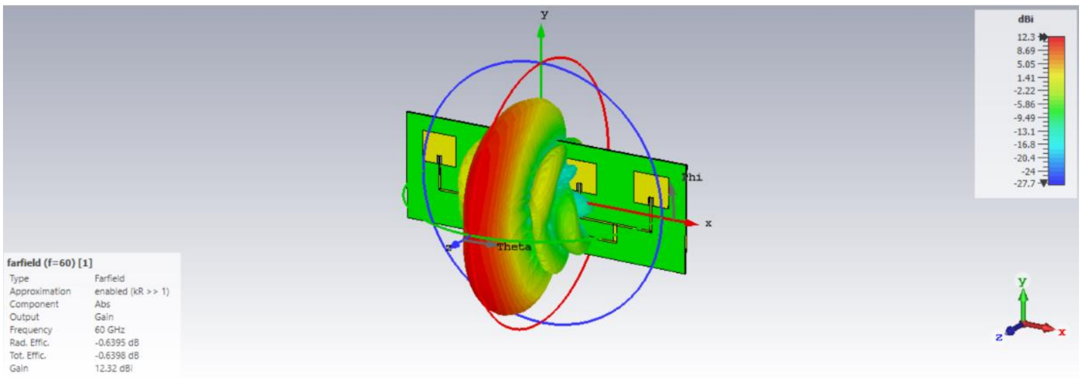
Figure 8. The bandwidth results for the simulated antennas (a) Bandwidth for the single element, (b) Bandwidth for 1x4 rectangular MP antenna array and (c) Bandwidth for 1x8 rectangular MP antenna array

6.3. Antenna Gain

In general, the MP antennas are a needy gain because they are influenced by the substrate altitude and dielectric constant [15]. The determined gain at the centre frequency of 60 GHz for single element is close to 7.07dBi, 12.7dBi for the 1x4 rectangular MP antenna array and 15dBi for the 1x8 rectangular MP antenna array, as presented in Figure 9.



(a)



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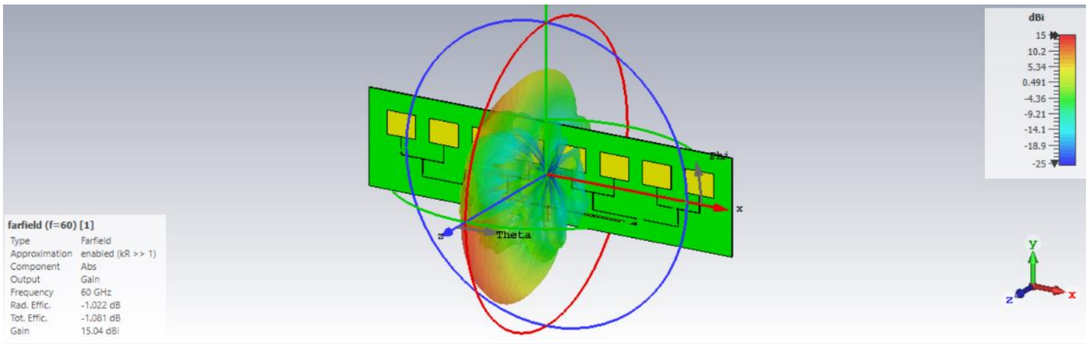

(c)

Figure 9. The gain results for the simulated antennas (a) gain for the single element, (b) gain for 1x4 rectangular MP antenna array and (c) gain for 1x8 rectangular MP antenna array

7. CONCLUSION

In this paper, a rectangular MP antenna has been simulated and optimized for 60 GHz applications. To consolidate the simulated single element gain and the different other parameters a 1x4, as well as 1x8 array antenna configuration supported by the cooperate feed technique, has been introduced. The simulated antennas approach was designed by using the finite integration that is offered by the CST software. The obtained results for the simulated antennas were 7.07dBi antenna gain and 1.5653GHz bandwidth for single element; 12.3dBi antenna gain and 1.7144GHz bandwidth for the 1x4 array configuration; finally 15dBi antenna gain and 1.6335GHz bandwidth for the 1x8 array configuration with a return loss $< -10\ dB$.

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