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Improvement of Bandwidth and Gain of Yagi Array Microstrip Antenna Series Corporate Feeding for 5G Application

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ABSTRACT

Purpose: This study aims to design and analyse advanced microstrip antennas operating at 28 GHz, focusing on improving gain and bandwidth to meet the requirements of fifth-generation (5G) applications.

Materials and Methods: The antenna designs were implemented and analysed using High Frequency Structure Simulator (HFSS) software. The research began with a single patch antenna as a baseline model. Subsequent designs incorporated director elements above the patch and reflector elements below it to enhance performance. Further improvements were achieved by developing a 1×2 array antenna, where patch elements were supported by Yagi structures. Finally, a 1×4 array antenna was designed using the Corporate Series Feeding technique to ensure optimal power distribution among elements.

Results: The single patch antenna provided fundamental performance characteristics. Adding director and reflector elements resulted in a significant increase in gain and bandwidth. The 1×2 array design further improved these parameters, demonstrating broader frequency coverage. The final 1×4 array antenna achieved the highest gain and widest bandwidth among all designs, confirming its suitability for high-performance 5G applications.

Conclusion: The progressive design approach demonstrated that integrating director, reflector, and array configurations substantially enhances antenna performance. The proposed 1×4 array antenna, optimised with Corporate Series Feeding, provides superior gain and bandwidth, making it a strong candidate for next-generation wireless communication systems. *(J Multidiscip Eng 2026;1:39-52)*

Keywords: Microstrip antenna, Bandwidth, Gain, 5G.

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1. INTRODUCTION

The emergence of 5G technology has introduced unprecedented challenges in antenna design. The requirements for high-speed data transmission, low latency, and increased network capacity necessitate antennas with superior performance metrics such as high gain, wide bandwidth, and reduced size. Microstrip antennas are widely used due to their flat structure, ease of manufacturing, and compatibility with modern circuits. However, its inherent limitations—low gain and narrow bandwidth—make it less ideal for fifth-generation applications. This paper addresses the design and analysis of a rectangular microstrip antenna operating at 28 GHz, enhanced with Yagi elements to improve gain, bandwidth, and radiation performance. The antenna uses an RT/Duroid 5880 substrate, known for its low dielectric constant ($\varepsilon_r = 2.2$) and low loss tangent, making it ideal for high-frequency applications. A basic microstrip patch antenna was designed first, followed by the integration of Yagi elements that function as directors and reflectors to enhance the

antenna's performance. The simulation was conducted using the HFSS software, and the results revealed significant improvements. Adding Yagi elements enhanced the antenna's bandwidth by 36% (from 0.7 GHz to 0.95 GHz), improved the return loss to −18.5 dB, and increased the gain from 6.31 dB to 7.52 dB. The radiation pattern analysis also confirms the super-directivity and reduced side lobes, meeting the stringent requirements of modern wireless systems. This work highlights the advantages of integrating Yagi elements into flat antenna systems, demonstrating their ability to achieve high efficiency, improve impedance matching, and provide superior directional radiation. The proposed design provides an integrated and cost-effective solution for fifth-generation applications and other high-frequency uses, such as radar and space communications.

2. BACKGROUND

A. Feed Network for Array Antenna

Antenna elements in an array configuration can be fed through a single line (series fed) or by multiple lines (corporate or parallel feeding). [1,2]

1. Feed Series Network

As seen in Figure (Fig. 1), a single line feeds each antenna in this feed network, as well as the radiating elements. Element feeds from the preceding one, as the graphic illustrates. The performance of each antenna element is directly impacted by any changes made to any other part. This feed network's benefits include a low sidelobe level of the array, less feed network losses, and ease of application and fabrication. This feeds network's limitations, however, come from its limited bandwidth and usage in arrays that either have a fixed beam or employ frequency scanning for beam scanning. [1,2]

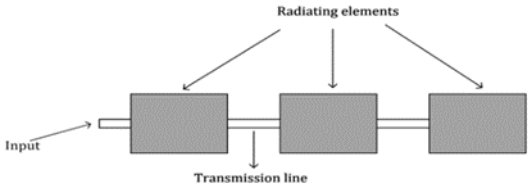


Fig 1. Series feed network.

2. Corporate Feed Network

As shown in Figure (Fig. 2), this feed network uses numerous lines to supply the antenna elements. Based on the figure, the corporate feed network's power splits or feedlines of 2^n (i.e n = 2, 4, 8, 16, 32, 64, etc.) are achieved by employing tapered lines or multiple-section quarter-wavelength impedance transformers. Benefits of this feeding include beam scanning capabilities, broad bandwidths, and equitable power distribution to all antenna parts. This method's drawback is substantial feed losses from several lines. [2]

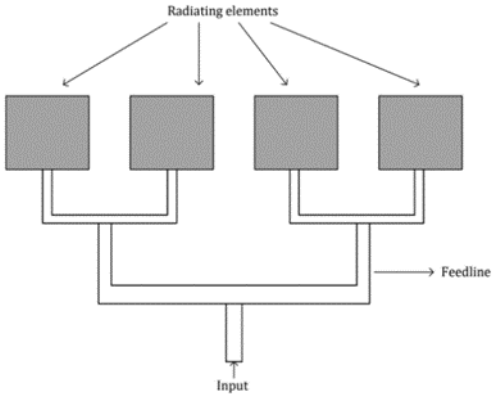


Fig 2. Corporate feed network.

3. METHODOLOGY

This paper begins with the design of a single-patch antenna without additional elements. The performance of this antenna is studied and analysed as a fundamental step in this study. In the next stage, the design is improved by adding director elements above the correcting antenna and two reflector elements below it. The performance improvement is evaluated. Next, a 1×2 array antenna is designed to operate at a frequency of 28 GHz, where the primary elements are patch antennas supported by Yagi elements. This design aims to increase gain and further broaden the frequency range. Finally, the targeted design is being developed, which is a 1×4 array antenna, fed using the Corporate Series Feeding technique to ensure optimal power distribution among the elements.

3.1 Design Methods

The design of a single rectangular patch antenna serves as the foundation for the planned phased antenna for 5G wireless applications. The design process for a single patch antenna includes determining the antenna's dielectric substrate, height (t), dielectric constant (ε_r), and resonant or operational frequency. The antenna's measurements, including its patch length and width, can be ascertained using these metrics. Will use (dielectric substrates RT-5880) to create a single

rectangular patch antenna. Following a performance evaluation of the design, Yagi components will be incorporated into the patch antenna and subsequently utilised as radiating elements for the suggested phased array antenna. [3,4]

Figure (Fig. 3) shows the single rectangular patch antenna that is suggested in this chapter. The antenna consists of a 50 Ω feedline, a quarter-wave transformer, and a rectangular radiating patch. The most widely used voltage in transmission lines to reduce reflection and return loss is 50 Ω. Copper with a thickness of 0.035 mm is used in this design to create the radiating patch of the single patch antenna. Additionally, copper serves as a conducting material for the antenna's transmission line and ground plane. Additionally, this suggested single rectangular patch antenna operates at 28 GHz. [5]

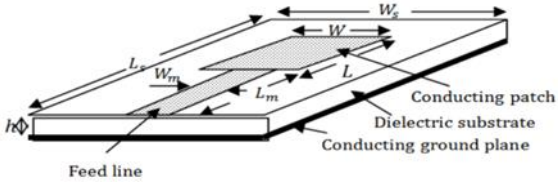


Fig 3. Rectangular patch with the feed line.

3.2 Design Equations

In terms of RL, B, and G, the microstrip patch antenna array is intended to perform better than the microstrip patch antenna. One of two feed configurations-parallel or serial-can supply the patch elements in the array configuration: many lines or a single line. Choosing the patch, substrate, and feed line sizes is the first step in designing the micro-strip patch antenna.

1. Design of Microstrip Single Patch Antenna

Key parameters such as the patch dimensions (width and length), the effective dielectric constant, the extension length, the ground plane dimensions, and the feedline properties must be calculated when designing a microstrip single patch antenna with the Rogers RT/Duroid 5880 dielectric substrate. Equations (1) to (16) are used in this section to calculate these parameters in detail. [4,5]

- Patch Width Calculation (W)

$$W = \frac{1}{2f_r\sqrt{\mu_o * \varepsilon_o}}\sqrt{\frac{2}{\varepsilon_{r+1}}} = \frac{C}{2f_r\sqrt{\frac{\varepsilon_r+1}{2}}} \quad \ldots\ldots\ldots\ldots (1)$$

Where:

C is the free space velocity of light.

f_r Resonance Frequency.

μ_o Absolute permeability.

ε_o Absolute permittivity.

Calculations begin with the width of the patch using equation (1).

$$W = \frac{3 \times 10^8}{2(28 \times 10^9)}\sqrt{\frac{2}{2.2+1}} = 4.232mm$$

- Effective Dielectric Constant

Due to the finite dimensions (length and width) of the radiating patch, fields at the patch edges go through a fringing effect. This makes the microstrip patch appear electrically wider compared to its physical dimensions. In order to account for the fringing effect, an effective dielectric constant is introduced, and it is calculated based on the equation. [4]

$$\epsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[\frac{1}{\sqrt{1+12\left(\frac{h}{w}\right)}}\right] \ldots\ldots\ldots (2)$$

The effective dielectric constant is calculated using equation (2) as:

- Effective Length

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}} - 2\Delta L \quad \ldots\ldots\ldots\ldots (3)$$

The Microstrip Patch Antenna is longer than its physical dimensions because of the effect of fringing. The effective length, therefore, differs from the physical length by (ΔL). A very popular method to calculate the extension of the length of the patch is given by [4, 5]:

$$\Delta L = 0.412h\left(\frac{(\varepsilon_{eff}+0.3)\left(\frac{w}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{w}{h}+0.8\right)}\right) \ldots\ldots\ldots (4)$$

The extension length of the patch using equation (4) is:

$$\Delta L = 0.412h\left(\frac{(2.3+0.3)\left(\frac{4.232}{0.5}+0.264\right)}{(2.3-0.258)\left(\frac{4.232}{0.5}+0.8\right)}\right) = 0.74m$$

- Patch Length (L)

The actual length of the radiating patch is calculated using equation (3) as:

$$L = \frac{3 \times 10^8}{2\,(28 \times 10^9)\sqrt{2.3}} - 2(0.74) = 3.28\,mm$$

- Ground Plane Dimensions

The ground plane's size is ascertained when the radiation patch's size is established. Equations (5) and (6), as follows, are used to determine the ground plane's dimensions [4]:

$$W_g = 6h + w \quad \ldots\ldots\ldots (5)$$

$$L_g = 6h + l \quad \ldots\ldots\ldots (6)$$

By substituting into equations (5) and (6) determined. The dimensions of the ground plane

$$Lg = 3.28 + 6\,(0.5) = 6.28mm$$

$$Wg = 4.232 + 6(0.5) = 7.232mm.$$

- Feedline Width (W_f)

Because of its simplicity and ease of analysis, the single rectangular patch antenna transmits power from the source to the radiating patch using a microstrip feedline for excitation. Equation (7) is used to calculate the width of the microstrip feedline for a given characteristic impedance " Z_0" of the feedline, where h is substrate height. The result is as follows [6]:

$$wf = \begin{cases} \frac{8e^A h}{e^{2A}-2} & for \frac{w}{h} < 2 \\ \frac{2}{\pi}\left[B - 1 - \ln(2B-1) + \frac{\epsilon_r - 1}{\epsilon_r + 1}(\ln(B-1) + 0.39 - \frac{0.61}{\epsilon_r})\right]h \end{cases} \quad \ldots\ldots\ldots (7)$$

Where :

$$A = \frac{Z_o}{60}\sqrt{\frac{\epsilon_r + 1}{2}} + \frac{\epsilon_r - 1}{\epsilon_r + 1}\left(0.23 + \frac{0.11}{\epsilon_r}\right) \quad \ldots\ldots\ldots (8)$$

$$B = \frac{377\,\pi}{2Z_o\sqrt{\epsilon_r}} \quad \ldots\ldots\ldots (9)$$

A microstrip feed line that is coupled to an input port source with a characteristic impedance of 50 Ω is used to excite the single rectangular patch antenna. Equations (7), (8), and (9) are used to determine the width of the feedline of the single patch antenna employing RT/Duroid substrate with this specified characteristic impedance. The auxiliary variable (B) is ascertained by using the w/h > 2 condition as follows [4]:

$$B = \frac{377\,\pi}{2(50)\sqrt{2.2}} = 7.9851$$

The width is determined from the following relationship:

$$Wf = \frac{2}{\pi}\left[7.9851 - 1 - \ln\left(2(7.9851) - 1\right) + \frac{2.2-1}{4.4}\left(\ln(7.9851 - 1) + 0.39 - \frac{0.61}{2.2}\right)\right]$$
$$0.5 = 1.64mm$$

The length is determined from the following relationship:

$$Lf = 3(0.5) = 1.5mm$$

- Quarter-Wave Transformer

The suggested single patch antenna uses a quarter-wave transformer for impedance matching in order to match the impedance between the radiating patch and the transmission line. To match a transmission line to a specific load, quarter-wave transformer transmission line sections are a quarter of the guided wavelength (λ_g/4). The quarter-wave transformer's impedance is as follows: [7, 8]

$$Z_{qwt} = \sqrt{Z_a Z_o} \quad \ldots\ldots\ldots\ldots (10)$$

Where Z_a is the impedance of the patch and is given by:

$$Z_a = 90\frac{\varepsilon r^2}{\varepsilon_r - 1}\left(\frac{L^2}{w}\right) \quad \ldots\ldots\ldots\ldots (11)$$

The width and length of a quarter-wave transformer are given by equations 3.10 and 3.11, respectively.

$$Z_{qwt} = \frac{60}{\sqrt{\epsilon_{reff}}} \ln\left(\frac{8h}{w_m} + \frac{w_m}{4h}\right) \quad \ldots\ldots\ldots (12)$$

The length of the quarter-wave transformer is given as:

$$L_m = \frac{\lambda}{4\sqrt{\epsilon_{reff}}} \quad \ldots\ldots\ldots\ldots (13)$$

Where: λ is the free space wave length.

Equation (10) where $Z_O = 50\Omega$, is used to determine the impedance of the quarter-wave transformer for the single patch antenna constructed with the RT/Duroid5880 substrate. The first step in this process is to calculate Z_a , which is as follows [4]:

$$Z_a = 90\frac{(2.2)^2}{(2.2)-1}\left(\frac{3.05^2}{4.232}\right) = 205.68$$

Therefore, the impedance of the quarter-wave transformer is:

$$Z_{qwt} = \sqrt{(50)(205.68)} = 101.41\Omega.$$

Also, the design dimensions of the single rectangular patch antenna are determined by the computed values of W_m and L_m, which are 0.304mm and 1.917mm, respectively.

Table 1: Dimensions for single rectangular patch antenna.

Parameter	Symbol	Dimension (mm)
Patch Length	L	3.28
Patch Width	W	4.232
Width of Transmission Line	W_f	1.64
Length of Transmission Line	L_f	1.5
Width of QWT	W_m	0.304
Length of QWT	L_m	1.917
Ground plane length	L_g	6.28
Ground plane width	W_g	7.232

2. Design of a Microstrip Patch Antenna with Yagi Elements

A rectangular patch antenna's directivity, gain, and radiation pattern are all improved with the addition of Yagi-Uda components, which are directors and reflectors. The updated design procedure and calculations for the patch antenna with Yagi-Uda elements are described below [9].

Step 1: Key Parameters for Yagi-Uda Elements

- Directors and Reflectors:

Directors: positioned above the patch antenna to improve directivity and gain. Usually, two directors are employed.

Reflectors: positioned on either side beneath the patch antenna to reroute radiation. One reflector is usually utilised on each side [9].

- Spacing and Dimensions:

The spacing and dimensions of Yagi-Uda elements depend on the resonant frequency (f_r=28 GHZ) and the wavelength (λ_0) in free space [9, 10]:

$$\lambda_o = \frac{c}{f_r} = \frac{3\times10^8}{28\times10^9} = 10.71mm$$

$$\lambda_g = \frac{\lambda}{\sqrt{\varepsilon_{eff}}} = \frac{10.71}{\sqrt{2.2}} = 7.22mm$$

Step 2: Director Dimensions

- Length of the Director (L_d): Directors are slightly shorter than the patch to enhance directivity

$$L_d = 0.45\lambda_g = 0.45 \times 7.22 = 3.249mm$$

- Width of the Director (W_d) The width is calculated similarly to the patch width:

$$W_d = 0.2\lambda_g = 0.2 \times 7.22 = 1.444mm$$

- Patch-to-Director Spacing (S_d)

$$S_d = 0.3\lambda_g = 0.3 \times 7.22 = 2.17mm$$

Step 3: Reflector Dimensions

- Length of the Reflector (L_r): Reflectors are slightly longer than the patch to reflect radiation [9]:

$$L_r = 0.55\lambda_g = 0.55 \times 7.22 = 3.97mm$$

- Width of the Reflector (L_r): The width is similar to the patch width:

$$L_r = 0.55\lambda_g = 0.55 \times 7.22 = 3.97mm$$

- Reflector – to – patch spacing

$$S_r = 0.2\lambda_g = 0.2 \times 7.22 = 1.44mm$$

Step 4: Calculating the Length and Width of the Substrate

- Width of the Substrate (W_s)

In order to minimise edge effects and increase radiation efficiency, the substrate's width (W_S) is often larger than the radiating elements' width. Using the following relationship, it is computed using the width of the widest element (such as the patch, reflector, or output) plus an extra margin on both sides:

$$W_s = \max(W_{patch}, W_{reflector}) + 2.\Delta W \qquad (16)$$

Where:

W_{patch} **:** Width of the patch (main antenna element)

$W_{reflector}$: Width of the reflector

ΔW: The clearance margin ΔW is chosen to avoid edge effects and ensure proper radiation pattern typically $\Delta W = 0.25\lambda_g$, where λ_g is the guided wavelength.

- Substrate Length (L_s):

Taking into account the edge effects and side effects, the length of the substrate is calculated by adding the lengths of the reflector, patch, and output (or outputs), in addition to the distances between them and the following equation to calculate the length of the substrate [9,10].

$$L_s = L_{reflector} + L_{patch} + L_{director} + S_r + S_d + 2.\Delta L$$

Where:

ΔL=6h+ 0.25λg , accounting for both fringing fields and spacing.

1. Design of the Basic 1 × 2 Power Divider

A linear, passive electrical component that complies with Ohm's law is called a power divider. As seen in Figure (Fig. 4 (a), (b)), it can be applied to power combination or division. In-phase output signals with an equal power division ratio (3 dB, 6 dB, or 9 dB) are often provided by this component. However, it is also conceivable for the power division ratio to be uneven. When designing an array antenna, this component is a must.

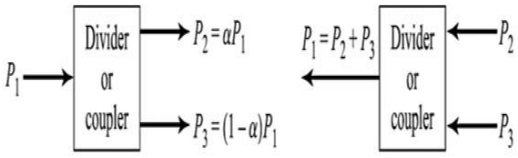


Fig 4. (a) Power divider. (b) Powers combiner

The simple 1× 2 T-shaped power divider is the most widely used magic -T power divider. As seen in Figure (Fig. 5), it is made up of three T-shaped transmission lines.

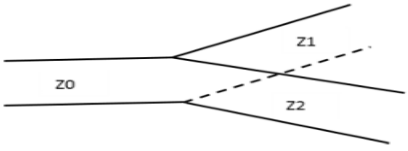


Fig 5. 1 X 2 T-shaped power divider port layout.

To have a lossless T-junction, the impedances Z_O, Z_1 and Z_2 must verify the following equation:

$$\frac{1}{Z_o} = \frac{1}{Z_1} + \frac{1}{Z_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (17)$$

Generally, the scattering matrix S of a 1 × 2 power divider consists of 9 independent parameters as shown below:

$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix}$$

A reciprocal power divider is free of anisotropic materials. Its S matrix thus becomes symmetric. ($S_{ij} = S_{ji}$) as follow:

$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & S_{23} \\ S_{13} & S_{23} & S_{33} \end{bmatrix}$$

If this structure is lossless with adapted ports ($S_{11} = S_{22} = S_{33} = Zero$) The S matrix becomes as follows:

$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & S_{23} \\ S_{13} & S_{23} & S_{33} \end{bmatrix}$$

Unfortunately, there's no lossless structure, but we accept that if $S_{11} = S_{22} = S_{33}$ are less than – 10 dB, the structure is considered a low-loss structure.

In microstrip technology, to design a power divider, equations (18) and (19) should be considered. These equations allow switching between the characteristic impedance and the width of each branch line. The most widely used feed line in microstrip technology is the one whose characteristic impedance is equal to 50 Ω. Equation (5) can be used to calculate the characteristic impedance of Z_{50} knowing its width w_{50}:

$$Z_{50} = \frac{120\,\pi}{\sqrt{\varepsilon_r}\left(\frac{w_{50}}{h}+1.393\ 0.0667\ln\left(\frac{w_{50}}{12}+1.44\right)\right)} =< \frac{126}{\sqrt{\epsilon_r}} \quad \ldots (18)$$

With $w_{50} > h$

Conversely, equation (19) can be used to calculate the width W_{50} knowing the impedance Z_{50} :

$$\frac{W_{50}}{h} = \frac{2}{\pi}\left[B - 1 - \ln(2B-1) + \frac{\varepsilon_r - 1}{2\varepsilon_r} + \left(\ln(B-1) + 0.39 - \frac{0.61}{\varepsilon_r}\right)\right] \quad \ldots\ldots\ldots\ldots \quad (19)$$

With: $B = \frac{377\,\pi}{2Z_{50}\sqrt{\epsilon_r}}$, $\frac{W_{50}}{h} > 2$

h: the thickness of the substrate, and ε_r its relative primitiveness. Z_{50} , W_{50} represent impedance and width, respectively, when the line has a characteristic impedance of 50 Ω. The design of the basic 1 × 2 magic-T power divider is shown in Figure (Fig. 6).

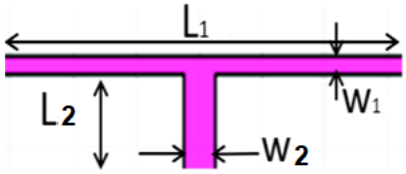


Fig 6. Design of the proposed 1 X 2.

The following methodology was used to calculate the various properties of this structure:

i) Knowing the input impedance $Z_0 = Z_{50} = 50\Omega$, We found out the output impedances $Z_1 = Z_{100} = 100\Omega$ using equation (1)
ii) Equation (6) is used to calculate the width W_{50} and W_{100} of each branch line from their impedances Z_{50} and Z_1 ($= Z_2$) respectively.
iii) the length of the impedance line, 100 Ω, is initially chosen $L_{100} \leq \frac{\lambda}{2}$
iv) A parametric study on lengths L_{50} and L_{100} was carried out to obtain a low-loss structure (S_{11} lower – 10 dB) capable of dividing the power feed into two equal parts.

The final optimal dimensions obtained for this structure are: W_{100} = 2.78 mm, W_f = 4.48 mm, L_{100} = 60.7 mm, L_{50} = 15 mm.

1. Design of 1 × 4 Magic-T Power Divider

The proposed 1 x 4 divider is a T junction having one input port and 4 output ports. It divides the input power into 4 equal quantities (6 dB) in phase. This type of divider will be able to feed an array antenna of 4 elements. For a reciprocal, lossless, symmetric and isotropic T junction 1 x 4, the S matrix is given by:

$$[S] = \begin{bmatrix} 0 & S_{12} & S_{13} & S_{14} \\ S_{12} & 0 & S_{23} & S_{24} \\ S_{13} & S_{23} & 0 & S_{34} \\ S_{14} & S_{24} & S_{34} & 0 \end{bmatrix}$$

Based on the 1 × 2 MTPD proposed in the previous paragraph, the design process has been extended to magic T 1 × 4 power dividers as shown in Figure (Fig. 7). It has one input port and four output ports. It consists of two identical 1 × 2 MTPD, which feed another 1 × 2 MTPD.

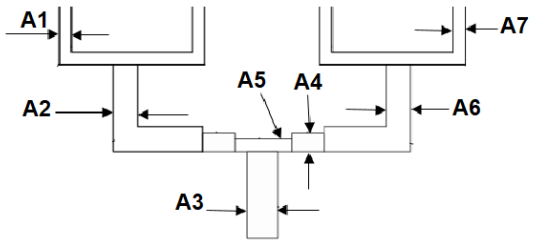


Fig 7. Structure of the proposed 1 X 4.

The parameters of this optimised structure are given as follows: W_{A1} = 0.50 mm = W_{A7} = W_{A5} , W_{A2} = 1.64 mm = $W_{A6} = W_{A3}$, $W_{A4} = 0.98mm$, L_{A1} = 0.438 mm = L_{A7} = L_{A5} , L_{A2} = 3 mm = $L_{A6} = L_{A3}$, $L_{A4} = 1.805mm$.

5. Simulation Results and Analysis

A. Design Microstrip Patch Antenna with and without Yagi Element

Using HFSS, in this part, the design and development of a 28 GHz rectangular microstrip patch antenna suitable for 5G communication systems is presented. The RT/Duroid 5880 substrate, which has a low dielectric constant (εr = 2.2) and low loss tangent, is used in the antenna's design to provide great efficiency and little signal attenuation at high frequencies.

As a baseline design, a typical rectangular microstrip patch antenna is first modelled. Yagi-like features are added to improve its gain and directional characteristics. These consist of reflectors positioned at the sides beneath the patch and two directors above it. In order to meet the demanding requirements of 5G networks, the updated design attempts to enhance the antenna's bandwidth, gain, and overall radiation performance. The advantages of including Yagi-like components

in microstrip antennas are demonstrated by the comparison of these two designs.

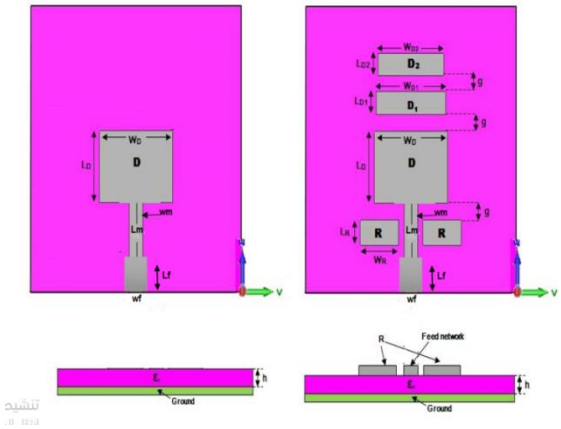


Fig 8. (a) Microstrip without Yagi element. (b) microstrip with Yagi element.

- Return loss Versus Frequency

The reflection coefficient of the antenna is referred to as the scattering parameter (S-parameter) in this case, S11. This is the relationship between the source and the antenna while the antenna operates in a single-port circuit. Therefore, the reflection coefficient of the single rectangular antenna is measured from the basic value of -10 dB, indicating that 10% of the incident power is reflected and 90% of the power is delivered to the antenna. The performance of the developed antennas can be better understood thanks to the reflection coefficient curves. The bandwidth of the patch antenna without Yagi components (Fig. 9-a) is roughly 0.7 GHz (27.6 GHz–28.3 GHz), and its VSWR of 1.32 and minimum reflection coefficient of -14.5 dB at 28 GHz suggest moderate impedance matching. Although functional, this design's bandwidth limitation makes it less appropriate for demanding applications like 5G.

The patch antenna with Yagi components, on the other hand, shows notable improvements (Fig. 9-b). The bandwidth has been increased by 36% to 0.95 GHz (27.5 GHz–28.45 GHz). With an outstanding VSWR of 1.11 and an enhanced minimum reflection coefficient of -18.5 dB at 28 GHz, this indicates excellent impedance matching and little signal loss. The addition of Yagi elements, which optimise the antenna's impedance and radiation properties by acting as directors and reflectors, is responsible for these enhancements.

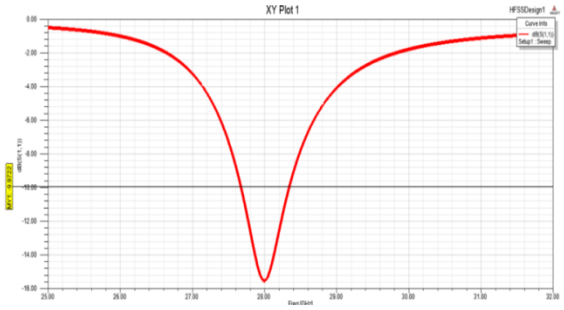


Fig 9. (a) Return loss without Yagi element.

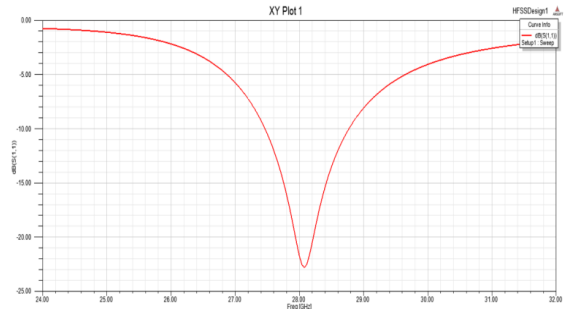


Fig 9. (b) Return loss with Yagi element.

- Voltage Standing Wave Ratio

For the microstrip patch antenna, the impedance matching between the patch and the transmission line is indicated by a voltage standing wave ratio (VSWR) of less than 2. The VSWR (Voltage Standing Wave Ratio) plots in figure (Fig. 10) illustrate the impedance matching performance of the designed antennas. At the resonant frequency of 28 GHz, the minimum VSWR value for the patch antenna without Yagi components (Fig. 10-a) is 1.32, and the VSWR exceeds allowable limits (VSWR > 2) beyond the constrained operational bandwidth of roughly 0.7 GHz. In high-frequency, broadband applications, this suggests inadequate impedance matching, which restricts the antenna's performance.

On the other hand, the patch antenna with Yagi elements (Fig. 10-b) exhibits a wider bandwidth of roughly 0.95 GHz and a noticeably better minimum VSWR value of 1.11 at 28 GHz. By lowering signal reflection and improving impedance matching throughout the frequency range, Yagi components

make the antenna extremely effective for 5G applications.

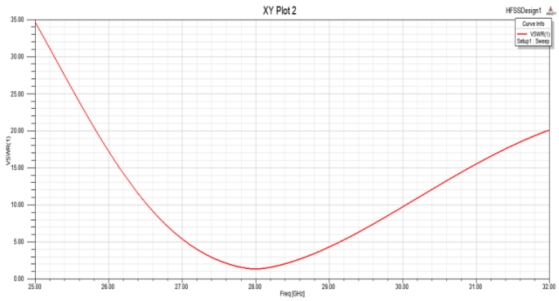


Fig 10. (a) V.S.W.R without Yagi element.

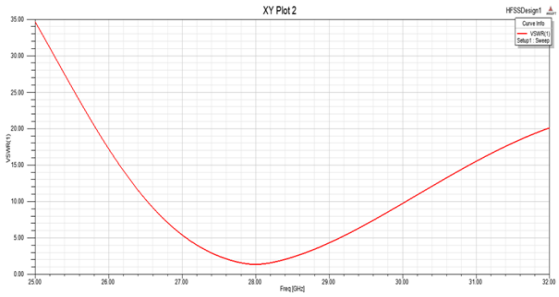


Fig 10. (b) V.S.W.R with Yagi element.

- Radiation Pattern 3D

The inclusion of Yagi elements greatly improves the antenna's far-field emission pattern, as shown in figures (Fig. 11-a) and (Fig. 11-b). The radiation pattern shows a maximum gain of 6.31 dB in the absence of Yagi elements figure (Fig. 11-a), with lower directivity and energy spreading widely. On the other hand, the gain rises to 7.52 dB with the Yagi elements figure (Fig. 11-b), which also shows a more focused main lobe and suppressed side lobes. Higher directivity, less interference, and improved signal efficiency are all reflected in this improvement. By integrating Yagi elements, the antenna's performance is optimised, making it appropriate for sophisticated applications including broadcasting systems, wireless communication, and radar that demand high precision and directional radiation.



Fig 11. (a) Radiation pattern 3D without Yagi element.



Fig11. (b) Radiation pattern with Yagi element.

- Comparative Analysis of Gain Patterns with and without Yagi Elements.

The effect of adding Yagi elements on the antenna's gain pattern is seen in figures (Fig. 12-a) and (Fig. 12-b). Without the Yagi components figure (12-a), the highest gain is 6.43 dB at θ=0, with bigger side lobes and lower directivity, leading to energy dispersion and probable interference. On the other hand, the gain rises to 7.94 dB with the Yagi elements figure (Fig. 12-b), which also has a narrower main lobe and suppressed side lobes, improving directivity and signal focus. This enhancement greatly increases efficiency, making the arrangement perfect for applications needing high precision, such as radar and satellite communication, even if it limits coverage flexibility and increases design complexity.

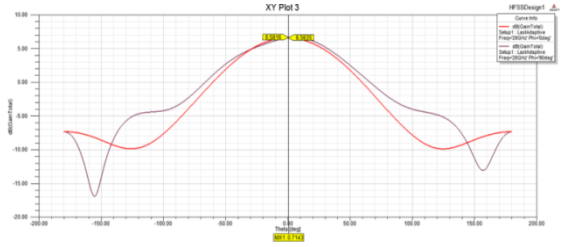


Fig12. (a) Elevation plane radiation pattern without Yagi element.

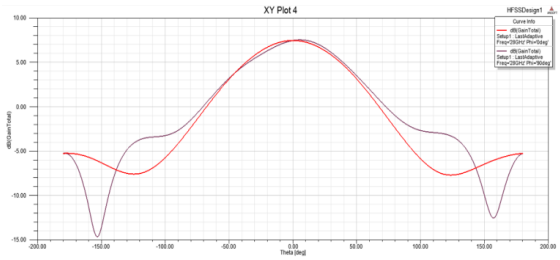


Fig12. (b) Elevation plane radiation pattern with Yagi element.

B. Design 1 × 2 Microstrip Array Antenna

In this work, a dual-element patch antenna array optimised with HFSS software operating at 28 GHz is designed and analysed. In order to create a Yagi-Uda-inspired arrangement, each patch antenna has one reflector element on each side and two director

elements above it. To guarantee low signal attenuation and great efficiency at millimetre-wave frequencies, the design makes use of RT/Duroid 5880, a high-performance substrate with low dielectric loss. Achieving maximum bandwidth, high gain, and improved directivity are the main goals because these are essential for contemporary applications, including radar systems, satellite communication, and 5G networks. The design uses this structure to reduce interference and increase radiation efficiency, making it a reliable option for high-frequency communication systems.

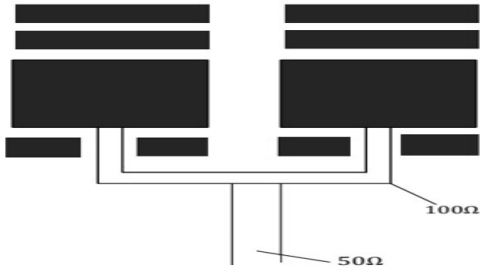


Fig13. Design 1 × 2 microstrip array antenna with Yagi element.

In follow table, shown Dimensions for the 1×2 Antenna Array Design.

Table 2: Dimensions for thr 1×2 antenna array design.

Component	Values (mm)
Substrate thickness (h)	0.508 mm
Substrate length	9.2 mm
Substrate width	11.95 mm
Patch length	3.68 mm
Patch width	4.78 mm
Main feedline impedance	
Main feedline width	1.17 mm
Branch impedance	100 Ω
Branch feedline width	0.62 mm
Impedance transformer	70.7 Ω
Transformer width	To be adjusted during simulation
Feedline length	3.61 mm
Director length	4.82 mm
Director width	1.0 mm
Reflector length	5.89 mm
Reflector width	1.0 mm
Distance between directors and patch	1.61 mm
Distance between reflectors and patch	2.14 mm

- Return Loss Versus Frequency

The reflection coefficient of a 1x2 antenna array intended to function at 28 GHz is seen in this S_11 plot, which was created using HFSS. Excellent impedance matching is indicated by the resonance frequency, which is precisely at 28 GHz, when S_11 reaches its minimum value of about -25 dB. The frequency range with tolerable reflection (less than 10% reflected power), or the -10 dB bandwidth, spans 27.5 GHz to 28.5 GHz, resulting in a bandwidth of 1 GHz. This outcome shows that the antenna is suitable for millimetre-wave applications due to its low power loss and effective signal radiation. Directivity is increased, and overall performance is improved by the array's design, which includes dual feed points above each patch and side reflectors below.

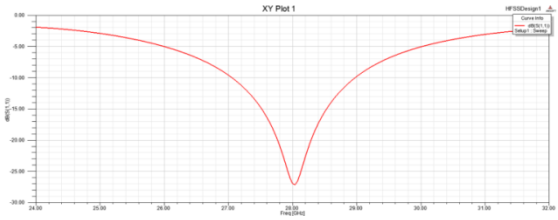


Fig 14. Return loss for 1×2 antenna array at 28 GHz.

- Voltage Standing Wave Ratio

The performance of a 1x2 antenna array that was developed and simulated using HFSS is seen in this VSWR figure. With a VSWR of roughly 1.1 and an operating frequency of 28 GHz, the antenna exhibits excellent impedance matching with low power reflection. From 27.5 GHz to 28.5 GHz, the frequency range where the VSWR stays below 2 (indicating effective matching) results in a bandwidth of 1 GHz. With very little reflected power, the low VSWR values across this range attest to effective power transfer between the antenna and the feed line. To increase impedance matching and directivity, the design includes two side reflectors and two directive elements above each patch. These characteristics highlight the antenna's appropriateness for high-frequency communication systems and guarantee optimal performance for millimetre-wave applications.

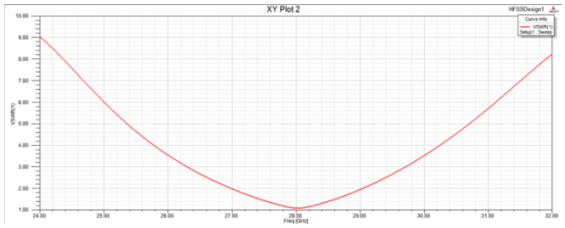


Fig 15. V.S.W.R for 1×2 antenna array at 28 GHz.

- Radiation Pattern for 1*2 Array Antenna

This 3D radiation pattern simulates the overall gain distribution of a 1x2 antenna array intended to function at 28 GHz. High directivity with a peak gain of roughly 9.95 dB, which is perfect for millimetre-wave applications, is indicated by the pattern's distinct main lobe that is well-focused along the Z-axis (broadside direction). The steady drop in gain in other directions indicates that the side and back lobes are effectively suppressed, exhibiting superior directional performance and little undesired radiation.



Fig 16. 3D radiation pattern for 1×2 antenna array at 28 GHz.

- Gain Versus Angle Plot

At 28 GHz, the 2D radiation pattern shows the antenna's total gain (dB (GainTotal)) as a function of the radiation angle (Theta) at Phi = 0° (red curve) and Phi = 90° (purple curve). The antenna has a well-focused main lobe that ensures effective forward-directed energy emission, as evidenced by its high directivity and maximum gain at θ = 0°. The dramatic suppression of back radiation at greater angles indicates how well the reflectors work to increase forward gain, while the low side lobes show little energy dispersion into undesirable directions. The overall pattern validates the design's high efficiency and appropriateness for millimetre-wave applications, such 5G, where narrow beams and high gain are crucial, despite modest asymmetry and the persistence of some side lobes.

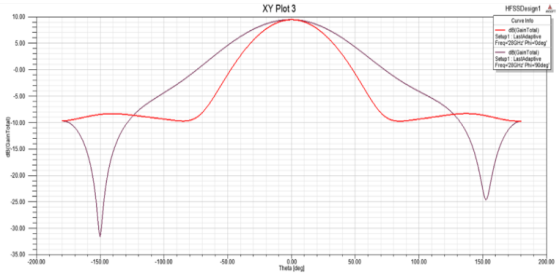


Fig 17. Elevation plane radiation pattern at 28 GHz.

C. Design Antenna 1×4 Array Antenna

In this step, will to create a 1x4 antenna array that operates at 28 GHz using the RT/Duroid 5880 as the substrate because of its high stability and low loss. To improve gain and directivity, each patch antenna element has two directors on top to increase forward radiation and two reflectors on the sides underneath to reduce back radiation. In order to achieve outstanding performance metrics like minimal return loss and high VSWR efficiency, the design is optimised using a corporate series feed network to guarantee uniform power distribution and phase alignment.

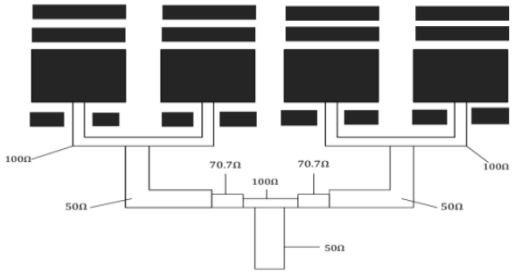


Fig18. 1x4 Antenna Array with corporate and series feed network.

- Return Loss Versus Frequency for array antenna

A four-element antenna array with two directors above and a reflector below each element is depicted in the plot as having a reflection coefficient S_11. The lowest S_11 value, which reaches about -40 dB at 28 GHz, shows good impedance matching and little power loss. The bandwidth, which is appropriate for contemporary communication systems, is specified by S_11 values below -10 dB and spans roughly 2 GHz (from ~27 GHz to ~29 GHz). Since the antenna is made to function best within a certain frequency range, the curve does not begin at zero. Instead, it climbs outside of this range because of decreased matching. Incorporating directors and reflectors improves gain and directivity, leading to increased performance and high efficiency. This design offers significant advantages, including a wide bandwidth, excellent impedance matching, and suitability for high-frequency applications like 5G.

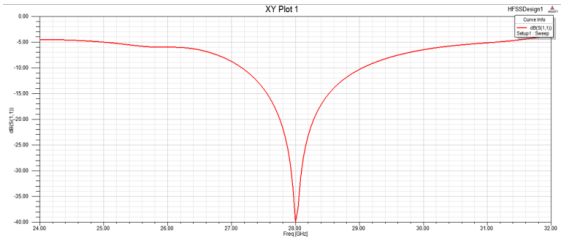


Fig 19. S11 parameter of the 28 GHz antenna array with corporate feed network.

- Voltage Standing Wave Ratio

A four-element antenna array with two directors above each element and a reflector below is plotted to display the voltage standing wave ratio (VSWR). Excellent impedance matching is indicated at 28 GHz, where the VSWR curve achieves its minimal value of about 1.1. In the working bandwidth (about 27 GHz to 29 GHz), a VSWR value less than 2 indicates low signal reflection and effective power transfer. As would be expected for a frequency-specific design, the increase in VSWR outside of this range represents decreased matching. High efficiency and robust performance across the intended frequency range are ensured by the array's directors and reflectors, which improve directivity and reduce reflections. High-frequency applications like 5G communications are ideally suited for this design.

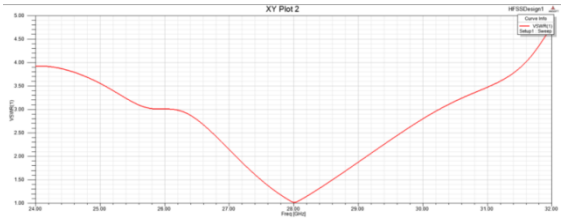


Fig 20. VSWR vs frequency for a 28 GHz design array antenna.

- Radiation Pattern

The overall gain of a four-element antenna array with two directors above each element and a reflector below is displayed in the 3D radiation pattern. In the Z-direction, the pattern shows a strong, concentrated main lobe with a maximum gain of roughly 12.9 dB. This significant gain demonstrates the design's superior efficiency and directivity. By adding directors and reflectors, side lobes are successfully decreased, and radiation is improved in the intended direction. The antenna is appropriate for applications needing high gain and accurate signal targeting, like 5G communication and radar systems, because of its small and evenly dispersed lobes, which show little energy loss in undesirable directions.



Fig 21. Radiation pattern for an array antenna.

- Gain Pattern

The graph provided illustrates the simulated radiation patterns of a 1 × 4 microstrip patch antenna array operating at 28 GHz with an enterprise-class power supply. Each patch is equipped with two drivers at the top and a reflector at the bottom to improve directionality and gain. The results show highly directional radiation with a maximum gain of about 15 dB, making the design suitable for 5G millimetre wave applications. The Phi = 0° diagram has sharper lobes and pronounced side lobes due to constructive and destructive interference, influenced by the separation of the elements and the energy network. On the contrary, the Phi = 90° diagram is smoother, with a larger main lobe and reduced side lobes, reflecting the anisotropy of the network structure. Although the reflector effectively suppresses flares (<- 15 dB), further optimisation of element spacing and power distribution can reduce side flare and improve performance. In general, this design achieves a high direction and is ideal for direct communication systems.

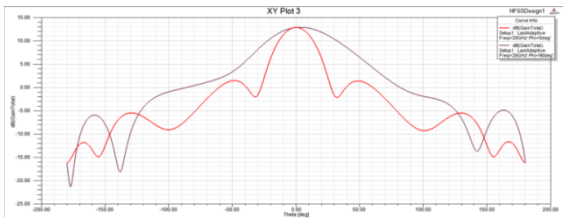


Fig 22. Radiation pattern versus theta.

6. Conclusion

This research focused on designing an efficient antenna system tailored for fifth-generation (5G) wireless communication applications operating at 28 GHz. The study began with the design and optimisation of a single patch antenna. The initial

results demonstrated satisfactory performance, achieving a bandwidth of approximately 0.7 GHz, a gain of 6.53 dB, and a VSWR of 1.32. These results confirmed the feasibility of using a simple patch antenna for 5G applications but highlighted opportunities for further enhancements in gain and bandwidth.

Yagi elements were incorporated into the patch antenna in order to overcome these restrictions. In particular, a reflector was positioned beneath each end of the patch, and two directors were positioned above the patch to enhance directionality. The antenna's performance was greatly improved by this change, resulting in a 0.95 GHz bandwidth, a 7.52 dB gain, and an outstanding VSWR of 1.11. These enhancements highlight how important it is to incorporate Yagi elements in order to improve impedance matching and radiation characteristics.

Building on this achievement, a modified patch antenna array measuring 1x2 was created, with two Yagi directors and a reflector in each element. With an increased bandwidth of almost 1 GHz, a gain of 9.45 dB, and a VSWR of 1.23, this array considerably enhanced the performance parameters. Because of the array configuration's enhanced gain and bandwidth, it is ideal for 5G base station applications that demand high efficiency and steady operation over a broad frequency range.

Ultimately, four patch antenna pieces were assembled into a 1x4 antenna array. Each patch antenna had two Yagi directors and a reflector, and the array was fed by a corporate-series feed network. This innovative design yielded an impressive bandwidth of nearly 1.9 GHz, a gain of 12.9 dB, and an exceptional VSWR of 1.11. The 1x4 array's outstanding performance met the rigorous requirements of 5G systems, which require low latency and high capacity.

The study's steady advancements demonstrate how flexible and scalable the suggested antenna designs are. In addition to improving the gain and bandwidth, the incorporation of Yagi components and the creation of array topologies preserved superior impedance matching throughout all designs. These developments aid in the creation of high-performance, small, and effective antenna systems appropriate for next-generation wireless communication. This work underscores the potential of combining patch antennas with Yagi elements and advanced feeding networks to achieve superior performance for modern wireless networks. The proposed designs lay the foundation for further optimisation, enabling their integration into complex phased arrays for even greater efficiency in 5G and beyond.

Conflicts of Interest: The authors declare no conflicts of interest.

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