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| RESEARCH ARTICLE

Compact and Efficient Monopole Antenna Design and Simulation for Wireless and Bluetooth Applications

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| ABSTRACT
Monopole antennas have a very widespread use today. They are used by radios, base stations, radar systems, satellite communication systems, mobile phones, wireless communication networks and Bluetooths. In this study, a monopole antenna design and simulation operating at a frequency of 2.4 GHz, with compact dimensions of 31 mm in length and 1.5 mm in diameter and a high efficiency of 75% was carried out. The designed antenna has a bandwidth of 230 MHz. The peak gain of the antenna is 3.25 dBi. The design and simulation of the monopole antenna were carried out using CST Studio software. The S1,1 reflection coefficient simulation, bandwidth simulation, 3D gain simulation, H field simulation, E field simulation, total gain simulation and Z impedance simulation of the monopole antenna were carried out. The simulations performed proved that the monopole antenna works successfully.

| KEYWORDS
Wi-Fi, Wireless LAN, Bluetooth, Monopole Antenna, Bandwidth, Antenna Efficiency, Radio Frequency, FR4 Substrate, Antenna Radiation Patterns, Antenna Design

| ARTICLE INFORMATION
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1. Introduction
Antennas are used in wireless communication, broadcasting, navigation, military and space vehicles [1], [2]. In telecommunications, monopole antennas are vertical antennas [3]. There are four main antennas according to their working types. These are dipole antennas, monopole antennas, array antennas and aperture antennas.

Dipole antenna is the simplest type of antenna [4]. It is widely used in amateur radio and television broadcasting [5]. Its cost is low. Its performance can be affected by surrounding structures and objects [6]. Its bandwidth is limited and it is not suitable for applications requiring wide frequencies. Its size is large [7].

Monopole antennas are used in radios, mobile phones, base stations, vehicle-mounted systems, Wireless LAN and RFID systems [8], [9]. Monopole antennas are also widely used in unmanned aerial vehicles [10], [11], [12]. The advantages of monopole antennas are their compact size, ease of installation, omnidirectional coverage and low profile [13]. Their disadvantages are their dependence on the ground plane, limited bandwidth and being affected by surrounding structures [14].

Array antennas are used in radar systems, satellite communications, wireless communication networks and astronomical observations [15], [16]. High directionality, enhanced gain, adaptability to different signal environments and electronic beam steering are the advantages of array antennas [17]. Complex design and construction, high cost and large size are the disadvantages of array antennas [18].

Aperture antennas work by directing radio waves through an aperture [19]. They are used in satellite communications, radio astronomy, deep space communications, and radar systems [20]. High Directionality, high gain and frequency versatility are the advantages of aperture antennas [21]. Disadvantages of aperture antennas are their large and heavy structure, wind sensitivity and complex alignment [22], [23].

Easy production, cheap price, less weight, low profile and combination with other devices are the features that make monopole antennas stand out among the 4 main antenna types. Monopole antennas are omni-type antennas, meaning that they broadcast equally in all directions on the horizontal plane [24]. Depending on the reflective properties of the soil, antenna gains can be twice that of a dipole antenna (3 dB in decibels). On the other hand, monopole antennas cannot broadcast to the top or bottom point. Monopole antennas were first developed by Guglielmo Marconi in 1895 [25]. Marconi invented radio and the wireless telegraph machine with the monopole antenna he developed [26]. Today, monopole antennas are used in broadcasting, mobile phones, Wi-Fi routers and Bluetooth devices, as well as radio communication [27].

Saad et al. developed a monopole antenna with cotton fabric material for wearable communication systems. The operating frequency of their antenna was 2.45 GHz [28]. Bai et al. developed a triple band monopole antenna for long range Internet of Things (IoT) applications. They designed the proposed antenna with CST software 2019 and used FR-4 material as substrate. The frequency bands of the designed antenna were 433 MHz, 868 MHz, and 915 MHz. The antenna had a gain of 2 dBi, 1.9 dBi, and 1.9 dBi at 433 MHz, 868 MHz, and 915 MHz, respectively [29]. Park et al. developed an ultra-wide band monopole antenna based on the FR4 substrate for an indoor positioning system. Their proposed antenna was operating between 3.1 GHz and 10.8 GHz frequencies [30]. Ahmad et al. designed an ultra-wide band monopole antenna for short-range wireless communication. They fabricated their antenna based on a low-cost FR4 substrate [31]. Islam et al. proposed a low-profile monopole antenna for biomedical applications. They used the flexible polyimide substrate. The operation range of their proposed antenna was between 7 GHz and 14 GHz [32]. Martinez-Lozano et al. developed an ultra-wide band printed monopole antenna for medical imaging. The working frequency of their antenna was between 2.7 GHz and 11.4 GHz. They used a low-cost FR4 material for antenna substrate [33]. Al-Hadeethi et al. worked on a reconfigurable monopole antenna. They used the Taconic RF-43 substrate for fabrication. In their work, they aimed to design an antenna for 5G applications. Their antenna's operating frequency was 5.85 GHz [34]. Wang et al. developed a frequency and polarization reconfigurable antenna. They used liquid metal to achieve frequency reconfigurability [35].

In this study, the design and simulation of a monopole antenna operating at 2.4 GHz frequency for Wi-Fi and Bluetooth applications was carried out. A monopole antenna with a compact structure of 31.23 mm in length and 1.5 mm in diameter was designed. The antenna is suitable for use in wireless communication applications and Bluetooth devices thanks to its compact dimensions. The designed antenna has a high efficiency of 75%. It has a peak gain of 3.25 dBi. The design and simulation of the antenna were carried out with CST software. The S1,1 reflection coefficient simulation, bandwidth simulation, 3D gain simulation, H field simulation, E field simulation, total gain simulation and Z impedance simulation were performed. The simulation results show that the antenna operates successfully in the specified frequency range.

2. Monopole Antenna Design

In this study, a quarter wavelength monopole antenna is used. The quarter wave monopole antenna is the most common type, where the wavelength of the radio waves is 1/4. The schematic diagram of a quarter wavelength monopole antenna is given in Figure 1. In Figure 1, I indicates the direction of the current. λ indicates the wavelength, and λ/4 indicates the length of the antenna.

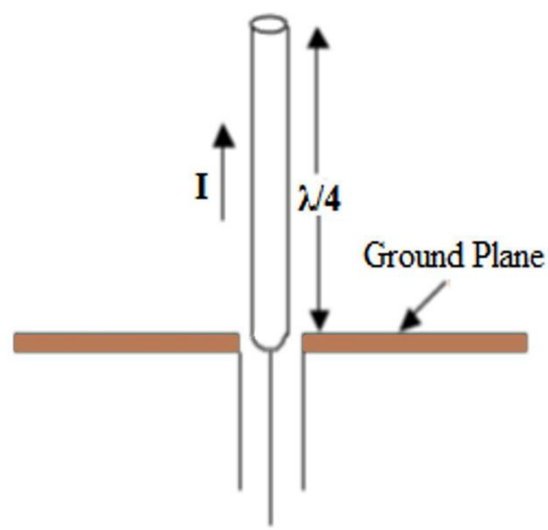

Figure 1: Quarter wavelength monopole antenna schematic diagram

Table 1 shows the parameters used in antenna design. In Table 1, Z_i indicates the input impedance, l indicates the length of the monopole antenna, and R indicates the diameter of the monopole antenna. X, Y, Z indicate the dimensions of the ground plane.

Table 1: Parameters of the monopole antenna

Parameter	Value
Z_i	36.5 Ω
L	31.23 mm
R	1.5 mm
X	50 mm
Y	50 mm
Z	1.9 mm

The antenna input impedance Z_i is calculated according to equation (1). The antenna input impedance Z is calculated according to equation (1). In equation (1), V is voltage and I is current.

$$Z_i = \frac{V}{R} \quad (1)$$

Total efficiency of the designed antenna is calculated according to the equation (2). In equation (2), T_e is the total efficiency and x is gain in dB.

$$T_e = \left(10^{\frac{x}{10}}\right)x100 \quad (2)$$

The design of the monopole antenna was carried out using CST Studio Suite. Figure 2 shows the 3D view of the monopole antenna designed with CST Studio Suite.

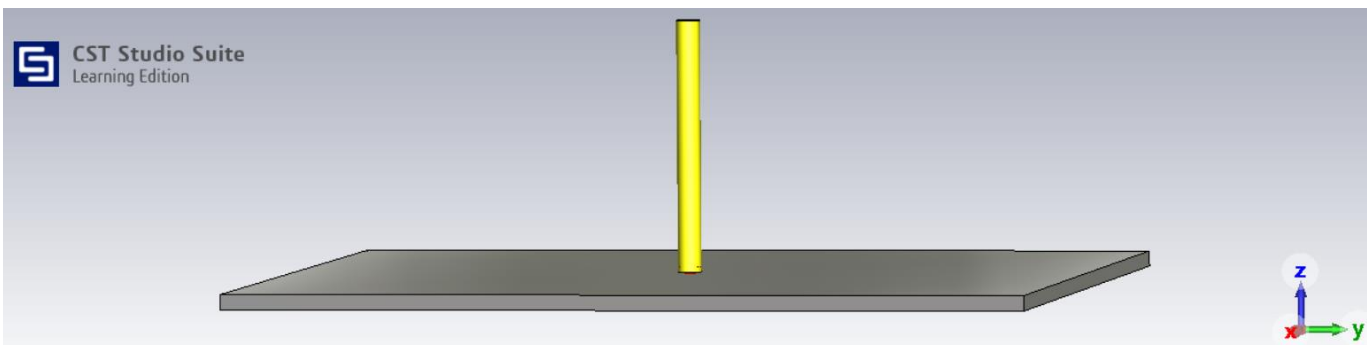

Figure 2: Monopole antenna design

Cylindrical monopole antenna FR4 material was used as substrate. Moisture resistance, wide operating temperature range, mechanical hardness, flame retardancy, insulation properties and low cost are the advantages of FR4 [36], [37]. Perfect Electric Conductor (PEC) is used as ground plane material. Electrical conductivity of PEC material is assumed to be infinite.

3. Simulations

In the simulations section, S1,1 reflection coefficient simulation, bandwidth simulation, 3D antenna gain simulation, H field simulation, E field simulation, total efficiency simulation and Z impedance simulation of the designed monopole antenna were carried out. Figure 3 shows the S1,1 reflection coefficient simulation.

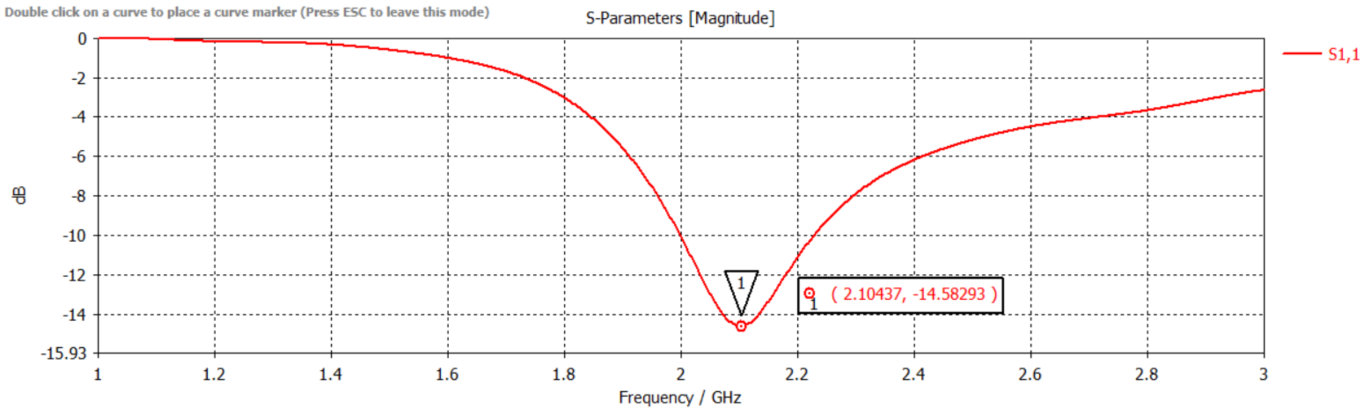

Figure 3: S1,1 simulation of the monopole antenna

Figure 4 shows the bandwidth simulation of the designed monopole antenna. The bandwidth is calculated by the difference between the f1 and f2 frequencies of the antenna at -10 dB. The bandwidth of the monopole antenna is 0.23 GHz, i.e. 230 MHz.

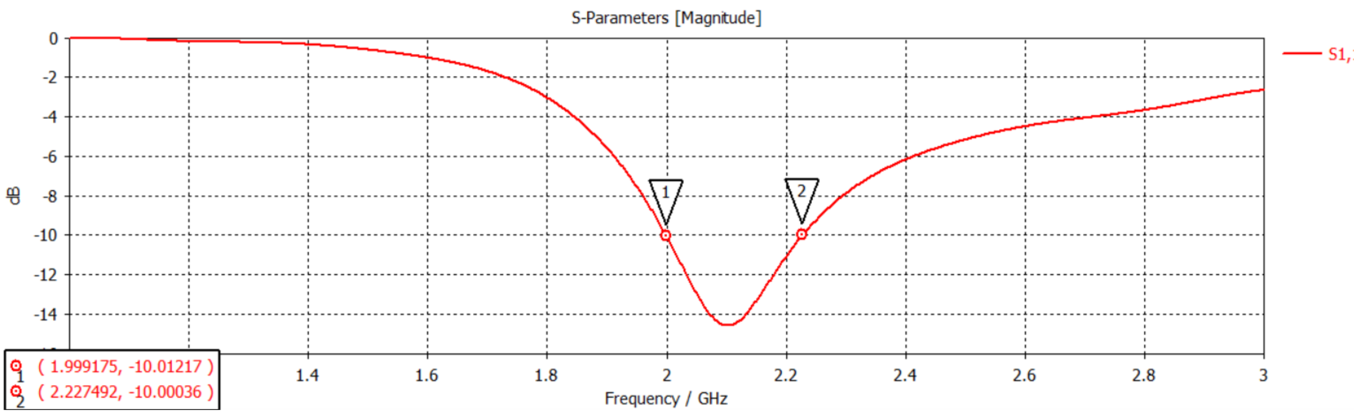

Figure 4: Bandwidth of the designed monopole antenna

Figure 5 shows the 3D gain simulation of the antenna. When the total efficiency of the antenna is calculated according to the equation (2), the total efficiency is found to be 75%. A high efficiency antenna design was obtained. The peak gain of the antenna is 3.25 dBi.

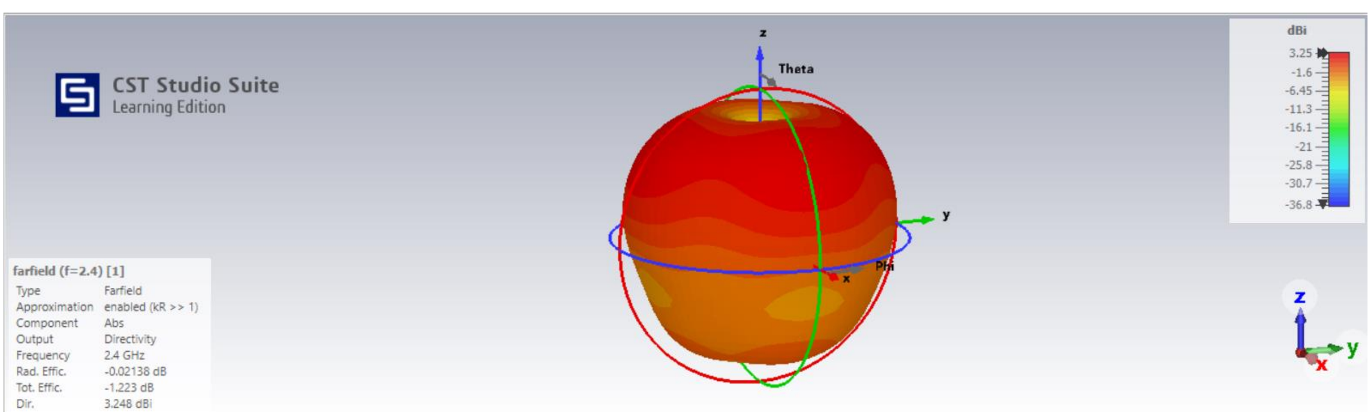

Figure 5: 3D gain front view of the monopole antenna

Figure 6 shows the top view of the 3D antenna gain simulation.

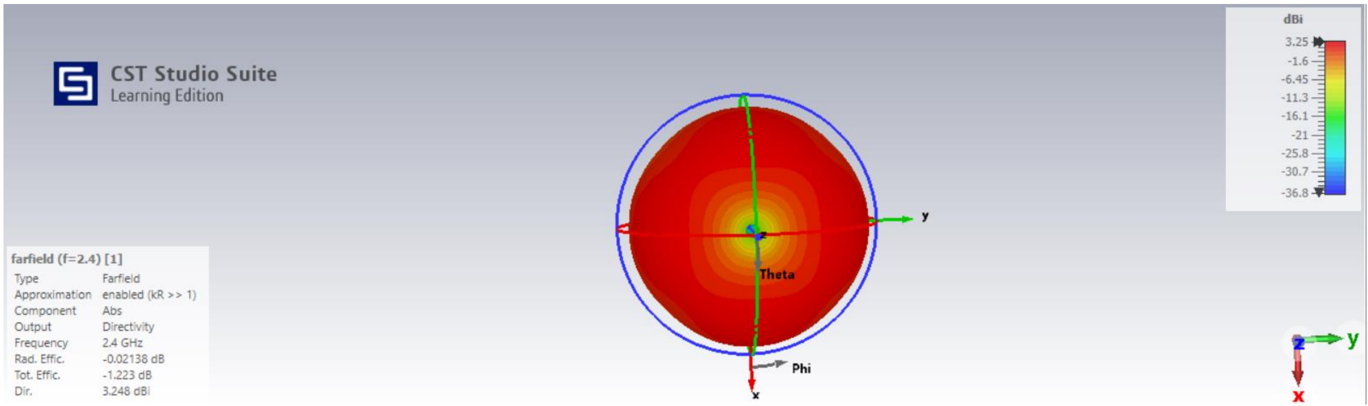

Figure 6: 3D gain top view of the monopole antenna

Figure 7 represents the bottom view of the 3D antenna gain simulation.

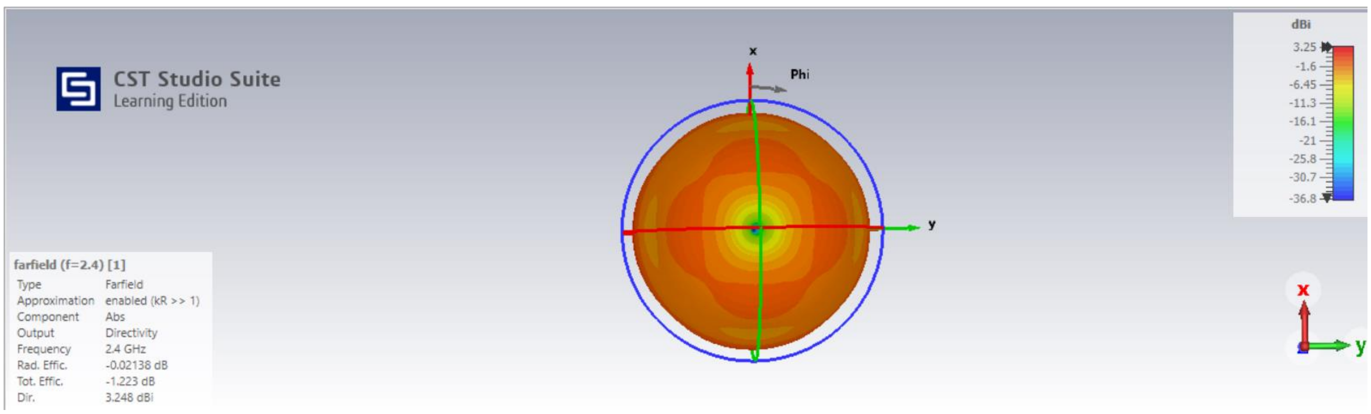

Figure 7: 3D gain bottom view of the monopole antenna

Figure 8 shows the transparent 3D antenna gain simulation.

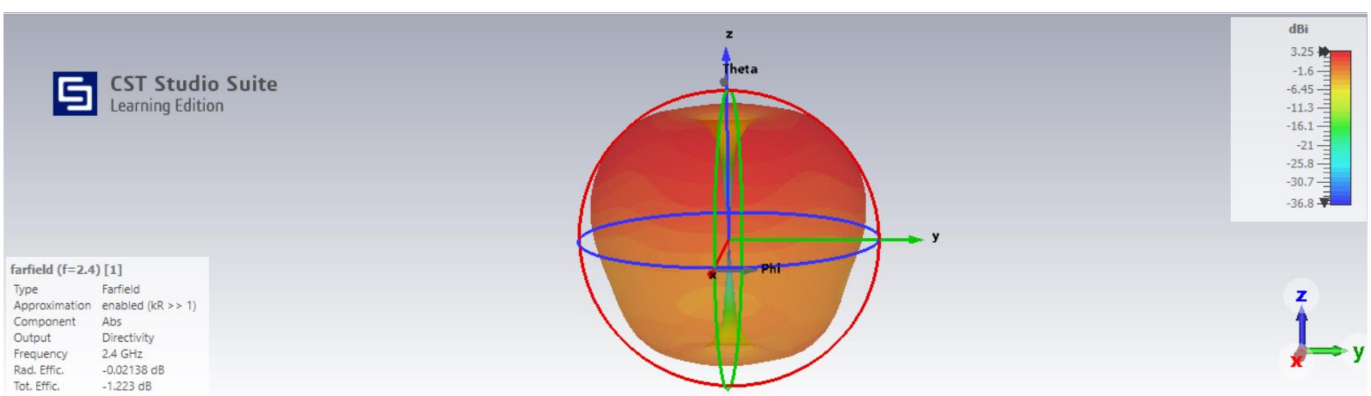

Figure 8: 3D gain transparent view of the monopole antenna

Figure 9 presents the H field simulation of the antenna. The H field represents the magnetic field. The H field is in Amps/Meter (A/m).

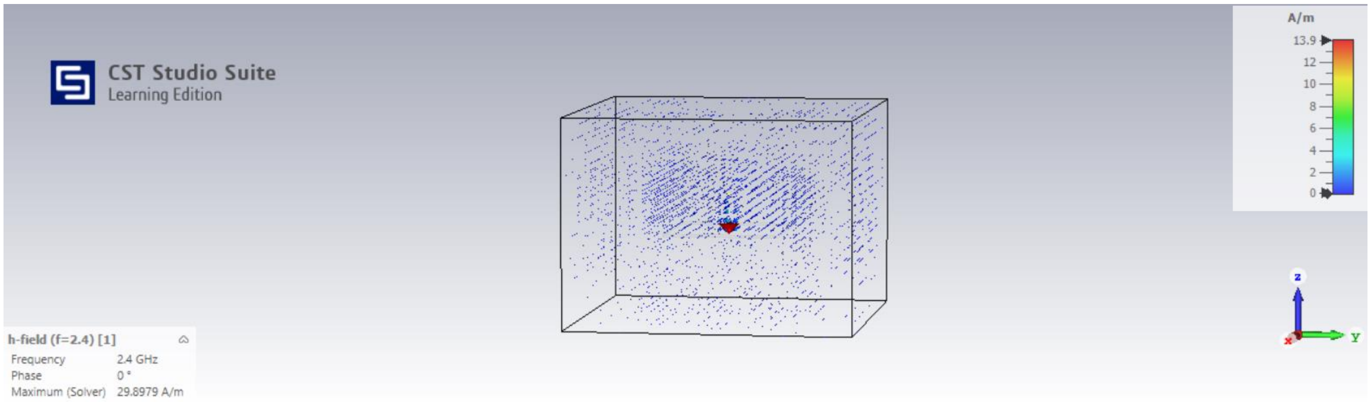

Figure 9: H field of the monopole antenna

Nearest axis H plane is represented in Figure 10. The direction of the H field is clearer in Figure 10.

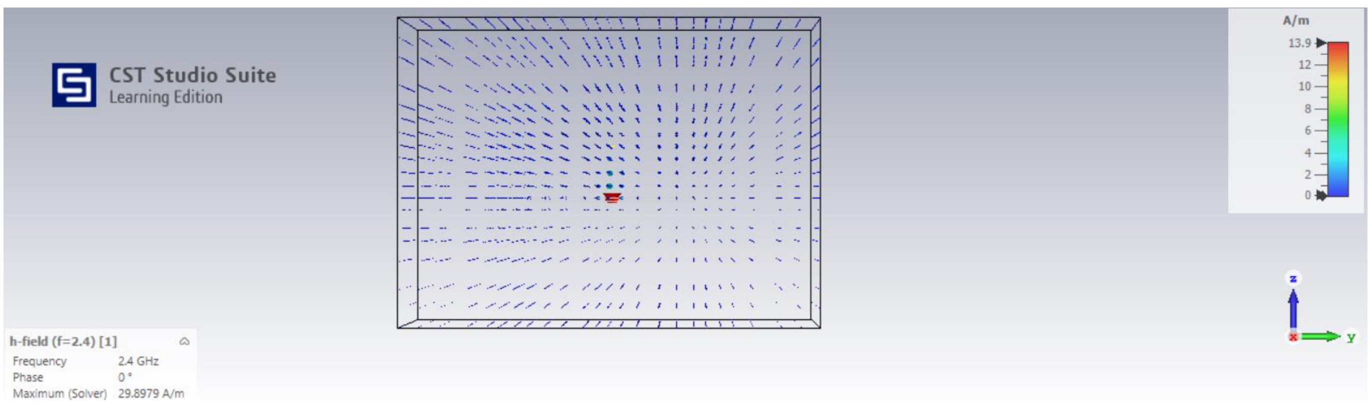

Figure 10: Nearest axis H plane of the monopole antenna

Figure 11 shows the E field simulation of the designed monopole antenna. The E field represents the electric field. The H field and the E field are perpendicular to each other.

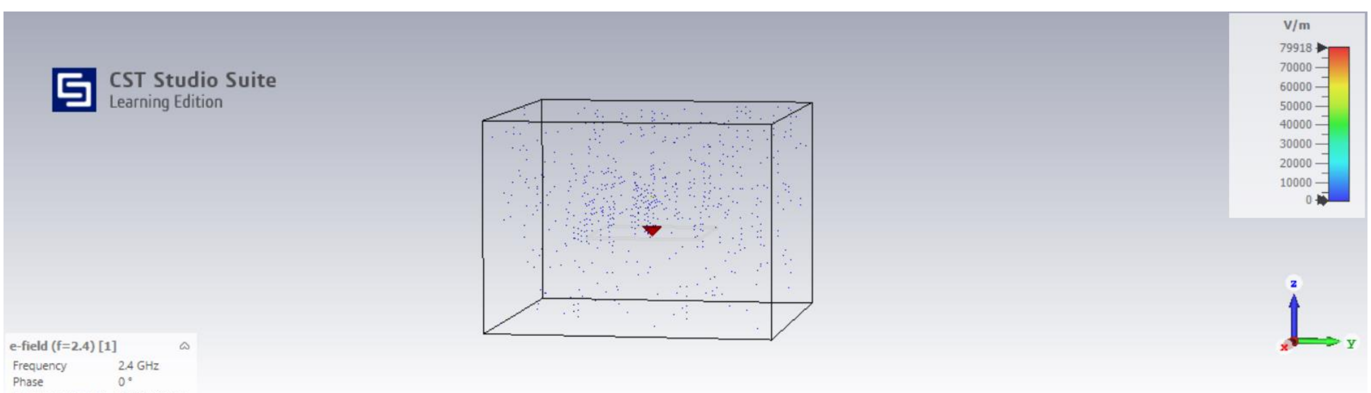

Figure 11: E field of the monopole antenna

Figure 12 presents the nearest axis E field of the designed monopole antenna. Figure 12 shows the direction of the E field more clearer than the Figure 11.

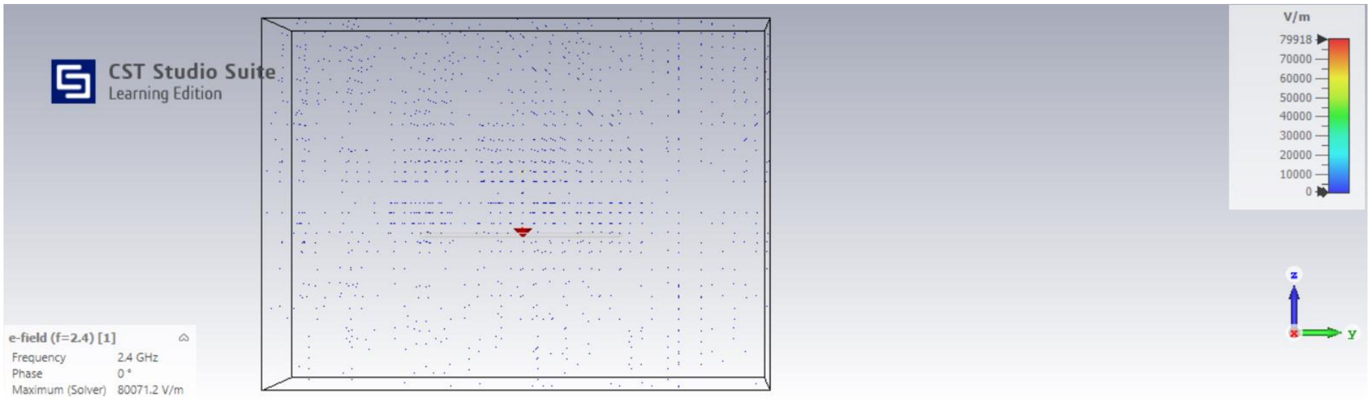

Figure 12: Nearest axis E field of the monopole antenna

Figure 13 shows the total efficiency of the designed monopole antenna in dB. When the total efficiency in dB is converted to % according to equation (2), there is a total efficiency of 75%.

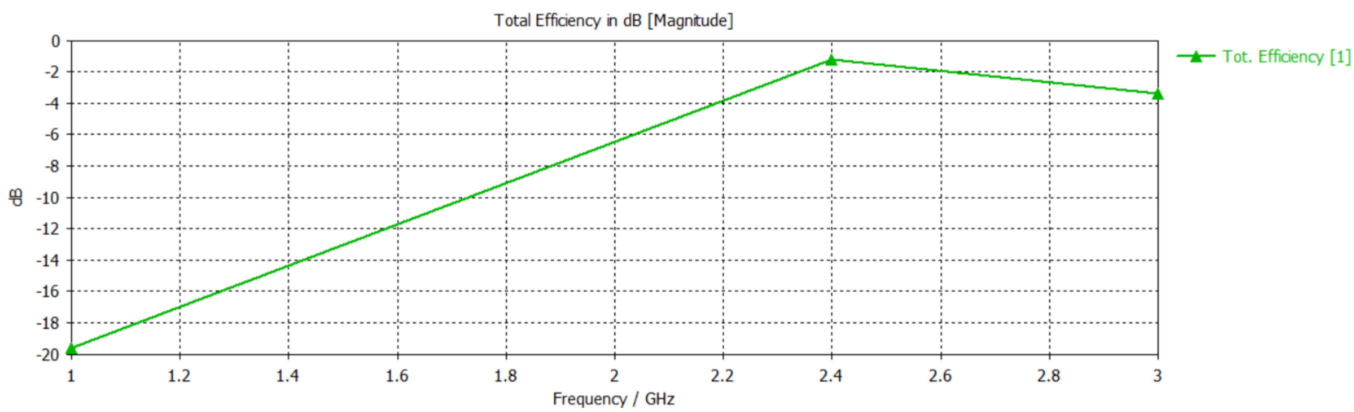

Figure 13: Total efficiency of the monopole antenna

Figure 14 shows the Z impedance simulation of the designed monopole antenna. In the simulation, the Z impedance appears as 36.5 Ohm. The obtained result is the same as the Zinput impedance, which was the initially determined design target.

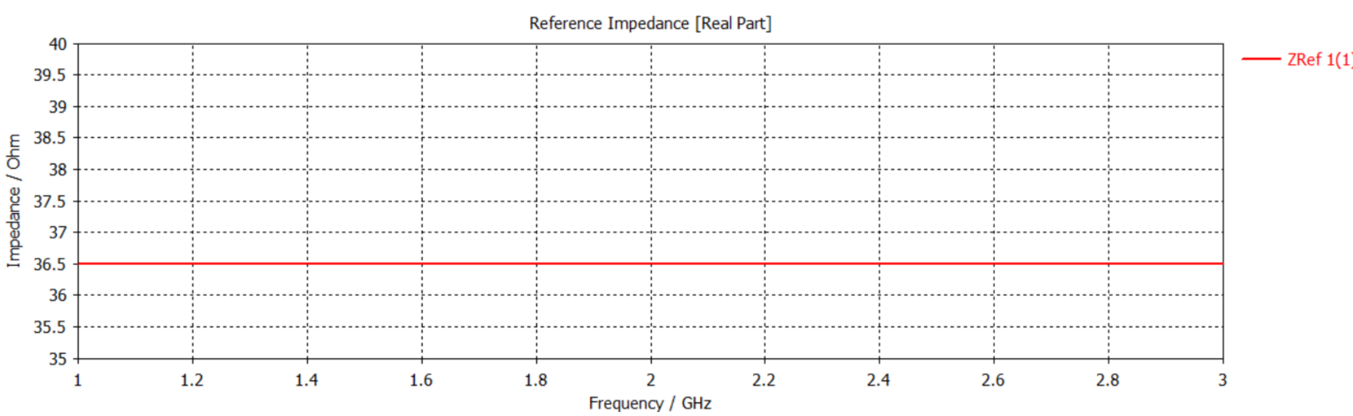

Figure 14: Z impedance of the monopole antenna

4. Conclusion

In this study, a compact and high efficiency monopole antenna design of 31 mm length operating at 2.4 GHz frequency for Wi-Fi and Bluetooth applications was realized. First of all, the application areas and working principle of a monopole antenna were explained. Then, the design and simulations of a monopole antenna were performed with the CST Studio program. FR-4 material was used in the design of the antenna. PEC was used in the design of the ground plane. S1,1 reflection coefficient simulation, bandwidth simulation, 3D gain simulation, H field simulation, E field simulation, total efficiency simulation, and Z impedance simulation were performed. The designed antenna has been shown to be 75% efficient and has a peak gain of 3.25 dBi. Simulations have proven that the designed monopole antenna works successfully.

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