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Proximity-Coupled-Fed Logo Antenna Design Operating in the C Band

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Abstract – Logo antennas are extensively utilized in various fields, and in this era where aesthetics, advertising, and recognition are important as well as functionality, the demand for such antennas is also on the rise. In this study, a logo antenna with the emblem of Aydın Adnan Menderes University operating in the C band (4.87 GHz) was designed and examined for use in wireless communication. In the antenna design, two FR4 layers with a thickness of 1.6 mm and an epsilon value of (4.3) were utilized, and the proximity-coupled feeding method, which is one of the non-conducting feeding types, was preferred for the antenna. The antenna was designed using the CST Microwave Studio program, and in the simulations, bandwidth, S11, gain, and radiation pattern were analyzed. The antenna dimensions showing the best performance were determined by performing parametric sweeps. As a result of simulation studies, the bandwidths of the designed antenna for |S11|<-10dB and |S11|<-6 dB return loss values were found to be 241 MHz and 483 MHz, respectively. The maximum gain of the antenna was found to be 4,567 dBi, and the VSWR value was found to be 1.45.

Keywords *– Logo antenna, Proximity-coupled feeding, Radiation pattern, Return loss, Bandwidth*

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I. INTRODUCTION

Antennas are the most crucial components of wireless communication systems, converting electrical signals into electromagnetic waves and electromagnetic waves into electronic signals. Beyond wireless communication systems, antennas are extensively utilized in various application areas, including RFID systems, radar systems, the defense industry, sensor systems, biomedical image processing, and some other medical technologies [1-4]. They have become indispensable components in the technological age.

Depending on the intended use, various types of antennas (wire, patch, aperture, reflector, lens, smart antenna, array antenna, etc.) and their combinations or derivatives can be utilized. Users can transmit and receive data across various environments thanks to these developed and employed antennas. Among these, most commonly used antennas today are patch antennas, which are planar antennas known for their low profile, ease of design, cost-effectiveness, and easily integration into electronic circuits [5]. Due to the advantages they provide, patch antennas are the most preferred antenna type for government applications such as aircraft, spacecraft, satellites and missiles, as well as commercial uses like mobile radio and wireless communications. Logo antennas are one of these application areas.

Logo antennas are increasingly in demand in various fields such as IoT, Internet of Vehicles (IoVs), RFID, 5G and wireless communication, security systems, medical and biomedical applications, and wearable technologies. As functionality, as well as aesthetics, advertising and recognition gain importance, interest in these types of antennas continues to grow. In addition to well-known institutions and companies like IEEE, Nike, Mercedes-Benz, the Chinese Smart EV brand XPENG [6], IBM, Louis Vuitton [7], Levi Strauss & Co.'s [8], many universities such as MIT, University of Florida Gators, Telkom University, South West University [9], University of Mississippi (UM) and Tampere University of Technology [10] also use logo antennas. There are also specially designed logo antennas for special purposes, such as the infinity symbol [11].

Another application of logo antennas is in wearable technologies. In these devices, antennas that transmit and receive signals across various frequencies are essential for wireless communication [12,13]. Medical emergencies, breast cancer imaging, and monitoring athletes' performances can be given as examples [14-16]. Additionally, it is important for the antenna to be aesthetically pleasing, so blending technology with design is crucial. Consequently, users now prefer logo antennas over simple patch antennas.

Logo antennas have recently gained popularity and been widely used in various fields, but there are notable limitations and challenges. In particular, the complex shapes of logos (irregular, asymmetrical, or curved) require a trade-off in gain [7,8,9,14,16]. In [8], a GPS-GSM-based antenna to be used in tracking systems is presented. The designed logo antenna can radiate in both GPS and GSM bands; however, the antenna gain and bandwidth were below a certain limit. Similarly, in [9], a fully textile dual-band logo antenna designed for use in IoT wearable devices in the ISM band is reported. Although in the 5.47 GHz frequency range a radiation efficiency of 90%

and a moderately high gain was achieved, in the 2.4 GHz range a radiation efficiency of 25–38% and a very low gain (0.5 dBi) are noted.

Another challenge is the antenna's bandwidth, since logo antennas are distorted patch structures and typically exhibit narrower bandwidths due to multiple competing modes [8,9,10,11,14]. In [10], two similar logo antennas proposed for advertising applications were designed and tested. More specifically, two RFID tags were designed based on the letters T, U, and M and fabricated on different substrates. However, the study reports -10dB bandwidths of 2.89% and 3.37% for the two antennas. In [9], the bandwidth value for radiation at 2.4 GHz for |S11|<-6 dB was examined, and even in this case, the result remained around 4%. In another study [11], an antenna was designed around the infinity symbol. The use of ring models offers more flexible design parameters, but the bandwidth is limited to 5.88% even though the gain is relatively good

Although various logo antenna designs for different frequency ranges exist in the literature, these studies are primarily concentrated on the C band, which is widely demanded for everyday applications [6,17,18]. The C band (4-8 GHz) encompasses the frequencies used for wireless communication, internet, and Wi-Fi, and it also includes the ISM band, which is open to free use.

In this study, an antenna with the logo of Aydın Adnan Menderes University was designed for wireless communication operating in the C band (4.87 GHz center frequency). Compared with other logo antennas, the proposed antenna offers a higher gain of 4.57 and a moderately good bandwidth of ~10%. To support high data rates and reach more users in internet access, the C band (4-8 GHz) frequency was preferred over the ISM band (2.4 GHz). Considering the potential of using the designed antenna in wearable technologies (such as hats, sweaters), its dimensions were kept limited (low profile, less size) and a planar antenna design was decided. Simulations were performed using CST MWS and the results were shared.

II. Materials and Method

Patch antennas are design with ground at the bottom, dielectric material in the middle and patch-shaped at the top. In patch antennas, substrate thickness, geometric shape of the patch and dimensions of the antenna are vital parameters for antenna performance. It is possible to obtain a completely new antenna with entirely different resonance frequency, polarization, bandwidth and impedance values by changing the patch shapes created. In this study, the logo of Aydın Adnan Menderes University is studied as the antenna pattern. The internally connected U-shaped rectangular patch antenna forming the logo is created by progressively cutting slots and the hat with sharp lines on the top is incorporated to the antenna. At each stage of the study, S11 parameters and radiation patterns are evaluated, and the results are discussed. The ADU logo, which is inspired by the design in the study, the designed antenna within the scope of the study and the dimensions of the antenna are shown in Figure 1.

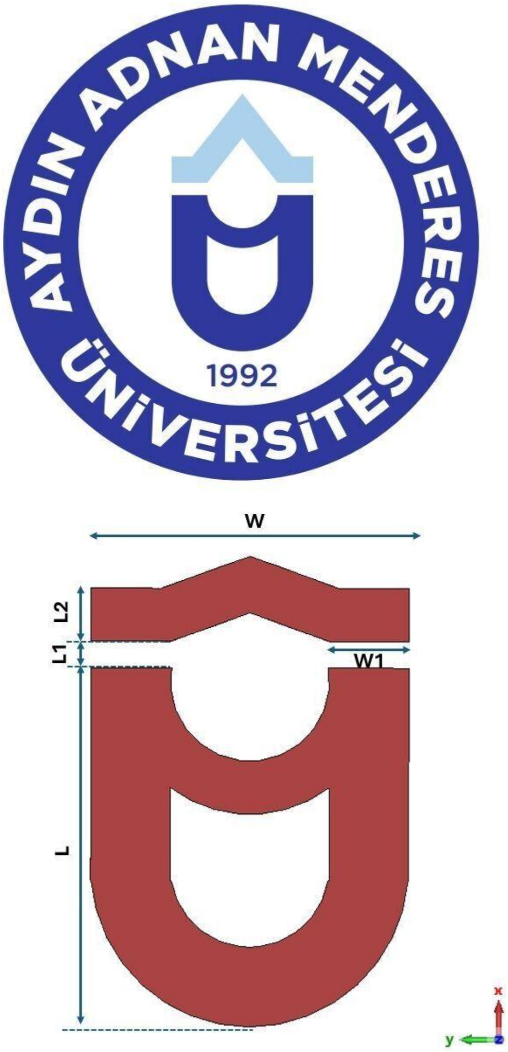


Figure 1. ADU university logo and the designed antenna with dimensions

The antenna is intended to emit in the C band and the design is shaped accordingly. The operating frequency is the primary factor influencing the antenna's size. In patch antenna design, there are some standard formulas used to calculate the dimensions [5]. To calculate the actual width and the actual length of the patch, Equation 1 and Equation 2 are used, respectively.

$$W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \quad (1)$$

$$L = \frac{1}{2f_r\sqrt{\varepsilon_{reff}}\sqrt{\mu_0\varepsilon_0}} - 2\Delta L \quad (2)$$

where v_0 is the free-space velocity of light, f_r is the resonant frequency of the antenna, ε_r is the dielectric constant of the substrate, ε_{reff} is the effective dielectric constant value and ΔL is the extension of the length (effective patch length). To determine the sizes of W and L, it is necessary to specify the weight-to-height ratio and f_r, ε_r values.

For h is the height of the substrate, as $W/h > 1$, Equation 3 and Equaiton 4 are used for ε_{reff} and ΔL .

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

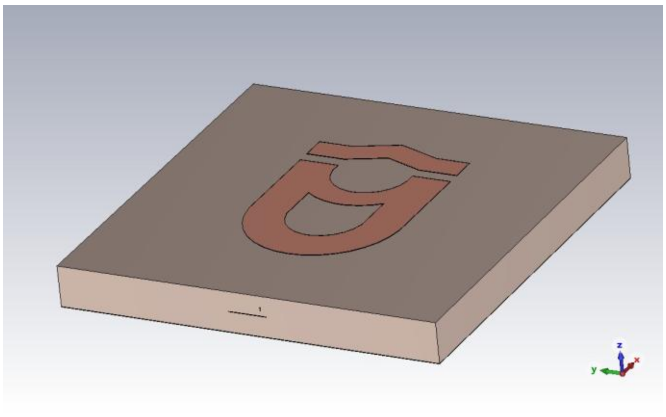
$$\Delta L = 0.412h\frac{(\varepsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)} \quad (4)$$

In the design, an FR4 substrate material with a ε_r value of (4.3) and a loss tangent of 0.025 is preferred, as it is widely used and easy to supply. The formulas specified were taken as reference when initiating the antenna design. However, the final dimensions of the antenna were determined at the conclusion of the simulation studies for optimum results in obtaining the logo shape. The width and length of letter U are W=11.98mm and L=13.5mm. The width of one branch of U and the width of hat are W1=3.04mm and L2=2mm, respectively. The distance between hat and letter is L1=1mm as shown in Figure 1. The designed antenna dimensions are given in Table1.

Table 1. The designed antenna dimensions

Parameter	W	L	W1	L1	L2	h
Value (mm)	11.98	13.5	3.04	1	2	2x1.6=3.2

Adding slots and stubs, using fractals and metamaterial structures are common methods for enhancing antenna performance. Another approach to improve antenna performance and bandwidth is to use the appropriate feeding method. While numerous feeding methods exist in the literature for patch antennas, four are particularly popular among them. These are microstrip line, coaxial probe, aparture coupling and proximity coupling feeding methods. Although microstrip line and coaxial probe feeding techniques are easy to design, they offer limited bandwidth and generate cross-polarized radiation [5]. In this study, the proximity-coupled feeding method, which is one of the non-conducting feeding types, is preferred to minimize the cross-polarization effect on the antenna radiation, achieve wide bandwidth and preserve the integrity of the logo image. The microstrip line with a length of 15 mm and a width of 3 mm used for feeding lies at the middle height of the dielectric material. The antenna design and feed line created in the CST MWS program are shown in Figure 2.



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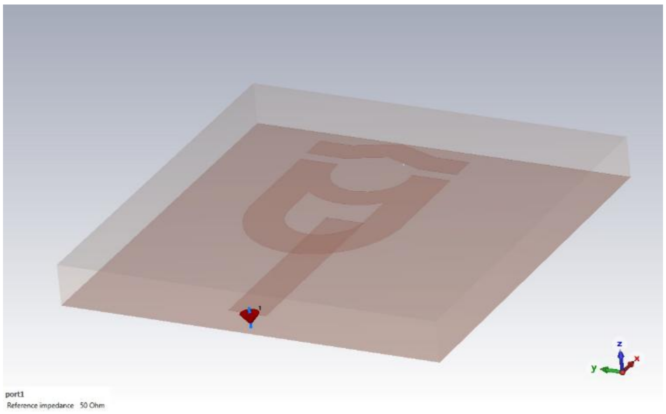
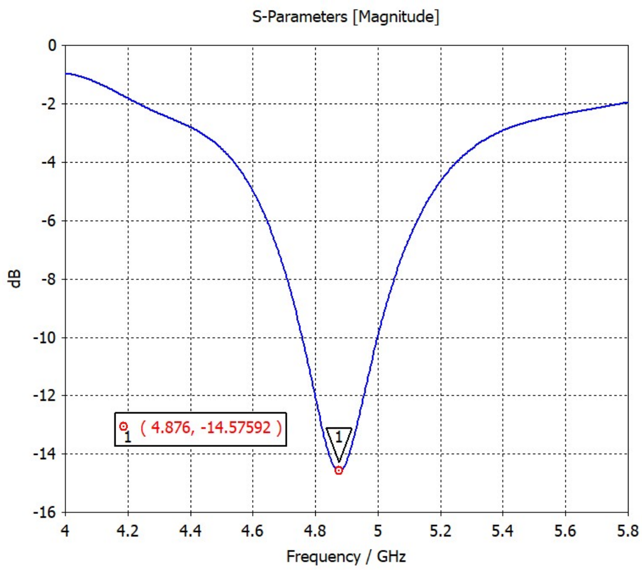


b

Fig. 2. CST view of the designed antenna and representation of proximity coupled feed

III. Results and Discussion

The proposed ADU University logo patch antenna was designed and analyzed using the CST Microwave Studio software. The simulation results showing the variation of the return loss parameter (S11) with frequency are presented in Figure 3. In the C (4-8 GHz) band, the resonance frequency is found to be 4.87 GHz, with a return loss of -14.58 dB at this frequency. Although the desired return loss is generally ≤ -10 dB (%90 transmission of power) across the operating bandwidth of the antenna, in wearable technologies and antennas that are in contact with the body such as phones, attention is paid to the specific absorption rate (SAR). For such devices, a return loss of ≤ -6 dB (%75 transmission of power) is acceptable [9,19]. The lower (f_{high}) and upper (f_{low}) frequency limits of the antenna bandwidths for return loss values of ≤-10 dB and ≤-6 dB are found as 4.75 GHz- 4.99 GHz and 4.644 GHz- 5.127 GHz, respectively. Therefore, the bandwidth for return loss value of ≤-10 dB is calculated to be 241 MHz, while the bandwidth for return loss value of ≤-6 dB is found to be 483 MHz (which corresponds to a fractional bandwidth of ~10%) and the results are seen to be in compliance with IEEE 802.11 a/b/g standards.



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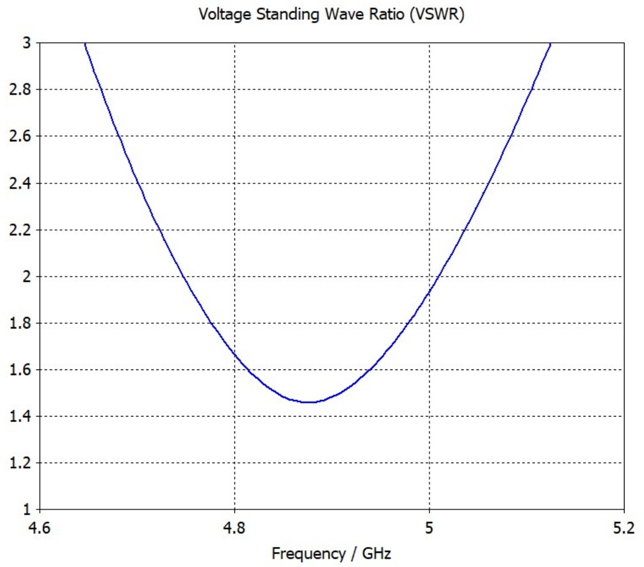

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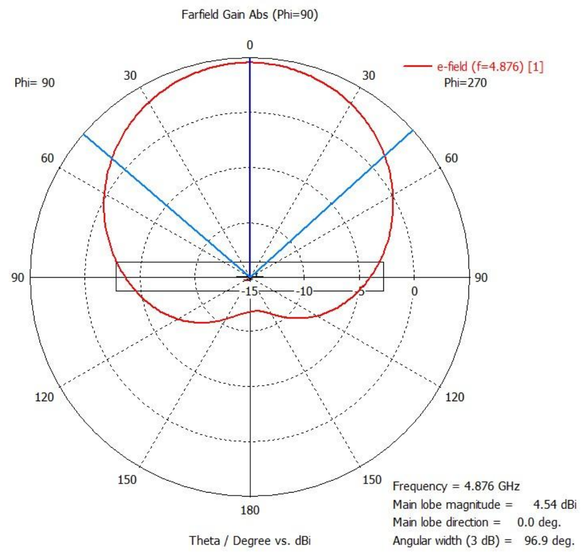
Fig. 3. a) The simulation results of the variation of the return loss parameter (S11) with frequency b) VSWR simulation results focusing on 4.6-5.2 GHz range

Figure 3.b shows the VSWR (Voltage Standing Wave Ratio) simulation results of the antenna in free space. According to the simulation results, at the center frequency of 4.87 GHz the VSWR of the antenna is found to be 1.45. VSWR is calculated with the formula 1-|Γ|/1+|Γ|, where Γ is the reflection coefficient and takes values between 0 and 1. As is well known, VSWR can vary from 1 to ∞ depending on the reflection condition and a VSWR value close to 1 and less than 2 is desired for antennas [5]. Thus, 1.45 indicates good impedance matching. Additionally, Figure 2.b shows that the bandwidth (for VSWR 2 values) for the center frequency of 4.87 GHz is 262 MHz. For the VSWR<2 the return loss is calculated to be -9.54 dB, indicatings that the antenna can operate with a good performance in that frequency range.



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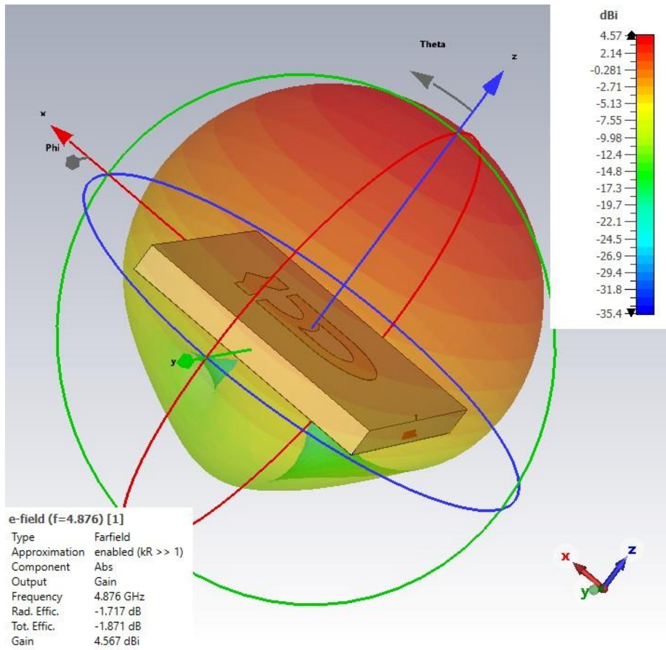

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Fig. 4. a) 1D Radiation pattern, b) 3D Radiation pattern of the proposed antenna at 4.876 GHz

Figure 4a shows the simulation results of the radiation patterns of the designed antenna in the YZ plane at the frequency of 4.876 GHz. From the radiation pattern, the main beam direction is found as 0^{O} , with a 3 dB angular beam width of 96.9^{O}. The 3D radiation pattern of the designed antenna is illustrated in Figure 4b. The radiation patterns indicate that the antenna radiation has monopole characteristics. The maximum gain of the antenna is found to be 4.567 dBi, is acceptable for the requirements in WLAN applications. Considering similar studies in the literature, the proposed antenna design demonstrates a good gain and relative bandwidth and acceptable VSWR values. The results of this study are comparatively summarized with selected works from the literature in Table 2.

Table 2. Performance Comparative Analysis of some Logo Antennas

Ref.	Antenna Dimension (mm^3)	Center Frequency C band(4-8 GHz)	Return loss (dB)	Substrate Material (ε_r)	Simulated Peak Gain (dBi)	Relative Bandwith (%)
[6]	142.25x60x 0.12	5.46	-19 *	Rogers 5880 (2.2)	5.8	7.1
[9]	43x85x7	5.47	-24 (in free space)	Polyester (1.49) Polar fleece (1.066) Cotton (1.587) (Thickness 0.5/1/5.5mm)	~ 6(in free space)	22.8*
[7]	22.3x22.5x3.5	4.5	−30*	Conductive textile and leather (2.5)	3.05	13
[14]	56x57X1.4	5.9	−28*	Jeans fabric (1.7)	6.47	16.2
[15]	70x60x1.6	1.6-11.2	<-10	Cotton (1.6)	6.17 @9.8 GHz	-
[16]	35x34x0.13	5.8	−20	Polyimide (3.5)	1.46	26
[17]	12.4x116x.4	5.8	-23	Rogers RT duroid 6002 (2.94)/duroid 6010 (10.2) (Thickness 0.762/0.635mm)	-	0.8 <10 dBi 1.6<6dBi
[18]	20x20x1.6	5.3	-15	FR4(-)	4.029	4.33
This work	11.98x13.5x3.2	4.87	-14.57	FR4 (4.3)	4.567	4.95 <10 dBi 9.91 < 6dBi

(*)represents calculated or approximate results from the given figures.

IV. CONCLUSION AND SUGGESTIONS

In this study, a logo antenna with the emblem of Aydın Adnan Menderes University that can be used in wireless communication is designed and to support high data rates and to reach more users in internet access the C band (4.87 GHz) is chosen as operating range. In the antenna design, 2 FR4 layers with 1.6 mm thickness and 4.3 epsilon value are used, and proximity-coupled feeding method among non-conducting feeding types is preferred. The antenna is designed in CST Microwave Studio program, in the simulation results, bandwidth, S11, gain and radiation pattern are examined, and by making changes in the parameters, the antenna dimensions showing the best performance are determined. As a result of the simulation studies, the bandwidths of the designed antenna for |S11|<-10dB and |S11|<-6 dB return loss values are found as 241 MHz and 483 MHz, respectively. In addition, the maximum gain of the antenna is found to be 4.567 dBi and the VSWR value is found as 1.45. The results obtained show that the designed antenna complies with the application standards and that logo antennas are applicable to many different applications and have design flexibility.

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Authors'Contributions

The authors' contributions to the paper are equal.

Statement of Conflicts of Interest

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The authors declare that this study complies with Research and Publication Ethics

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