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Enhancing Yagi-Uda Antenna Performance: Optimizing Gain and Bandwidth with Directors Modification

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Abstract

The Yagi-Uda antenna is a popular design for high gain in directional antennas. Antennas represent challenging to design due to high gain sensitivity. It is conventionally used for high gain and directionality applications, often inserting additional directors lead to increase the gain. The aim of this paper is to optimize and improve its gain and bandwidth by changing director lengths and optimizing spacing between directors. In this paper, to optimize this gain, four elements of directors and spacing between them have been considered. Adding number of directors can increase gain. However too many elements can raise losses and decrease efficiency. Spacing between directors is crucial for overall performance. The length and diameter of directors also affect gain. By adding more uniform and non-uniform directors, the maximum gain reached. Simulation and testing were applied on the model using MATLAB simulation tool. A significant improvements were obtained in gain and bandwidth compared to the original design, making Yagi-Uda antenna more suitable for applications in field of wireless communication or radar systems.

Keywords: Yagi-Uda antenna, active Element antenna gain, Antenna directors.

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تعزيز أداء هوائي ياقي–يودا: تحسين الكسب وعرض النطاق بواسطة تعديل الموجهات.

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الملخص:

يعد الهوائي ياقي–يودا تصميما شائعا لتحقيق كسب عالي في الهوائيات الاتجاهية. تمثل الهوائيات تحديا في التصميم بسبب حساسية الكسب العالية. يتم استخدام هوائي ياقي–يودا تقليديا في الحصول علي كسب عالي وفي تطبيقات الهوائيات الاتجاهية. إضافة موجهات للهوائي يؤدي إلي زيادة الكسب. الهدف من هذه الورقة هو تحسين الكسب وعرض النطاق الترددي للهوائي عن طريق تغيير طول الموجة وتحسين المسافة بين الموجهات.

في هذه الورقة لتحسين الكسب ، تم الأخذ في الاعتبار أربعة عناصر من الموجهات والمسافة بينهم . زيادة عدد الموجهات ممكن أن يؤدي لزيادة الكسب ، لكن الكثير من العناصر يمكن أن تؤدي إلى الفقد ونقص الكفاءة . المسافة بين الموجهات مهمة في الأداة الإجمالي للهوائي، كذلك طول وقطر الموجه لهما تأثير علي الكسب .يمكن الوصول إلي أقصي كسب بواسطة إضافة موجهات متماثلة وغير متماثلة . تم تطبيق المحاكاة والاختبار علي نموذج باستخدام أداة المحاكاة في برنامج الماتلاب ،وتم التحصل علي تحسينات هامة في الكسب و عرض النطاق الترددي مقارنة بالتصميم الأصلي ، مما يجعل من هوائي ياقي–يودا مناسبا أكثر للتطبيقات في مجال الاتصالات اللاسلكية و أنظمة الرادار.

الكلمات المفتاحية : هوائي ياقي–يودا، العنصر نشط، موجهات الهوائي، كسب الهوائي

1. Introduction

The Yagi-Uda antenna, commonly known as the Yagi antenna, is a popular and effective design for achieving high gain in a directional antenna. The gain of a Yagi-Uda antenna can be optimized by changing the number and spacing of directors, which are elements positioned in front of the driven element [1-3]. The Yagi-Uda antenna consists of parallel elements with a reflector, driven element, and director elements. It achieves highest gain along the axis and side with directors as shown in figure 1. The reflector acts as a ground plane, and design parameters include element lengths, inter-element spacing, and diameters [4, 5].

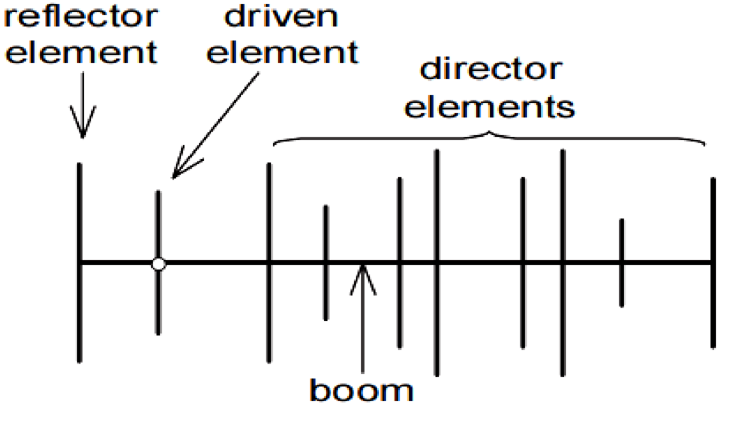

Figure 1 Typical Yagi antenna [5].

The Yagi-Uda antenna is a popular design for high gain in directional antennas. To optimize the gain, the number and spacing of directors should be considered. The number of directors can increase the overall gain, but too many can introduce losses and decrease efficiency. This paper presents a design for conventional Yagi-Uda antenna with four directors, ensuring uniform element lengths and spacing between directors. Spacing between directors is crucial for determining the antenna's performance, and closer spacing can increase gain [5].

The length and diameter of directors also affect the performance, and optimizing these parameters can improve impedance matching and radiation pattern control, in addition, reducing the lengths of the last three directors while maintaining uniform space.

Simulation and testing are recommended before making any changes to the Yagi-Uda antenna design [6-8]. By considering these

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factors and making adjustments, the gain is optimized for specific applications or operating frequencies. However, optimizing one aspect of an antenna's performance may impact other characteristics, so trade-offs have been made during the optimization process [9,10].

2. Methodology

2.1 Elements of Yagi antenna

The Yagi antenna consists of several elements, including a reflector, driven element, directors, boom, feed line, and mounting hardware as shown in figure 1. The reflector reflects radio waves forward, increasing anntena directivity and gain. The driven element is connected to the feed line and receives or transmits radio waves. Directors help focus and direct radio waves in specific directions. The boom holds the antenna in place and supports mounting and aiming, while feed lines connect the antenna to transmitters or receivers. Mounting hardware secures the antenna to a support structure.

The Yagi antenna typically has one reflector behind the main driven element, improving performance by reducing radiation or pick-up. Reflectors can be made of a reflecting plate or parallel rods, adding 4-5 dB of gain in the forward direction.

Directors are placed in front of the driven element, adding 1 dB of gain in the forward direction. The antenna can be optimized to reduce or maximize forward gain [10, 11].

2.2. Conventional Yagi-Uda Antennas

Conventional Yagy-uda antennas consist of an active element, reflectors, and directors. The active element, also known as a feeder or driven dipole, ranges from 0.45λ to 0.49λ in length. The reflector, 5% longer than the active element, improves reflections. Directors, 5% shorter than the active element, enhance gain and directivity. Standard designs vary in spacing between directors and active elements, with a radius of 0.00425λ [6-8].

2.2. Design and simulation of the Yagi antenna

In this study, different designs were developed to enhance the Yagi antenna's characteristics and gain, with initial parameters calculation required, as illustrated in figure 2.

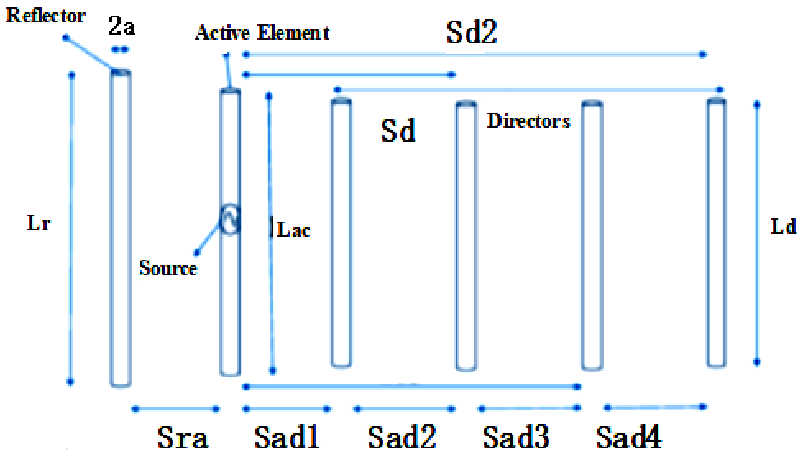

Figure 2 Model of Yagi antennas with parameters[13]

2.3. Calculate the wavelength (λ)

The wave length is dependent on the frequency and the light speed in free space and we can find the value of wave length by the formula:

$$\lambda = \frac{c}{f} = \frac{(3\times10^{8})}{(2.45\times10^{9})} = 122.448\ \text{mm.} \qquad (1)$$

2.3.1. Radius of each element (a)

The Radius of each element is the same and typically it is 0. 0425λ ,

(a) = 5.204 mm.

2.3.2. Length of each element (L)

The lengths of elements are not the same, these lengths are:

- Length driven element (Lac)

Length driven element is slightly less than λ/2 ranges from 0.45λ to 0.49λ.

$$Lac = 0.45\lambda = 55.1016\ \text{mm.} \qquad (2)$$

- Length of reflector (Lr)

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Length of reflector (Lr) is 5% greater than the length of active element. Having a length greater than the active element causes good reflections towards forward direction.

$$Lr = 0.5\lambda = 61.227 \text{ mm} \quad (3)$$

- Length of directors (Ld)

In the design of Yagi-Uuda antenna, directors play a key role in achieving better gain and directivity. Usually, the length is near to 5% smaller than the active element. In this project it well be a variable to optimize the gain of the Yagi antenna.

$$Ld = 0.45\lambda \times 0.05 = 55.33 \text{ mm} \quad (4)$$

2.4. The space between elements

The reflector is located behind active element at a distance (Sra) of 0.25λ. Spacing between directors and the spacing between active element directors varies between 0.35λ to 0.4λ, and the spacing will be a variable to optimize the gain of the Yagi antenna.

$$S = 122.448 \times 0.4 = 48.4\text{mm} \quad (5)$$

2.5. Uniform lengths of directors and no Uniform spaces between the directors

This paper presents a design for conventional Yagi-Uda antennas with four directors, ensuring uniform element lengths and spacing between directors. Figure 3 illustrates this design, showcasing uniform element lengths and spacing.

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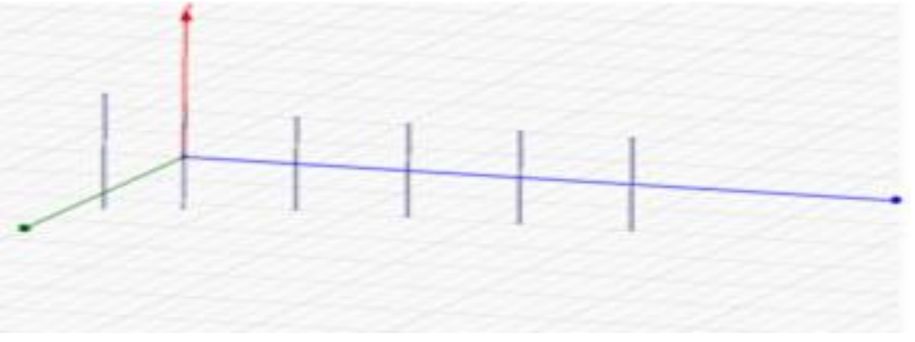

Figure 3 Yagi antenna with 4 directors, uniform elements lengths and uniform spacing between the directors

Initially, the wave length of the antenna has been calculated for operating frequency.

$$\lambda = c / f = (3\times10^{8}) / (2.45\times10^{9}) = 122.448 \text{ mm} \tag{6}$$

All parameters of the antenna are calculated and summarized in table 1.

Table 1 Parameters of 4 directors with uniform elements lengths and uniform spacing between the directors

Parameter	A (mm)	Sra (mm)	Sad1-Sad4 (mm)	Lac (mm)	Lr (mm)	Ld1-Ld4 (mm)
Value	5.204	30.61	42.85	55.1016	61.227	48.97

3.6. Increasing the number of directors (uniform length – uniform space)

Number of directors have been increased to 6 elements as illustrates in figure (4), those directors are uniformly long directors with equal spacing, maintaining all antenna parameters and dimensions as shown in table 1.

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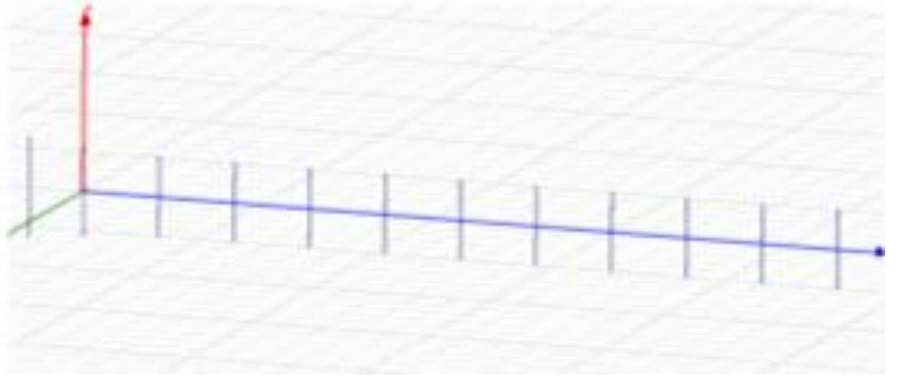

Figure 4. Yagi antenna with 10 directors, uniform elements lengths and uniform spacing between the directors

3.7 Increasing number of directors

Figure 5 shows the design was optimized by increasing the number of directors to 13, which the lengths is reduced of the last three directors while maintaining uniform space.

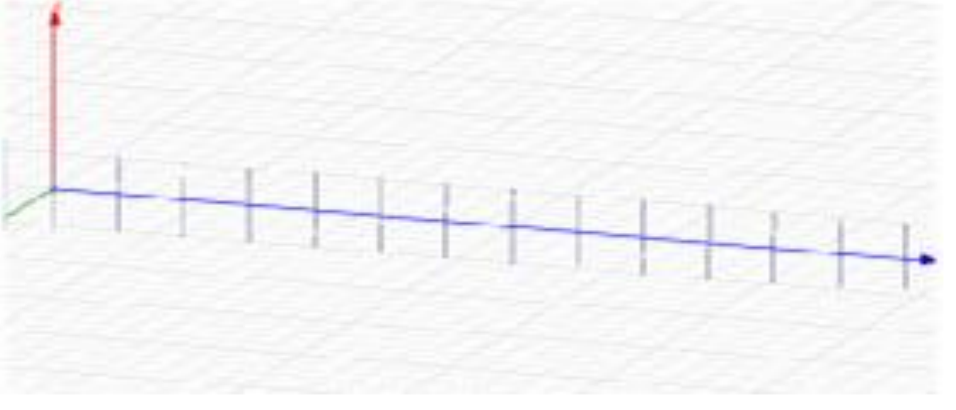

Figure 5 Yagi antenna with 13 directors, non-uniform elements lengths and uniform spacing between the directors.

The new Yagi antenna now has 13 directors, with the parameters remaining unchanged, but the number and length of directors have been changed. Table 2 summarizes these changes.

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Table 2 Parameters directors with non- uniform elements lengths and uniform spacing between the directors.

Parameter	a	Sra	Sad1- Sad4	Lac	Lr	Ld1- Ld10	Ld11	Ld12	Ld13
Value(mm)	5.204	30.61	42.85	55.116	61.227	48.97	46.97	44.97	42.97

4. Results and Discussion

The Yagi-Uda antenna, with four director parameters, was initially simulated to determine its maximum gain and bandwidth, with a red color indicating a gain of 11.26 dB and a bandwidth of 1.5 MHz as shown in figures (6, 7)

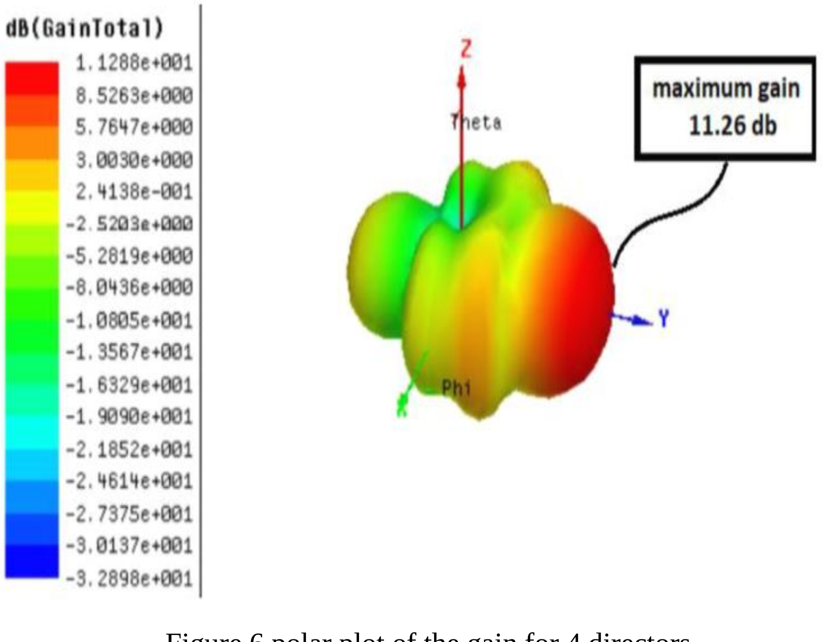

Figure 6 polar plot of the gain for 4 directors

In the optimized design with 10 directors with uniform lengths and the space is uniform between the directors, the gain of the antenna is increased.

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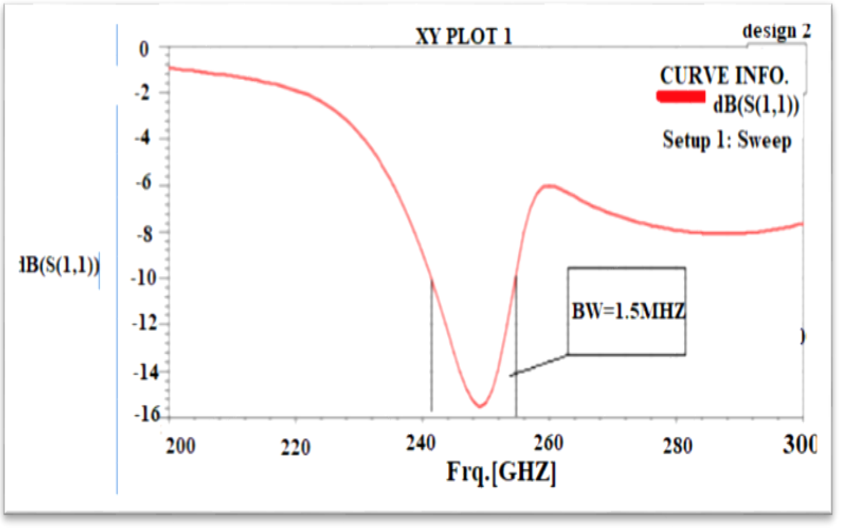

Figure 7. Return loss of 4 directors

Figure 8 shows polar plot of the maximum gain with the red color, the gain with directors reaches to 14.77 dB. The Bandwidth of the antenna in this case is 180 MHz is shown in Figure 9.

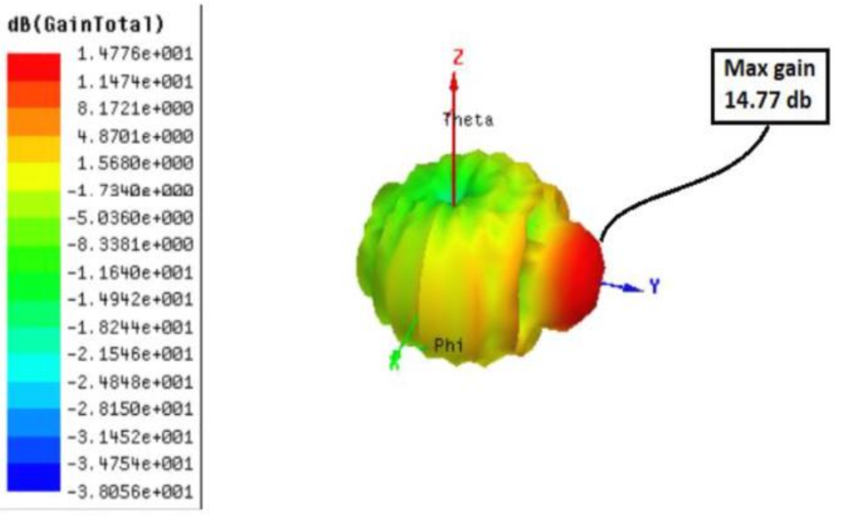

Figure 8. polar plot of the gain with 10 uniform directors.

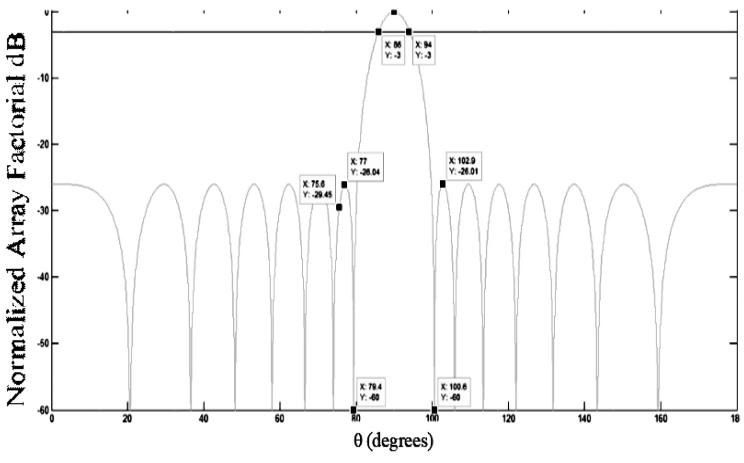

Figure 9. Return loss of the optimized yagi antenna with 10 uniform directors.

Finally, three more directors are added to the optimized Yagi antenna. Those directors (Ld11, Ld12, Ld13) have non uniform lengths. The antenna gain has increased to 15.54 dB as shown in Figure 10**.** The maximum gain denoted with the red color. Figure11 shows that return loss has been expanded to 200 MHz for 13 non-uniform directors.

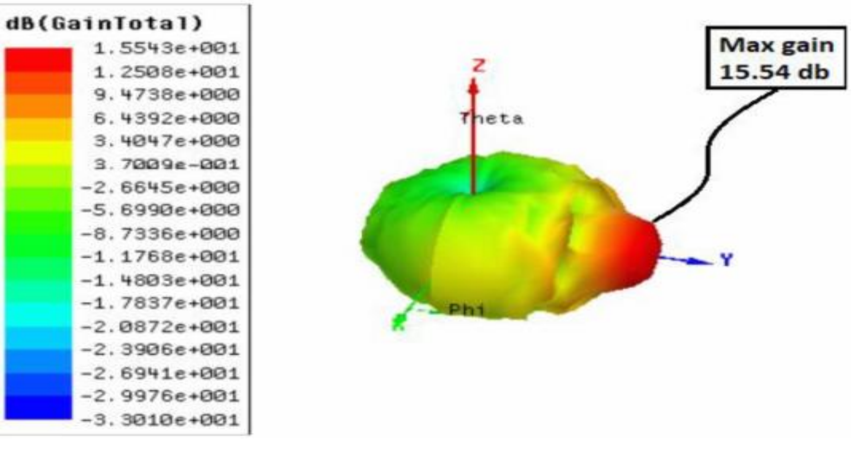

Figure 10 polar plot of the gain with 13 non uniform directors.

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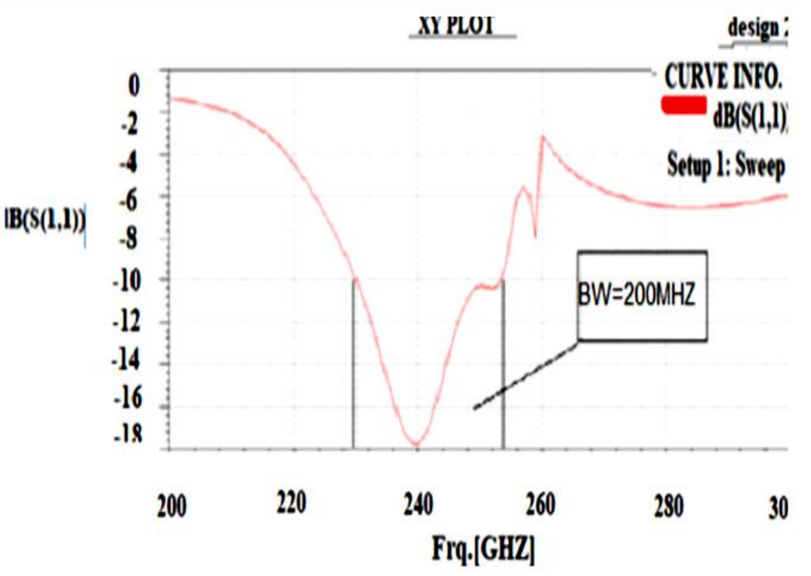

Figure 11 Return losses for Yagi antenna with 13 non uniform directors.

Simulations were conducted to determine the relationship between the number of directors and antenna gain, with Table (3) and Figure (12) illustrating the maximum gain and Yagi-Uda antenna maximum.

Table 3. the maximum gain of the antenna with different number of directors.

Number of directors	Gain dB
4	11.26
7	12.544
10	14.77
13	15.543
15	15.836

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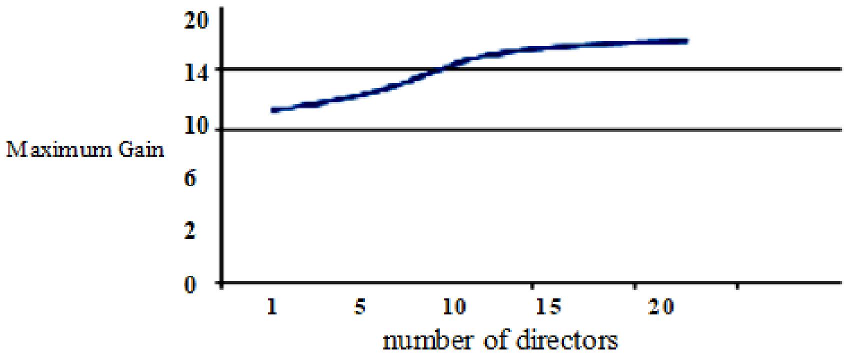

Figure 12. Relationship between number of directors and the maximum gain of the Yagi-Uda antenna.

5. Conclusion

Paper focuses on optimizing the gain of a Yagi antenna. It initially designed a conventional Yagi-Uda antenna with four uniform directors and uniform spacing. By adding more uniform and non-uniform directors, the maximum gain reached 15.54 dB and the bandwidth reached 200 MHz.

The study found that increasing the number of directors and modifying the space between directors with varied lengths can enhance gain and bandwidth compared to the initial design.

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