Feature Enhancement of Three Log-Periodic Antennas Based on Antipodal Vivaldi Patch

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Abstract Today, microstrip antennas have received a lot of attention due to their unique features such as low weight and volume, easy and cheap construction, and the ability to adapt to planar structures. Of course, the important problem with these antennas is their small gain and bandwidth. In this paper, the gain and bandwidth of the microstrip antenna with a patch in the form of Antipodal Vivaldi are improved by using log-periodic structures. Three 8-element log-periodic structures designed in a straight-line, U-shaped and V-shaped are proposed, simulated and fabricated. The dimensions of these antennas are 287.2 × 48 mm², 182.5 × 160 mm² and 195 × 200 mm² respectively, and their maximum gain are 6.26, 8.3, and 7.61 dBi, respectively, which has increased the bandwidth by approximately 125% compared to the single element mode and increased the gain from 2.26 to 4.3 dBi.

1. Introduction

With the proliferation of communications, the need to build small, compact, multi-band, and high-gain antennas are clearly felt. Therefore, researchers make great efforts to improve the radiation characteristics and reduce the size of the antenna (Lee et al., 2016). Over the past few decades, microstrip antennas have been widely used in this field. Microstrip antennas have advantages over conventional antennas, such as their small size, which is used in wireless devices, airplanes, and satellites. Various methods reduce the dimensions and increase the microstrip antenna gain (Balanis, 2005).

Common methods for designing a multi-band antenna include fractalization, the use of various slots, incomplete ground structure, and parasitic elements. Also, antenna miniaturization methods include the use of high dielectric constant materials, short-circuit microstrip antennas, shorting posts, and the use of cross-slots. The use of materials with high dielectric constant causes surface waves and reduces bandwidth and efficiency. In the shorting post method, the input impedance of the antenna power supply is sensitized to the distance between the shorting posts and the power cable. The method of cross-slots of equal length in the center of the patch is used in double-band antennas. All methods have problems such as decreasing gain and increasing the size of the antenna (Khalaf et al., 2018; Soliman et al., 2015; Zebiri et al., 2019).

Today, there is an increasing need for broadband antennas with low cross-section and directional radiation patterns for military and commercial applications (Wu et al., 2010). The use of microstrip antennas in these areas is severely limited due to the inherent narrow bandwidth of their radiation elements (Almutawa & Mumcu, 2013). To increase the bandwidth, a substrate with a low dielectric constant or a substrate with a higher height can be used, but these two methods will also have problems (Rahim & Gardner, 2004).

Log-periodic structures are used to design broadband antennas. One of these structures, known as a log-periodic array, has multiple elements and directional radiation. The geometry of these antennas is such that their impedance and radiation properties are repeated periodically with frequency logarithm. In practice, the frequency band changes are minor and as a result, these antennas are usually considered frequency-independent (Stutzman & Thiele, 2021). The most famous log-periodic antenna is the model introduced in Balanis (2005). This structure consists of a series of parallel linear dipoles that form an all-plane array. Although this antenna has relatively little
directivity, it can achieve wider bandwidth. Today, using the log-periodic microstrip patch arrays, bandwidths higher than 2 octaves (120%) can also be achieved. The use of such broadband arrays in radars and measurement systems is necessary, while a low cross-section is important (James Hall, 1989).

The Vivaldi antenna is a member of a series of irregularly scaled continuous antennas, gradually curved, transient, and slowly leaky waves. At different frequencies, different parts of the antenna radiate, while the size of the radiant part is based on the wavelength. For this reason, Vivaldi antennas have a theoretically unlimited frequency range with a fixed beamwidth in this range (Ali Omar et al., 2017). Vivaldi antennas are mainly used in radar and wireless applications due to their high bandwidth, low cross-polarization and directional pattern. Conventional Vivaldi antenna is modified by exponential narrowing of both the inner and outer edges. Therefore, it represents a narrow slot antenna in the form of dual exponentials. This antenna model has a wider bandwidth and improved pattern characteristics than the narrow slot antenna as a single exponential (Hood et al., 2008). At the Antipodal Vivaldi, the patches are separated by the substrate and concentrated. This antenna is powered by a standard microstrip transmission line.

Extensive research has been done on log-periodic antennas in recent years. In Pues et al. (1981) a new design for the broadband array of microstrip resonator antennas is presented that is scaled by the log-periodic concept. The radiation elements are fed in series by a simple co-planar microstrip network. In Rahim & Gardner (2004) a log-periodic antenna with an internal power supply and 9 patch elements has been designed and simulated. The designed structure consists of square patches and the selected substrate is FR4. In (Dadel et al., 2011) a log-periodic array was designed using a rectangular microstrip patch with an internal feed for 1, 3 and 5 elements. One of the most important items in the log-periodic antenna is the geometric shape of the patch. In Dadel & Srivastava (2011) triangular patch and in Ghanbari et al. (2013) elliptical patch is considered. In Rahim et al. (2007) simulation and fabrication of ultra-wideband antennas for the shape of the straight-line and U-shaped

Figure 1. Vivaldi antenna is used as a simple initial patch.

Figure 2. How to compress a log-periodic antenna using the proposed Vivaldi patch, (a) distance between two antennas, (b) distance between metal parts.
structure have been done using 17 elements with the log-periodic technique. Finally, in Ding et al. (2012), Wang et al. (2008) simulation and fabrication of log-periodic antennas with dipole elements have been done.

In this paper, by using log-periodic structures, the bandwidth and gain of the microstrip antenna with a patch in the form of Antipodal Vivaldi are discussed. Three 8-element log-periodic structures designed in a straight-line, U-shaped and V-shaped are proposed, simulated and fabricated. In the continuation of this paper, in the second section, the design of the Antipodal Vivaldi patch element and its matching network is done, and in the third section, simulation and measurement of a single Vivaldi antenna based on the proposed structures are done.

![Figure 3](image1.png)

**Figure 3.** Return loss ($|S_{11}|$) of a single Vivaldi antenna.

![Figure 4](image2.png)

**Figure 4.** Three-dimensional patterns of a single Vivaldi antenna at the operating frequency, (a) 6.4 GHz, (b) 8.2 GHz.
section, the design of the 8-element straight-line, U-shaped and V-shaped log-periodic antennas is performed. In addition, in the fourth section, the results of fabrication and measurement are presented and compared with simulation results. Finally, a conclusion is given in the fifth section.

2. Design of Patch Element

2.1. Design of Antipodal Vivaldi Patch Element

As mentioned earlier to design a log-periodic antenna, first a simple patch antenna must be designed and is called this antenna A1, and then multiply the dimensions of antenna A1 by a fixed number such as K, and the antenna is created by multiplying the number K in antenna A1 is called A2. Therefore, antenna A3 is obtained by multiplying the number K by antenna A2. This procedure repeats for any number of required elements. Therefore, to design a log-periodic antenna, a suitable patch element must be selected in the first step. It can be said that the most important challenge in designing a log-periodic antenna is the choice of the initial simple patch antenna because when a simple patch antenna with specific dimensions has been designed, it resonates at a certain frequency, such as f1, but when its dimensions is multiplied by the scale factor, due to the change in the dimensions of the antenna, the input impedance of the antenna changes, and due to the change in impedance, the resonant frequency of the antenna changes and shifts to another frequency, such as f2. As a result, for example, if the design of a log-periodic antenna with 8 elements is to be considered, 8 antennas with different impedances and resonant frequencies, must be connected. The main problem after connecting the elements is that when these 8 elements are connected with different impedances, the impedance of each element affects the other elements and thus the total impedance of this antenna will be unpredictable. This is why adapting and increasing the bandwidth of log-periodic antennas is very difficult. To solve this problem, the Vivaldi antenna is used as the initial simple patch antenna. The reason for this choice is that the Vivaldi antenna has very good adaptation and radiation characteristics, and for this reason, it is widely used in array antennas. In this paper, a new idea of the Antipodal Vivaldi patch element for the log-periodic antenna is introduced. In previous log-periodic antennas, almost most simple patch models of square, rectangular, triangular, ellipse and rhombus have been used, but so far Vivaldi antenna has not been used in the design of the log-periodic antenna. Therefore, this idea is proposed and introduced for the first time in this paper. The Vivaldi antenna that has been used in this paper, has two parts in the shape of a butterfly wing, and one of these parts is above and the second part is below the antenna. This causes compression in log-periodic antennas because if both parts of the butterfly wing were on one side.

Figure 5. The maximum gain of a single Vivaldi antenna.

Figure 6. Proposed power supply network model.
of the antenna, there should be a large distance between them so that it does not interfere with the side antenna. However, in this model, the Vivaldi antenna is considered, even if there is no distance between the two antennas, there is still a very large distance between the upper parts of the log-periodic antenna and no part of the antennas is connected. The geometry of this simple Antipodal Vivaldi antenna and its dimensions is shown in Figure 1. In this structure, the wings are flattened with the following exponential formulas:

\[
x_i = \pm C_S \cdot \exp(K_S y) \pm (C_S + 0.5 \cdot C_W)
\]

(1)

\[
x_o = \pm C_W \cdot \exp(K_W y) \pm (C_S + 0.5 \cdot C_W)
\]

(2)

where \(x_i\) and \(x_o\) are distances from the center line of the gap to the inner and outer edges, and \(C_S, C_W, K_S\) and \(K_W\) are the parameters that control the exponential shape of the patch.

Based on the dimensions considered in Figure 1 and by selecting FR4 with a dielectric constant 4.3, loss tangent 0.025 and substrate height 1.6 mm, the structure is simulated and its results are investigated below. How to compress a log-periodic antenna using the selected Vivaldi antenna is shown in Figure 2. As shown in Figure 2a, for the metal parts of the two antennas not to be connected, there must be a distance of at least 1 mm between the two antennas, so the dimensions of the two antennas are together in this case 65 mm. While in Figure 2b it can be seen that as much as 65 mm dimensions of the two antennas, the metal parts of the two adjacent antennas are spaced about 16 mm apart. In this case, without the metal parts of the two antennas being connected, they can be brought very close together.

![Figure 7. Straight-line 8-element log-periodic antenna. (a) top. (b) behind.](image_url)
The magnitude of return loss related to the single Antipodal Vivaldi of Figure 1, is shown in Figure 3. This figure shows that the return loss of a simple single Vivaldi antenna in a frequency range of 6.4–8.2 GHz is below −10 dB, so its bandwidth is about 1.8 GHz. The three-dimensional patterns of the Vivaldi antenna at operating frequencies of 6.4 and 8.2 GHz are shown in Figure 4. The maximum gain of this antenna is shown in Figure 5. This figure shows that the maximum gain of a Vivaldi antenna is at a frequency of 17 GHz, which is equal to 5.7 dBi, but the antenna does not adapt well at this frequency. As a result, the maximum antenna gain at the operating frequency of 6.4–8.2 GHz is equal to 4.06 dBi which occurs at a frequency of 8.2 GHz.

### 2.2. Design of Matching Network

In this paper, 8 elements are used to design a log-periodic antenna. Here the simple primary antenna is the Vivaldi antenna. Since in a log-periodic antenna, the elements are formed by multiplying a number by all the dimensions of the previous antenna, so the width of the transmission line of the first antenna is calculated according to the substrate material and thickness and impedance 50 Ω and called it w1. The width of the second antenna transmission line is obtained by multiplying the number \( K \) by w1, that is, \( w_2 = K \times w_1 \). As a result, because the substrate material and its thickness are constant for all elements, the impedance corresponding to the width \( w_2 \) becomes a number other than 50 Ω. Therefore, with the direct power supply network, only the first antenna can be excited by 50 Ω. To solve this problem, the stepped feed network model can be used. In this way, first, by the substrate material and the thickness of the substrate, the width of the main transmission line of the power supply network for the impedance of 50 Ω is obtained, and then to excite each antenna by 50 Ω, instead of connecting the main transmission line network directly to the antennas, connect it to the antennas in two steps. By changing the width of these two steps, it can adjust what impedance is seen by the antenna. The proposed power supply network model is shown in Figure 6.

The value of \( w_1 \) in Figure 6, which is based on the substrate material, substrate thickness and impedance 50 Ω, is obtained 3 mm, by Equation 3. Now, \( w_2 \) and \( w_3 \) are obtained according to the width of the first antenna input transmission line and \( w_4 \) and \( w_5 \) are also obtained according to the width of the second antenna input transmission line. In other words, by changing the width of \( w_2 \) and \( w_3 \), it can adjust what impedance enters the first antenna (Anuar et al., 2012).

\[
\frac{w}{d} = \frac{8\varepsilon^4}{\varepsilon^2 + 2} \quad \left( \frac{w}{d} < 2 \right)
\]

(3)

where \( d \) is the substrate thickness and \( A \) is calculated by the following relation:

\[
A = \frac{Z_0}{60} \sqrt{\frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1} \left( 0.23 + \frac{0.11}{\varepsilon_r} \right)}
\]

(4)

Where \( \varepsilon_r \) is the relative permittivity of substrate and \( Z_0 \) is the line characteristic impedance.
Figure 9. Two-dimensional radiation patterns of the proposed straight-line 8-element log-periodic antenna at frequency, (a) 4 GHz, (b) 8 GHz, (c) 12 GHz.
3. Log-Periodic Antenna

3.1. Straight-Line Log-Periodic Antenna

After designing a single Vivaldi antenna and its power supply network, 8 antenna elements using the primary Vivaldi antenna are created. Multiply the primary element by a scale factor of $K = 1.05$ to obtain the second element, then continue this procedure until the end for 8 elements. Selecting this coefficient causes the frequency response to lead to the best gain and bandwidth. However, the dimensions along the $x$ and $y$ axes should be multiplied by a fixed number of 1.05, and the $z$-dimensions of the antenna should not be changed. As mentioned in the previous section, the distance between the elements does not follow the rule of scale coefficient and should be positioned to have the best response to the antenna parameters. Therefore, first, by considering the distances based on the scale coefficient and then optimization to make the matching, the best spacing between elements is listed in Table 1. Also, Figure 7 shows the proposed straight-line log-periodic antenna in the Computer Simulation Technology (CST) software environment. The dimension of the antenna with this arrangement is $A_287.2 \times 48$ mm$^2$.

The magnitude of return loss is shown in Figure 8. It is observed that the return loss of this antenna, is approximately below $-10$ dB at a frequency range of 3–16 GHz. As a result, the bandwidth of the proposed antenna is greater than 13 GHz which is about several times the bandwidth of similar antennas. Of course, as it can be seen, in some frequencies the $|S_{11}|$ is located above the $-10$ dB, that this is a natural phenomenon in most broadband log-periodic antennas and does not lose its good performance. The cause of this phenomenon is the incomplete matching in these structures. Naturally, by applying a more complete matching, this problem can also be solved.

Two-dimensional radiation patterns of this proposed antenna at three frequencies 4, 8 and 12 GHz and in the H-plane ($\varphi = 90^\circ$) and E-plane ($\theta = 90^\circ$) are shown in Figure 9 and its maximum gain is shown in Figure 10. As can be seen, the maximum gain of this antenna occurs at a frequency of 5 GHz and is equal to 6.26 dBi, which is increased by 2.26 dBi compared to a single Vivaldi antenna.

3.2. U-Shaped Log-Periodic Antenna

In the previous section, it was observed that the proposed straight-line 8-element log-periodic antenna had good adaptation and bandwidth, and also its gain was higher than a single antenna. In this step, to increase the gain of the log-periodic antenna, instead of arranging the elements in a straight-line, it arranges in two directions and in a U-shaped. The distance between the elements has been optimized and the values in Table 2 have been obtained.
to create suitable matching conditions. Also, Figure 11, shows the proposed U-shaped log-periodic antenna in the CST software environment. The dimension of this antenna with this arrangement is $A \times 182.5 \times 160 \text{mm}^2$.

The magnitude of return loss is shown in Figure 12. In this figure, it is observed that the return loss of this antenna, is approximately below $-10 \text{dB}$ at a frequency range of 2.5–18 GHz. As a result, the bandwidth of the proposed antenna is greater than 15 GHz which is about several times the bandwidth of similar antennas and 2 GHz greater than a straight-line structure. Of course, in some frequencies the $|S_{11}|$ is located above $-10 \text{dB}$, but the number of points is less than the straight-line structure.

Two-dimensional radiation patterns of this proposed antenna at three frequencies 4, 8, and 12 GHz and in the H-plane ($\phi = 90^\circ$) and E-plane ($\theta = 90^\circ$) are shown in Figure 13. The maximum gain of this antenna is shown in Figure 14. As can be seen, the maximum gain occurs at a frequency of 8 GHz and is equal to 8.33 dBi, which is increased, approximately by 2 dBi compared to a straight-line structure and 4.33 dBi compared to a single Vivaldi antenna.

### 3.3. V-Shaped Log-Periodic Antenna

One of the methods of arranging the elements of log-periodic antennas is a V-shaped structure. The advantage of V-shaped over U-shaped is that if the size of the angle between the two main transmission lines is small, the dimensions of the V-shaped log-periodic antenna are smaller than U-shaped. In this paper, two different arrangements of V-shaped log-periodic antenna are proposed. In the first method, the elements are arranged one-sided and in the second method, they are arranged one in between.

![](image1.png)

**Figure 11.** U-shaped, 8-element log-periodic antenna, (a) top, (b) behind.

![Figure 12. $|S_{11}|$ of the proposed U-shaped, 8-element log-periodic antenna.](image2.png)
Figure 13. Two-dimensional radiation patterns of the proposed U-shaped, 8-element log-periodic antenna at frequency, (a) 4 GHz, (b) 8 GHz, (c) 12 GHz.
3.3.1. One-Sided V-Shaped Log-Periodic Antenna

The geometry of the proposed one-sided V-Shaped, 8-element log-periodic antenna is shown in Figure 15. In this arrangement, all patches of the Vivaldi elements are placed on one side of the substrate. Also, the distances between the elements to adapt to the 50 Ω line, are obtained using optimization and are shown in Table 3. The dimension of the proposed log-periodic antenna with this arrangement is 195 × 200 mm² and the angle between two main transmission lines is 30°. However, by reducing this angle, the dimensions can be made much smaller, but coupling between elements increases and reduction of directivity occurs. That is why this angle and these dimensions have been chosen so that all the specifications of the antenna are good. Where size is limited, it can be halved by reducing this angle. The magnitude of return loss is shown in Figure 16. It is observed that the return loss of this antenna, is approximately below −10 dB, at a frequency range of 2.5–18 GHz. As a result, its bandwidth is greater than 15 GHz which is about several times the bandwidth of similar antennas and 2 GHz greater than a straight-line structure. Of course, in some frequencies the $|S_{11}|$ is located above −10 dB. However, the number is less than the straight-line structure. Two-dimensional radiation patterns of this proposed antenna at three frequencies 4, 8, and 12 GHz and in the H-plane ($\varphi = 90^\circ$) and E-plane ($\theta = 90^\circ$) are shown in Figure 17.

The maximum gain of this antenna is shown in Figure 18. As can be seen, the maximum gain of this antenna occurs at a frequency of 7.5 GHz and is equal to 7.61 dBi, which is increased, approximately by 1.4 dBi compared to a straight-line structure and 3.61 dBi compared to a single Vivaldi antenna, but concerning the U-shaped structure is decreased by 0.72 dBi. The reason for this is more coupling between elements. However, by increasing the

![Figure 14](image1.png)  
**Figure 14.** The maximum gain of the proposed U-shaped, 8-element log-periodic antenna.

![Figure 15](image2.png)  
**Figure 15.** One-sided V-Shaped, 8-element log-periodic antenna, (a) top, (b) behind.
aperture angle of the structure, the coupling between the elements can be reduced, which leads to an increase in antenna size, which is not desirable.

3.3.2. One in Between V-Shaped Log-Periodic Antenna

Another way of arranging elements is to arrange one in between. This arrangement causes a lot of compressions. In this state, the direction of each antenna is opposite to the next antenna, that is, if the first antenna is on the positive side of the y-axis, the second antenna is on the negative side of it. Because antennas are in two different directions, even if there is no distance between them, there is no connection. Here, the 8 elements are placed one in between on either side of the main transmission line and are fed by a V-shaped network model with an angle of 40°. The overall dimension of the structure is 195 × 170 mm², which is reduced by 15% compared to the one-sided case. The geometry of this proposed antenna is shown in Figure 19. Also, the distances between the elements to adapt to the 50 Ω line, are obtained using optimization and are shown in Table 3.

The magnitude of return loss is shown in Figure 20. It is observed that the return loss of this antenna, is approximately below −6 dB (VSWR = 3) at a frequency range of 2.3–14 GHz. As a result, not only has the frequency range decreased, but it has also moved away from the desired value in parts. Two-dimensional radiation patterns of this proposed antenna at three frequencies 4, 8, and 12 GHz and in the H-plane (θ = 90°) and E-plane (φ = 90°) are shown in Figure 21.

As can be seen from Figures 9, 13, 17, and 21, the radiation patterns rotate with the change of frequency. The reason for this is that because the phase difference of currents between the array elements is dependent on the wave number and also depends on the frequency, then this phase difference changes with the change of frequency, and electronic scanning occurs and the radiation patterns rotate (Masoumi et al., 2021; Mohammadi Shirkolahi & Galibafan, 2021). Also, mutual coupling between array elements has many negative effects, including unwanted rotation of the main lobe, creation of additional lobes, lack of proper impedance matching, scan blindness, etc. But one of the most important negative effects of this mutual coupling is the increase in side lobe level (SLL). In this article, there is mutual coupling between the elements of the array, which increases SLL. Of course, by increasing the distance between the elements, this effect can be reduced, but this increases the size of the antenna, which is not desirable.

The maximum gain of this antenna is shown in Figure 22. As can be seen, the maximum gain of this antenna occurs at a frequency of 6 GHz that is equal to 5.28 dBi, which is increased, approximately by 1.22 dBi compared to a single Vivaldi antenna, but concerning the straight-line, U-shaped and one-sided V-Shaped structures is

| Table 3 | Optimized Distances (mm) Between Elements in a One-Sided V-Shaped Structure |
|---|---|---|---|---|---|---|---|---|---|
| d1 | d2 | d3 | d4 | d5 | d6 | d7 | d8 | d9 | d10 |
| 25.5 | 36.05 | 37.12 | 41.2 | 50.12 | 28.62 | 40.14 | 42.8 | 44.58 | 16.3 |

Figure 16. |S₁₁| of the proposed one-sided V-Shaped, 8-element log-periodic antenna.
Figure 17. Two-dimensional radiation patterns of the proposed one-sided V-Shaped, 8-element log-periodic antenna at frequency, (a) 4 GHz, (b) 8 GHz, (c) 12 GHz.
decreased by 0.98, 3.05, and 2.33 dBi, respectively. Despite the reduction in the size of the proposed one in between structures, the antenna parameters deteriorated and therefore this structure is not recommended.

4. Fabrication and Measurement

To ensure the accuracy of the proposed log-periodic antenna designs, three samples were fabricated and tested. After performing the measurements, the simulation and measurement results are compared with each other. It can be seen that there is a good agreement between these results. It is worth noting that the way of feeding the antenna arrays is series feeding. The advantage of series feeding over parallel feeding is that in parallel feeding, due to the use of more conductors, ohmic losses increase, which in turn reduces the gain of the antenna. Also, parallel feeding increases the dimensions of the antenna structure. Additional specifications of series and parallel feedings are given in references (Mohammadi Shirkolahi, 2020a, 2020b; Mohammadi Shirkolahi, Dalili Oskoui et al., 2021).

4.1. Fabricated Sample of Straight-Line 8-Element Log-Periodic Antenna

The fabricated sample of the proposed straight-line 8-element log-periodic antenna is shown in Figure 23. FR4 with a dielectric constant of 4.3, loss tangent of 0.025 and substrate height of 1.6 mm is used and its dimensions and distances between elements are shown in Table 1. Also, the measured and simulated return loss for this antenna is shown in Figure 24, simultaneously.
4.2. Fabricated Sample of U-Shaped 8-Element Log-Periodic Antenna

The fabricated sample of the proposed U-shaped 8-element log-periodic antenna is shown in Figure 25. FR4 with a dielectric constant of 4.3, loss tangent of 0.025 and a substrate height of 1.6 mm is used and its dimensions and distances between elements are shown in Table 2. Also, the measured and simulated return loss for this antenna is shown in Figure 26 simultaneously.

4.3. Fabricated Sample of One-Sided V-Shaped 8-Element Log-Periodic Antenna

The fabricated sample of the proposed one-sided V-shaped 8-element log-periodic antenna is shown in Figure 27. FR4 with a dielectric constant of 4.3, loss tangent of 0.025 and substrate height of 1.6 mm is used and its dimensions and distances between elements are shown in Table 3. Also, the measured and simulated return loss for this antenna is shown in Figure 28 simultaneously.

Table 5 compares the proposed structures that are presented in this paper. In this table, parameters such as the number of elements, size, frequency range and bandwidth, maximum gain and directivity and scale factor are compared. Based on this table, it is observed that the U-shaped structure has the best performance among these structures. The main reason for this is the proper coupling between the elements. Therefore, in Table 6 this structure is compared with some of the structures that are presented in previous articles. This table shows that the antenna proposed in this paper has better performance than previous similar antennas. As it can be deduced from Table 6, the antenna proposed in this article has much more bandwidth, maximum directivity and maximum gain than the antennas designed in past works. In previous works, log-periodic structures were worked with ordinary microstrip patches, such as square, triangular, rectangular, elliptical and rhombus, while in this work, these patches designed and fabricated in the form of Antipodal Vivaldi. Also, the structure of V-shaped with normal patches has not been worked on and reported until now. The proposed structures in this article are smaller than the previous structures. Relatively high gain and bandwidth show that these structures work well. This clearly shows the innovation in this article.

It can be concluded that:

1. There are many methods to increase the bandwidth of log-periodic antennas that can be used according to their geometric shape of it. In this work, the technique of incomplete ground structure was used to increase the bandwidth.
2. By changing the existing structures to increase gain and bandwidth, the desired results can be achieved and it is not always necessary to design a different pattern.

![Figure 20](image-url)  
*Figure 20. |S| of the proposed one in between V-Shaped, 8-element log-periodic antenna.*
Figure 21. Two-dimensional radiation patterns of the proposed one in between V-Shaped, 8-element log-periodic antenna at frequency, (a) 4 GHz, (b) 8 GHz, (c) 12 GHz.
3. By changing the antenna parameters, the antenna design can be optimized according to the intended purpose for other applications.

5. Conclusion

In this paper, four different structures of log-periodic antennas based on the Antipodal Vivaldi patch, are proposed. The bandwidth of these antennas is more than 16 GHz per $|S_{11}|$ standard less than $-10$ dB from the frequency range of 2–18 GHz. As explained in previous sections, the biggest drawback of log-periodic array antennas is their very low bandwidth, and many solutions to this challenge have been proposed in similar previous articles. However, despite these solutions, the bandwidth of the proposed antennas in some cases has not even reached 1 GHz. In this paper, four different models of log-periodic array antennas are introduced, all of which

![Figure 22. The maximum gain of the proposed one in between V-Shaped, 8-element log-periodic antenna.](image)

![Figure 23. Fabricated sample of the proposed straight-line 8-element log-periodic antenna, (a) top, (b) behind.](image)
Figure 24. Measured and simulated of $|S_{11}|$ for the straight-line 8-element log-periodic antenna.

Figure 25. Fabricated sample of the proposed U-shaped 8-element log-periodic antenna, (a) top, (b) behind.

Figure 26. Measured and simulated of $|S_{11}|$ for the U-shaped 8-element log-periodic antenna.
Figure 27. Fabricated sample of the proposed one-sided V-shaped 8-element log-periodic antenna, (a) top, (b) behind.

Figure 28. Measured and simulated of $|S_{11}|$ for the one-sided V-shaped 8-element log-periodic antenna.

Table 5

| Structure              | No. of elements | Element shape | Dimension in $\lambda^2$ | Frequency range (GHz) | Bandwidth | Maximum gain (dBi) | Maximum directivity (dBi) | Scale factor |
|------------------------|-----------------|---------------|--------------------------|------------------------|-----------|-------------------|---------------------------|--------------|
| Single element         | 1               | Vivaldi       | 0.85 × 0.63              | 6.4–8.2                | 27%       | 4                 | 4.7                        | -            |
| Straight-line          | 8               | Vivaldi       | 2.87 × 0.48              | 3–18                   | 142%      | 6.26              | 7.7                        | 1.05         |
| U-shaped               | 8               | Vivaldi       | 1.58 × 1.38              | 2.6–18                 | 149%      | 8.3               | 12.5                       | 1.05         |
| One-sided V-shaped     | 8               | Vivaldi       | 1.6 × 1.56               | 2.4–18                 | 152%      | 7.61              | 11.8                       | 1.05         |
Table 6
Comparison of the Proposed U-Shaped Antenna With Other Log-Periodic Antennas

| Ref. | No. of elements | Element shape          | Dimension in $\lambda^2$ | Frequency range (GHz) | Bandwidth | Maximum gain (dBi) | Maximum directivity (dBi) | Scale factor |
|------|----------------|------------------------|--------------------------|-----------------------|-----------|-------------------|--------------------------|--------------|
| Dadel et al. (2011) | 5   | Square                  | 1.06 $\times$ 0.56       | 2–2.5                | 22%       | –                 | –                        | 1.05         |
| Dadel et al. (2011) | 7   | Square                  | 1.5 $\times$ 0.6         | 2–2.8                | 33%       | –                 | –                        | 1.05         |
| Dadel et al. (2011) | 9   | Square                  | 1.9 $\times$ 0.65        | 2–3.15               | 44%       | –                 | –                        | 1.05         |
| Dadel and Srivastava (2011) | 3   | Rectangle               | 0.8 $\times$ 0.65        | 3.1–7                | 77%       | 5.87              | –                        | 0.9          |
| Dadel and Srivastava (2011) | 5   | Rectangle               | 0.9 $\times$ 0.85        | 3.1–5.7              | 59%       | 6.98              | –                        | 0.9          |
| Ghanbari et al. (2013) | 4   | Square                  | 0.96 $\times$ 0.64       | 2.4–2.5              | 7.47%     | 2.75              | 7.05                     | 1.03         |
| Rahim et al. (2007) | 3   | Triangle                | 2.1 $\times$ 1.7         | 8.2–11.2             | 30%       | 4.8               | –                        | 0.7–0.98     |
| Rahim et al. (2007) | 5   | Triangle                | 2.4 $\times$ 2.2         | 7.8–11               | 34%       | 7.7               | –                        | 0.7–0.98     |
| Wang et al. (2008) | 17  | Square (straight-line)  | 2.85 $\times$ 0.95       | 3–8.5                | 95%       | –                 | –                        | 1.05         |
| Wang et al. (2008) | 17  | Square (U-shaped)       | 1.85 $\times$ 1.4        | 3.5–10               | 96%       | –                 | –                        | 1.05         |
| Anuar et al. (2012) | 11  | Rectangle               | 2.25 $\times$ 0.9        | 3.2–5.8              | 57%       | –                 | –                        | 1.1          |
| Anuar et al. (2012) | 11  | Ellipse                 | 2.25 $\times$ 0.9        | 2.8–5.2              | 60%       | –                 | –                        | 1.1          |
| This work | 8   | Vivaldi                 | 1.58 $\times$ 1.38       | 2.6–18               | 149%      | 8.3               | 12.5                     | 1.05         |

have a bandwidth of at least several times the bandwidth of the previous similar antennas. After designing the four proposed structures, each model was compared with the other model to determine the best arrangement. Finally, out of these proposed antenna design models, three models have been fabricated and measured and then the simulation and measurement results are mentioned. The measurement results show that the bandwidth of the 8-element straight-line, U-shaped and one-sided V-shaped antennas are 3–18, 2.6–18, and 2.4–18 GHz respectively, and their maximum gain is 6.26, 8.3, and 7.61 dBi, respectively, which has increased the bandwidth by approximately 125% compared to a single element mode and increased the gain from 2.26 to 4.3 dBi.

Data Availability Statement
All data in the figures and tables can be reproduced from description and equations in the present work and no additional data sets were used in this work. All simulation results are obtained with the CST software. A download source for this software is at https://edu.3ds.com/en/software/cst-studio-suite-learning-edition. All data that are used in this work are available at Zenodo via https://zenodo.org/record/7178233%23.YOLk13ZBw2w. Also, the data that support the findings of this study are available from the corresponding author upon reasonable request.

Acknowledgments
The authors consider it necessary to express their sincere gratitude to Iran Madar Sanat Company for manufacturing the antenna and to the person in charge of the antenna room of Khajeh Nasir al-Din Tusi University, Dr. Abu Turab, for testing the antenna.

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