Design and Development of Dipole Array Antenna for Wi-Fi Applications

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Abstract
This paper illustrates the design and development of the series-fed two-dipole-array antenna (STDA) for Wi-Fi applications. The proposed antenna consists of two dipole elements of different lengths, which are serially joined by the coplanar strip line. The design incorporates a coaxial/probe feeding technique with balun as an alternative feeding mechanism. The main goal of this paper was to create a high-gain antenna with an array configuration for Wi-Fi applications. For STDA array configurations, antenna performance parameters such as return loss, radiation pattern, gain, and directivity are investigated. It operates at 2.4 GHz and has a high gain of 21.6 dBi when used with a reflector. In order to improve overall gain, the STDA was analyzed for different array configurations in the formation of 1 × 4, 1 × 8, and 2 × 8 STDA arrays. The proposed antenna is made of a FR-4 substrate with a dielectric constant of 4.4 and a loss tangent (tan) of 0.007 and a thickness of 1.6 mm. An antenna measures approximately 105 mm × 80 mm in size. The proposed antenna meets the requirements for a 2.4-GHz antenna with a bandwidth of 200 MHz, and thus, it is found to be suitable for Wi-Fi applications.

Keywords STDA · Dipole array antenna · Wi-Fi · Balun · Feeding · CPS

1 Introduction
Various types of wireless communication antennas have been widely used in recent years, because high data rate services are most required [1]. Wi-Fi is commonly used indoors and outdoors to provide wireless connectivity to end users of this system such as routers and wireless repeaters. The efficiency of these devices depends on the antenna capacity that determines how the wireless network covers efficiently. The traditional
STDA is used in many mobile communication base station applications due to its ability to operate with lower mutual coupling losses and to provide greater gain. The series-fed two-dipole-array antenna consists of two dipoles with different lengths and truncated ground plane, which are further connected in series through a parallel strip line, which is chosen from different types of broadband antennas [2]. This kind of antenna is used in mobile communication in a wide range of applications such as base station antennas, phased array antennas, printed dipole with an integrated balun, a printed dipole pair, a double-dipole antenna, a planar, almost yagi, a two-layer, printed dipole, and a trapezoidal dipole antenna due to their balanced gain of the wide bandwidth. In most cases, the antenna size is very difficult to reduce because an antenna size often requires total control over the performance of wireless devices [3].

There are several types of antennas designed for Wi-Fi applications through different mechanisms. Parametric evaluation of the log-periodic dipole array antenna (MLPDA) microstrip is performed using the transmission line’s corresponding circuit. Hence, this MLPDA antenna is ideal for wireless C band applications such as Wi-Fi and wireless applications with a 5-GHz band. The thickness of the substrate is 1.6 mm, and its dielectric constant is 4.2. The gain of the antenna is 4.8 dBi [4]. For multi-3G/4G applications, a quasi-antenna with a modified bow-driver has been developed. The measurements show that the antenna has a return loss of 10 dB, with 80.4 percent of the bandwidth between 1.45 and 3.4 GHz, because the antenna is constructed using the FR4 substrate with a dielectric constant of 4.2. Measured gains in all the bandwidth are greater than 4 dBi [5]. A dual-band series dipole pair antenna is constructed using proximity-coupled strips and split-ring resonator controllers. The antenna provides dual-band characteristics with the 1.56–1.63 GHz and 1.68–2.87 GHz frequency bands. This antenna comes with VSWR < 2. The antenna gain ranges between 5.9 and 7.5 dBi. The antenna is designed on FR4 substrate. [6].

The linear array of mutually coupled parallel dipole antennas has been designed with desired side lobe level and return loss. The dipole antenna has an omnidirectional radiation pattern, and it achieves a return of 25 dB. The antenna is built using a 1.6-mm-height FR4 substrate [7]. Log periodic planar dipole array antenna, constructed on the FR4 substrate, has a maximum gain of 7.5 dBi between 3 and 6 GHz range [8]. A series-fed two-dipole array antenna using nearby parasitic director for bandwidth and gain enhancement has been developed. This performance is compared to the traditional STDA antenna that operates in a 1.7- to 2.7-GHz frequency band with a gain of > 5 dBi. A VSWR < 2 is achieved in this antenna, which satisfies the condition [9]. A compact ultra-wideband planar printed quasi-yagi antenna has been designed for water detection in the Egyptian desert. Its bandwidth extends from 47 to 150 MHz with 45% size reduction, and the gain of the antenna was around 4.5 dBi [10]. A series-fed dipole pair broadband antenna with parasitic strip-pair director has been developed. The performance is compared with the performance of the traditional SDP antenna generated on a FR4 substratum. The antenna frequency was 1.63–2.97 GHz; the antenna gain was 5.6–6.8 dBi and 58.26 percent performance [11]. The design of a band-notched broadband series-fed two-dipole-array antenna has been simulated and analyzed. To get a band rejection, the WLAN band was conducted in 2.4–2.484 GHz. Compact series-fed two-dipole-array antenna has been designed using top-loaded components [12]. A size-reduced STDA is achieved, which covers a frequency band from 1.7 to 2.7 GHz with a gain of > 5 dBi. The conventional STDA has a bandwidth of 48.7 percent from 1.68 to 2.76 GHz and a reasonable gain of 5.6–6.0 dBi compared with the proposed antenna parameters [13].
A series-fed two-dipole-array antenna has been modified to get a reduction in size. The antenna covers at 1.7–2.7 GHz frequency range, with a 5-dBi gain. The antenna had a bandwidth of 49.7 percent. The frequency ranges from 1.68 to 2.79 GHz with the gain range from 5.86 to 6.13 dBi [14]. A wide-scanning tightly coupled wideband dipole array is constructed. The architecture adopts an integrated balun. When compared to traditional feeding methods, the size, weight, and cost are significantly reduced. By removing bulky external baluns, the bandwidth is simultaneously increased by over 30 percent. In a dual-polarization configuration, this antenna has low cross-polarization of 20 dB over most channels. Measured results for a prototype 8×8 module antenna display good simulation agreement [15]. For improved gain and front-to-back ratio, a series-fed two-dipole array antenna was designed using bow-tie components. The frequency band, with the gain > 5 dBi, ranges from 1.7 to 2.7 GHz. The antenna has a bandwidth of 48.8 percent in the 1.69–2.78 GHz range. Its gain ranges from 5.8 to 6.3 dBi and the front-to-back ratio ranges from 14 to 17 dBi with a decrease of 10 percent in the overall antenna width [16].

A dual-band loop-loaded printed dipole array antenna, which is incorporated with a balun structure, has been designed. It is designed with loop-loaded printed dipole antenna array. It operates in a dual-band at 3.0 and 5.5 GHz. To achieve balanced and matched excitation to the antenna array, a new corporate balun/feed structure is employed [17]. A double-layered printed dipole antenna with parasitic strips has been developed. This antenna has 75% impedance bandwidth, VSWR < 2, operating between 2.5 and 5.5 GHz bands. Moreover, stable radiation patterns with 6.3–9.1 dBi peak gain and low cross-polarization are obtained within the bandwidth. An eight-element printed dipole antenna array is assembled and measured, showing a good performance in the array [18]. A double-printed trapezoidal patch dipole antenna for UWB applications has been designed. The proposed antenna exhibits, band-notched characteristics. The antenna covers the entire UWB band ranging from 3.1–10.6 GHz with a gain of 3.1dBi. It has a notched band for the IEEE 802.11a frequency band at 5.825 GHz, which has a gain of 5.1dB [19].

According to the above literature review, antenna parameters such as bandwidth, gain, and directivity are extremely low. Several attempts have been made to realize the antenna for Wi-Fi band applications, with the array elements added in either serial or parallel formation. As a result, the STDA with reflector antenna was used as an array element and was analyzed in 1×4, 1×8, and 2×8 STDA array configurations. With various array configurations, high directivity, high gain, bandwidth, and a better signal-to-noise ratio have been recognized. The proposed antenna operates in S-band (2–4 GHz) and is constructed on a 1.6-mm-thick FR4 substratum with 4.4 dielectric constant. This antenna has a Wi-Fi functionality. The array antenna is designed and evaluated for S-band applications.

In the previous literature, to enhance the bandwidth and gain, the parasitic director with STDA is used. In this attempt, to enhance the gain and bandwidth, the parabolic reflector with STDA is incorporated. The STDA with reflector antenna has considered as the array element and analyzed in 1×4, 1×8, and 2×8 STDA array configurations. High directivity, high gain, high bandwidth, and better signal-to-noise ratio have been acknowledged with different array configurations.

The minimum gain requirement for Wi-Fi system is about 3dBi. A higher-gain antenna, installed for instance on an access point, improves range from the access point to the client radio and from the client radios to the access point. This is different from increasing transmit power on only the access point, which would only increase range for the communications going from the access point to the client radios. The reason is that a higher-gain antenna improves range in both directions. It is identified that the higher gain of the antenna improves both transmission and reception of radio waves. Therefore, the installation of
higher-gain antennas can provide significant increases in range without making changes to the client radios. In addition to using higher-gain antennas, antenna diversity can also help extend range in both directions because it minimizes multipath propagation. Diversity is an important part of 802.11n, and various vendors sell 802.11n access points and client radios that have different levels of diversity.

An advantage of using higher-gain antennas is that it impacts range in both directions. As a result, it may be able to get by with changing the antenna configuration on only the access point, avoiding the need to alter each client radio. The cost of upgrading the antennas, however, might be. Therefore, the cost might be prohibitive in larger networks. Be sure to take into account different antenna gain and diversity with actual propagation testing in the target-operating environment to determine the lowest overall cost of deploying the network. The trouble with increasing antenna gain for the purposes of extending range is that you will likely place the access points farther apart. This results in a larger 802.11 collision domain, which limits the capacity of the WLAN. Finally, in order to enhance the distance, reduce the diversity, and the cost, the antenna gain is improved through array configurations.

The antenna array is used to increase overall gain, provide diversity of reception, cancel interference, maneuver the array in a particular direction, gage the direction of arrival of incoming signals, and maximize the signal to interference plus noise. Most types of array antennas are constructed using several dipoles, typically half-wave dipoles. The aim of using multiple dipoles is to increase the directional gain of the antenna over the gain of one dipole [30–34].

The structure of the paper is as follows: Sect. 2 discusses the geometry and the method to construct the STDA antenna. Array implementation of the STDA is presented in Sect. 3, which is followed by the analysis of the simulated and measured results in Sect. 4. The result and discussion are presented in Sect. 5, and Finally, Sect. 6 concludes the paper.

2 Antenna Geometry

The proposed antenna is 80 mm × 105 mm in size and has a thickness of 1.6 mm on a FR4 substrate with a dielectric constant of 4.4. Table 1 lists the design parameters such as the dielectric constant (εr), substrate height (h), loss tangent (tan), patch length, patch width, and patch thickness.

The proposed antenna is shown in Fig. 1. The STDA consists of two printed-strip dipoles with various lengths, which are connected via a CPS line, and a ground reflector.

| Table 1 | Design parameters of the STDA |
|---------|------------------------------|
| Abbreviate | Value (mm) | Abbreviate | Value (mm) |
| L | 80 | WSL | 1.6 |
| W | 105 | WCPL | 20 |
| S1 | 34 | Wg | 12.5 |
| S2 | 34 | Lg1 | 2.5 |
| W4 | 25.2 | Lg | 36 |
| W3 | 29.2 | W1, W2 | 11 |
| WGD | 15 | W5 | 27.2 |
placed below the first dipole to increase the gain at the low frequency band. An integrated balun between the MS line and the CPS line is implemented on the CPS line to feed the antenna, and the end of the MS line is shorted using a shorting pin at the feeding point. The length and width of the elements (two dipoles and ground reflector) and the spacing between these elements are optimized to maximize the bandwidth and the realized gain of the antenna. In this design, FR4 is chosen as a substrate because of low material cost and easy to fabricate, along with its ability to produce optimal performance for a variety of applications.
3 Design Procedure

3.1 Design of STDA

A STDA is designed with a reduced size, which consists of two-strip dipole elements (D₁ and D₂) having different length and a ground reflector. The height of the ground plane WGD is 12.5 mm. The length L₂ = 70 mm and width W₂ = 11 mm for dipole 1 of D₁, respectively, and for dipole 2, D₂ and L₁ = 74.4 mm and W₁ = 11 mm, respectively, as shown in Fig. 1. Figure 1a–c shows the front, ground plane, and side view of the STDA, respectively. The STDA is devised by cutting the CPS with the width of 1.6 mm from the top till the ground as shown in Fig. 1a. The balun is adjusted and a stub is introduced in order to match the impedance. The impedance matching is achieved simply by adjusting the position of the feed point of the integrated balun.

3.2 Design of Balun

The dipole cannot be fed directly from a microstrip line because the electric field of the microstrip line is normal to the substrate and the electric field across the gap is between the arms of the dipole along with its length. Balun is needed for the feeding mechanism, which is used to bring an unbalanced transmission line into balance. The balun is designed to match 50Ω input impedance in order to feed the designed antenna through the hole. In a two-conductor shorted stub, the outer conductor of the coaxial line and the λ/4 short-circuited wire form λ/4. It has infinite impedance at the feed point, which is fixed at the top of the balun, and the eliminating current flow is on the outer surface of the coaxial line’s outer conductor. To match the input impedance of the antenna with a range of 50Ω feed line, an integrated balun is designed between the microstrip (MS) and CPS lines. At the feed point, a shorting pin is used to short the end of the MS line. WCPL and WSL are the widths of the CPS line and slot line, respectively.

In this attempt, initially, the antenna design begins by designing a conventional STDA antenna with the help of literature. The STDA is optimized to operate at 2.4 GHz. The antenna was printed on an FR4 substrate with a dielectric constant of 4.4 and a thickness of 1.6 mm (loss tangent = 0.007). It consists of two-strip dipole elements (D₁ and D₂), which is having different lengths and a ground reflector. The minimum distance between the dipoles and ground plane is maintained in order to reduce the return loss. The length of the short and long dipoles is selected in such a way that the upper and lower operating frequencies are controlled. The radiation mechanism of this antenna depends on the dipole length and width, distance between two dipole pairs, and ground plane and balun dimensions. Figure 2a shows the current distribution of the proposed antenna, which starts from the feeding point through the balun from the bottom to top surface of the dipole antenna. The current flow indicated by the red region shows how current is effectively distributed over the effective aperture of the proposed antenna. The current is concentrated on the first dipole at 2.4 GHz, which is the operating frequency of the antenna, as shown in Fig. 2a.

STDA is shown in Fig. 2. Antenna fabrications are shown in Fig. 2b and c from the front and the back, respectively. The antenna’s overall size is approximately 80 mm × 105 mm = 8400 mm² in total.
Fig. 2  a Surface current of the proposed antenna, b the proposed fabricated STDA front view, and c back view
The proposed antenna is designed using commercial EM software CST Microwave Studio. The antenna is developed at Nucleus Satellite Communication Madras Pvt Ltd, Chennai, India. Finally, it is measured using vector network analyzer at Saranathan College of Engineering, Trichy, Tamil Nadu, Chennai.

4 Formation of Array

4.1 Single STDA Without Reflector

Many techniques are used to increase the gain of the antenna such as super state, multilayer stack and array of elements. An antenna array is a combination of several single-element antennas forming a single STDA in order to achieve an improved performance in comparison with an elementary antenna. The performance may increase the overall gain. However, the use of different types of antenna in an array is also possible. Monopoles, dipoles, slot-in waveguides, and microstrip are the types of elements that are generally used in arrays. There are many advantages of an antenna array that includes increasing gain and achieving desired radiation pattern. The gain is equal to the product of antenna radiation efficiency and directivity.

4.2 Array of 1 × 4 STDA Without Reflector

Figure 3 shows the array of 1 × 4 STDA. The spacing between the two elements is 5 mm, which is obtained using the formula W/2 [20]. It has four dipole antennas and four ports as $S_{11}$, $S_{22}$, $S_{33}$, and $S_{44}$. $S_{11}$ is the input port voltage reflection with coefficient, $S_{22}$ is the output port voltage reflection with coefficient, $S_{21}$ is the forward voltage gain, and $S_{12}$ is the reverse voltage gain. The scattered parameters describe the input–output relationships between the ports.

4.3 Array of 1 × 8 STDA Without Reflector

Figure 4 shows the array of 1 × 8 STDA. The spacing between the two elements is 5 mm. This configuration has 8 antennas and 8 ports as $S_{11}$, $S_{22}$, $S_{33}$, $S_{44}$, $S_{55}$, $S_{66}$, $S_{77}$, and $S_{88}$.
4.4 Array of 2 × 8 STDA Without Reflector

Figure 5 shows the array of 2 × 8 elements. The spacing between the two elements is 5 mm. This configuration has 16 antennas and 16 ports as $S_{11}$, $S_{22}$, $S_{33}$, $S_{44}$, $S_{55}$, $S_{66}$, $S_{77}$, $S_{88}$, $S_{99}$, $S_{1010}$, $S_{1111}$, $S_{1212}$, $S_{1313}$, $S_{1414}$, $S_{1515}$, and $S_{1616}$.

4.5 STDA with Reflector

The parabolic reflector converts an incoming electromagnetic wave that moves along the axis into a converging spherical wave toward the target. The STDA uses a parabola reflector, a curved surface with a parabolic cross-sectional form to guide the radio waves. The most common type is a reflector in the shape of a dish and is generally referred to as a dish antenna or parabolic dish. A parabolic reflector’s biggest benefit is that it has high directivity. It functions similarly to a reflector of a searchlight or flashlight to direct the radio waves in a narrow beam or receive radio waves from one direction only. The parabolic reflector has some of the highest gains, which means they can generate the narrowest beam widths, of any form of antenna. The schematic view of a reflecting parabolic reflector is shown in Fig. 6.
Parabolic antennas are used as high-gain antennas for point-to-point communications, in applications such as microwave relay connections that carry telephone and television signals between neighboring cities, wireless WAN/LAN connections for data communications, satellite communications and spacecraft communication. They are used in radio telescopes too.

The reflector in Figs. 7, 8, 9, 10 is made of Aluminum (Al), but the diameter is different. Typically, the reflector converts an incoming electromagnetic wave that moves along the axis into a converging spherical wave toward the target. The STDA uses a parabola reflector, a curved surface with a parabolic cross-sectional form to guide the radio waves. In array configuration, the number of elements increases, so the size of the reflector becomes larger. Hence, the radiated signals are directed to one direction to achieve more gain in different array configurations. The simulated results are obtained using commercial EM software CST Microwave Studio.

4.6 Single STDA with Reflector

Figure 7 shows the single STDA with reflector.
Fig. 8 1×4 STDA with reflector

Fig. 9 1×8 STDA with reflector

Fig. 10 2×8 STDA reflector
where A is the aperture area of the antenna, d is the diameter of the parabolic reflector using the formula above, the diameter was determined. The single STDA with parabolic reflector with a diameter of 90 mm is designed, simulated, and fabricated. The spacing between reflector and the antenna is 5 mm. The experimental results reveal that the antenna parameters such as return loss, antenna gain, and bandwidth are better than STDA without reflector. In terms of antenna gain with reflector, it is 11.2dBi, and without reflector, it is 6.74. There is an improvement of 41.3% of gain if we implement STDA with reflector.

4.7 Array of 1 × 4 STDA with Reflector

Figure 8 depicts the structure of 1 × 4 STDA inside a parabolic reflector element, which is designed using aluminum material. The reflector is designed with a diameter of 200 mm, and all the four elements of STDA are enclosed within the parabolic reflector area such that electromagnetic signals from STDA are reflected back, which results in unidirectional radiation pattern. In terms of antenna gain with reflector, it is 14.8dBi, and without reflector, it is 11.9. There is an improvement of 19.5% gain for 1 × 4 STDA with reflector. The simulated STDA design with 1 × 4 reflectors is shown in Fig. 9, which reveals that the antenna parameters are improved if the antenna elements are increased. It is noticed that there is about 24.3% of gain improvement in 1 × 4 STDA compared with single STDA.

4.8 Array of 1 × 8 STDA with Reflector

Figure 9 shows the array of 1 × 8 STDA with reflector elements. The spacing between reflector and the antenna is 5 mm. A 400-mm-diameter parabolic aluminium reflector with 8 elements STDA is designed and simulated. The result shows that the gain of the antenna is 14.2dBi without reflector and 18dBi with reflector. While incorporating the reflector, 21% of gain improvement is noticed.

4.9 Array of 2 × 8 Elements with Reflector

Figure 10 shows the array of 2 × 8 STDA with reflector elements with a 500-mm-diameter parabolic reflector. To enhance the gain and bandwidth further, the STDA is arranged in 2 rows with 8 elements. This entire STDA contributes a total of 16 elements placed within the diameter of parabolic reflector. The simulated results of antenna gain without reflector is 15dBi and with reflector 21.6dBi with 30% increase.

5 Result and Discussion

5.1 Return Loss (with and without Reflector)

Figure 11. shows plot of the simulated return loss (S11) of the single SDTA, 1 × 4, 1 × 8, 2 × 8 SDTA without reflector antennas resonating at 2.4 GHz. Figure 12. shows plot of the simulated return loss (S11) of the single SDTA, 1 × 4, 1 × 8, 2 × 8 SDTA with reflector.
antennas resonating at 2.4 GHz. The above plots show better performance when compared to SDTA without reflector antenna. Figure 13a depicts a plot of the simulated and measured return loss ($S_{11}$) of the single STDA without reflector antenna. The proposed antenna resonates at 2.4 GHz frequency.
A plot of the simulated and measured return loss (S11) of a single STDA with reflector antenna is shown in Fig. 13b. The proposed antenna is resonating at 2.4 GHz frequency and shows a better performance when compared to the single STDA without reflector antenna. A significant improvement in gain and directivity is observed, making it highly reliable for
effective Wi-Fi communication where signal strength is lost over longer distances. In the proposed structure, there is an improvement in return loss.

The return loss for single STDA with and without reflector is simulated from the CST Microwave Studio software and measured using Vector Network Analyzer (VNA) and the experimental setup as shown in Fig. 14.

5.2 Radiation Pattern (Without Reflector)

Figure 15a, b, c, d displays the 3D radiation pattern of the single STDA, 1 × 4, 1 × 8, 2 × 8 without reflector. It displays the simulated gain values for STDA without a reflector. The proposed antenna has a gain of 6.74 dBi for single STDA, 11.9 dBi for 1 × 4 STDA, 14.2 dBi for 1 × 8 STDA and 15 dBi for 2 × 8 STDA, respectively.

5.3 Radiation Pattern (with Reflector)

Figure 16a, b, c, d displays the 3D radiation pattern of the single STDA, 1 × 4, 1 × 8, 2 × 8 with reflector STDA. It displays the simulated gain values for STDA with a reflector. The proposed antenna has a gain of 11.5 dBi for single STDA, 14.8 dBi for 1 × 4 STDA, 18 dBi for 1 × 8 STDA and 21.6 dBi for 2 × 8 STDA, respectively.

5.4 Gain (with and Without Reflector)

The proposed antenna operates at 2.4 GHz and exhibits an omni-directional radiation pattern. As a result, the signals are transmitted and received without loss in all directions, revealing that the radiation pattern obtained from the proposed antenna is the sum of all the patterns generated by each array element. As a result, the gain and directivity of the presented STDA antenna are improved.

Fig. 14 Photograph of the STDA with VNA measurement
Fig. 15 3D Radiation Pattern without reflector for a single STDA, b 1×4 STDA, c 1×8 STDA, and d 2×8 STDA
Fig. 16 3D Radiation Pattern with reflector for a single STDA, b $1 \times 4$ STDA, c $1 \times 8$ STDA, and d $2 \times 8$ STDA
Fig. 17 Radiation pattern of the proposed a single STDA without reflector and b single STDA with reflector

Figure 17a depicts the simulated and measured radiation patterns of the STDA without a reflector at 2.4 GHz with a gain of 6.74dBi, which is matched to the simulated pattern. The simulated and measured radiation pattern of the STDA with reflector at 2.4 GHz with a gain of 11.5dBi is shown in Fig. 17b. When compared to a single STDA without a reflector antenna, it performs better. There is a significant improvement in gain and directivity, and this radiation pattern closely matches the simulated pattern.

The photograph of the proposed STDA antenna with anechoic chamber is depicted in Fig. 18, and the radiation pattern of single STDA without reflector and with reflector is obtained.

5.5 Result and Analysis of the STDA in Arrays

The proposed antenna clearly shows that the proposed antennas in terms of return loss and gain in a Wi-Fi band. The comparison of gain and return loss between the proposed STDA antenna and array antennas is clearly analyzed. The antenna parameters vary greatly between the single STDA antenna and the formed array antennas. An antenna’s performance improves significantly as the number of array elements increases, even at the expense of increased size and complexity. When the number of radiating elements in the antenna is increased, the gain increases linearly. By radiating each element, the proposed antenna produces an efficient output.
5.6 Gain and Return Loss Comparison for Different Array Configuration

There is a comparison and analysis of the gain of the single STDA 1×4, 1×8, and 2×8 arrays STDA for Wi-Fi application. Clearly, the proposed antenna performs better existing Wi-Fi antennas in terms of gain and return loss. Antenna arrays and STDA antennas are compared in Table 3. The table shows that the STDA antenna and the array antennas with and without reflectors have significant differences in their antenna parameters. Increasing the number of array elements always improves performance, but it also increases the size and complexity of the antenna. VSWR is less than 2 for all the antennas.

Antennas with different configurations such as single STDA, 1×4 STDA, 1×8 STDA, and 2×8 STDA with and without reflectors are designed and simulated. This study is conducted to analyze the impact of increasing the number of elements and placing the STDA within the diameter of parabolic reflector. Figure 19 shows the gain (dBi) vs frequency (GHz) of single STDA, 1×4 STDA, 1×8 STDA, and 2×8 STDA array with and without reflector. It can be seen that as number of elements is increased from 1 to 2^n, where n = 2, 3, 4, the gain is increased from 6.74 (dBi), 11.9 (dBi), 14.2 (dBi), and 15 (dBi) for STDA without reflector, respectively.

Further study with reflector reveals that the gain parameter is 11.5 (dBi), 14.8 (dBi), 18 (dBi), 21.6 (dBi). The impact of gain for single STDA, 1×4, 1×8, and 2×8 STDA with and without reflector array configurations with respect to the number of elements is illustrated in Fig. 19. It is observed that as the number of array elements increases, the gain increases linearly.

Antenna’s gain is measured and compared. The antenna gain is a parameter that determines how effectively the antenna can radiate. To improve overall gain, various configurations, including single STDA, 1×4, 1×8, and 2×8 STDA with and without reflectors are designed and measured. The impact of return loss on the number of elements for single STDA, 1×4, 1×8, and 2×8 STDA with and without reflector array configurations is depicted in Fig. 20. It is observed that the gain increases linearly as the number of array elements increases.

The impact of return loss and gain with and without reflector is reported in Table 2. From this, it is clearly shows that the return loss and gain is enhanced significantly by
incorporating reflector which is highly sufficient for real-time applications. There is around 28% of return loss and 46% of gain is improved due to the incorporation of reflector.

Fig. 19 Gain comparison of single STDA, 1×4 STDA, 1×8 STDA, and 2×8 STDA array with and without Reflector

Fig. 20 Return loss comparison of single STDA, 1×4 STDA, 1×8 STDA, and 2×8 STDA array with and without Reflector
Table 2  Return loss and gain comparison of the proposed antenna with and without reflector

| S. No | Types (STDA) | Return Loss (dB) without Reflector | Return Loss (dB) with Reflector | Gain (dBi) without Reflector | Gain (dBi) with Reflector | Gain improvement in percentage (%) | Return loss improvement in percentage (%) |
|-------|--------------|-------------------------------------|----------------------------------|-----------------------------|--------------------------|-------------------------------------|------------------------------------------|
| 1     | Single       | -19                                 | -36                              | 6.74                        | 11.5                     | 41.3                                | 47.2                                     |
| 2     | 1×4          | -15                                 | -30                              | 11.9                        | 14.8                     | 19.5                                | 50                                       |
| 3     | 1×8          | -15                                 | -27                              | 14.2                        | 18                       | 21                                  | 44                                       |
| 4     | 2×8          | -15                                 | -27                              | 15.0                        | 21.6                     | 30                                  | 44                                       |
The functional parameters of the proposed antenna, such as its resonant frequency, return loss, bandwidth, gain, and size, are compared with those of the reported antenna, which are listed in Table 3. According to the table, if the gain is large, either the return loss or the size is large. Also, if the reported antenna return loss is lower, the gain is reduced. According to the literature review, there must be a trade-off between gain and loss or size. However, in this attempt, the proposed antenna has a higher gain of about 11dBi and a lower return loss of -36 dB.

| Ref. | Resonant Frequency (GHz) | Return Loss (dB) | Size (mm²) | Bandwidth (MHz) | Maximum Gain (dBi) |
|------|-------------------------|------------------|------------|----------------|-------------------|
| [2]  | 1.4, 1.5                | −15              | 18.6 × 18.6 | 91             | 9                 |
| [3]  | 3.3, 3.8, 5             | −10              | 204 × 175  | 190            | 5.4               |
| [4]  | 5.2, 6.2, 7.4           | −23              | 35 × 25    | 2511           | 4.8               |
| [5]  | 1.5, 3.4                | −10              | 80 × 65    | −              | 4                 |
| [6]  | 1.5, 1.8, 2.8           | −12              | 90 × 135   | −              | 5.9–7.5           |
| [7]  | −                       | −25              | 6 × 2      | −              | −                 |
| [8]  | 6.36                    | −35              | 16.9 × 4.1 | 151            | −                 |
| [9]  | 1.58, 3                 | −15              | 90 × 115   | 1470           | 6.5               |
| [10] | 0.050, 0.100, 0.150     | −10              | 72 × 70    | 150            | 6.5               |
| [11] | 1.69, 2.3, 2.8          | −18              | 90 × 135   | −              | 5.6               |
| [12] | 1.8, 2.45               | −30              | 90 × 115   | 113            | 5.8               |
| [13] | 1.8, 2.35, 2.6          | −15              | 90 × 115   | 200            | 6                 |
| [14] | 1.8, 2.35, 2.6          | −25              | 90 × 115   | 110            | 5.86              |
| [15] | 0.69–4.37               | −                | 12 × 18    | 680            | 5                 |
| [16] | 1.8, 2.35, 2.6          | −30              | 72 × 115   | 300            | 5.8               |
| [17] | 3, 5.5                  | −29              | 66 × 36    | 150            | 6                 |
| [18] | 2.5, 5.5                | −29              | 48 × 32.2  | 180            | 9                 |
| [19] | 3.5, 5.8                | −15              | 48 × 46    | −              | 5.9               |
| [20] | 5.8                     | −18              | 35 × 35    | 186            | 10                |
| [21] | 1.8, 2.6, 5.8           | −10              | 120 × 120  | 1100           | 7                 |
| [22] | 1.88, 2.34, 2.7, 3.08, 3.6 | −22          | 111 × 77   | 300            | 5.54              |
| [23] | 1.71, 2.69              | −23              | 210 × 170  | 1130           | 10.1              |
| [24] | 2.45, 5.2, 5.8          | −7.5             | 100 × 100  | 470            | 4.7 and 3         |
| [25] | 4, 6, 8.5               | −10              | 40 × 40    | 7000           | 7.7               |
| [26] | 4.2, 6.2, 9.6           | −10              | 30 × 28    | 8000           | 2.5–7             |
| [27] | 3.61, 5.5, 9.45         | −18              | 27 × 27    | 7900           | 4.77              |
| [28] | 4.79                    | −10              | 26 × 26    | 8700           | 7                 |
| [29] | 3.5, 5.5                | −25              | 50 × 50    | 118            | 2.8               |
| Proposed antenna | 2.4 | −36 | 80 × 105 | 200 | 11.5 |

*Not discussed*
6 Conclusion

The design of compact STDA antenna for Wi-Fi application is presented. The proposed antenna consists of two dipole elements with different lengths and a ground plane that are serially connected through a parallel strip line. STDA antenna with rectangular shaped top loading is employed for the two dipole elements. Coplanar strip lines are adopted to improve the impedance matching of the antenna and to increase the gain. The proposed antenna resonates at 2.4 GHz with 200 MHz bandwidth. It is also fabricated and tested, and array analysis was performed for comparative study. The 2 × 8 STDA array with reflector has a maximum gain of 21.6 dBi, which is a very good result. Due to this, array antennas with STDA configurations can be deployed for Wi-Fi applications in the S band.

Authors’ Contributions KM is designed and simulated with the 1 × 4, 1 × 8, 2 × 8 STDA array configuration, MS calculates the structural parameters, such as, length and width of the patch, dimension of the proposed STDA. The design procedure, return loss plot, radiation pattern plot, gain plot shall be analyzed by MW. SR is given the idea, verify the all the simulated results and corrected the manuscript. Authors read and approved the final manuscript.

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Declarations

Conflict of interest The authors declare that there are no competing interests related to this article.

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