

DESIGN OF A YAGI-UDA ANTENNA WITH GAIN AND BANDWIDTH ENHANCEMENT FOR WI-FI AND WI-MAX APPLICATIONS

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ABSTRACT

There are various patch antennas used for Wi-Fi and Wi-MAX applications. But, the problems with them are low gain, low power handling capacity and hence, conventional yagi-uda antennas are used. Conventional yagi-uda antennas are used in applications where high gain and directionality are required. Generally, numbers of directors are added to increase gain of these antennas. But, here we present modified yagi-uda antennas, in which the gain and bandwidth can be enhanced by not adding additional directors.

In this paper, we initially discuss the designs of various yagi-uda antennas with uniform, non-uniform spacings between directors and then we discuss their gain and bandwidth enhancement by various approaches. Simulation results show that, the proposed techniques can enhance gain as well as bandwidth when compared with the traditional yagi-uda antennas.

Index Terms

Bandwidth, FEKO, gain, non-uniform spacing, uniform spacing, Wi-Fi, Wi-MAX.

1. INTRODUCTION

In recent years, Wi-Fi and Wi-MAX technologies are playing a vital role in wireless communication because of their advantages like high speed data transfer and anytime, anywhere internet access. There are various patch antennas proposed in [1-3], for these applications. But, the problems with them are low gain and low power handling capacity. The drawback of low gain and low power handling can be overcome by using conventional yagi-uda antennas.

1.1. WI-FI AND WI-MAX BANDS

Basically, Wi-Fi and Wi-MAX technologies use unlicensed and licensed spectrums for wireless communication. There are five Wi-MAX bands available in all over the world. Those frequency bands are 2.3GHz, 2.5GHz, 3.3GHz, 3.5GHz and 5.8GHz. The links mentioned in [4], can also give us a clear idea about Wi-MAX bands and their channels in different frequency bands. Different countries use similar or different frequency bands for Wi-MAX applications. For example, USA uses 3 bands and Canada uses 4 bands [5].

There are two bands dedicated for Wi-Fi applications. One is 2.4GHz band and another one is 5GHz band. The frequency band of 5GHz covers frequencies ranging from 5.1GHz to 5.8GHz. All over the world, 2.4GHz band is not having any major power limitation. But, if we consider the 5GHz band, there is a power limit that varies from country to country [6]. The 2.4GHz band covers frequencies ranging from 2.401GHz to 2.484GHz as shown in figure 1.

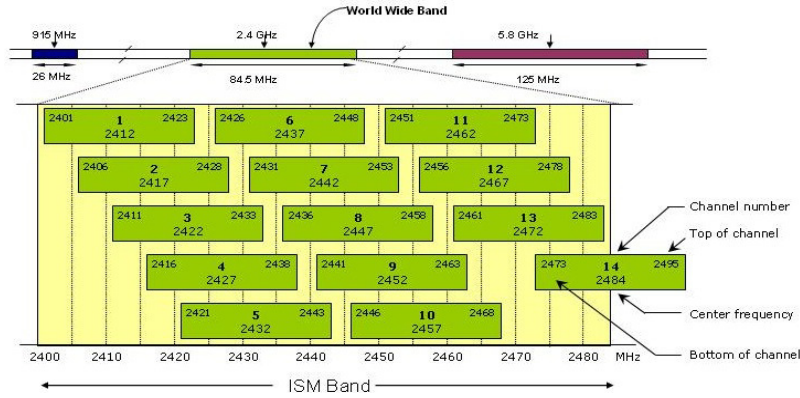


Figure 1: Wi-Fi bands [7].

1.2. CONVENTIONAL YAGI-UDA ANTENNAS

Conventional yagi-uda antennas were invented in 1926 by Shintaro Uda of Tohoku imperial university, Japan along with his colleague Hidetsugu Yagi. These antennas are used in HF (3-30MHz), VHF (30-300MHz), and UHF (300-3000MHz) ranges. Basically, yagi-uda antennas consist of three different types of linear dipole elements as shown in figure 2.

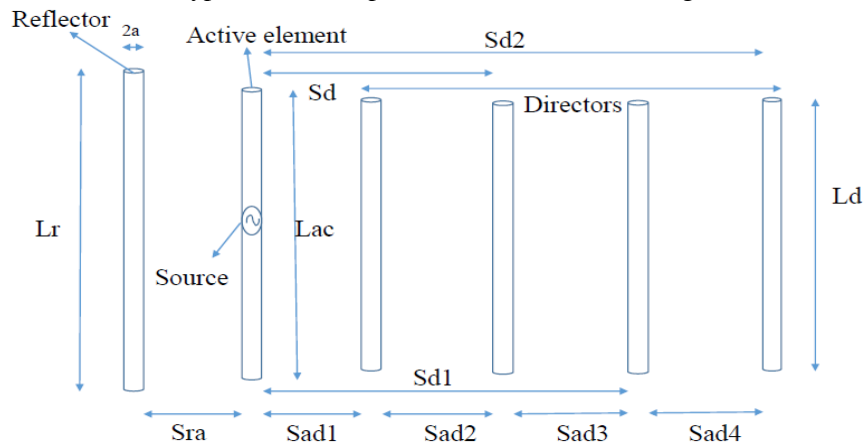


Figure 2: Conventional yagi-uda antenna with various linear dipole elements.

The elements are active element, reflectors and directors [8, 9]. An active element is the one to which the source or excitation is applied. Generally, length (Lac) of this element is slightly less than $\lambda/2$ i.e. ranges from 0.45λ to 0.49λ . Active element is also known as a feeder or a driven dipole. 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. Basically, more than one reflector can be used, but it does not add any advantage specifically. A reflector is located behind active element at a distance (Sra) of 0.25λ . In the designs of yagi-uda antennas, directors play a key role in achieving better gain and directivity. Usually, their length is 5% smaller than the active element i.e. lies between 0.4λ to 0.45λ . Generally, gain is enhanced by adding number of directors as well as by optimizing the spacing between them. In the standard designs, spacing between the directors and the spacing between an active element, directors varies between 0.35λ to 0.4λ . Radius (a) of each element is 0.00425λ [8].

2. RELATED WORK

There are various yagi-uda antennas presented in [10-13]. The proposed antennas are covering frequencies around 2.4GHz for different applications. In the paper [10], the authors discuss about a miniaturized yagi antenna for GSM, WLAN and Wi-MAX applications. The proposed

antenna for WLAN and Wi-MAX applications is covering 10dB return loss frequencies ranging from 2.25GHz to 2.72GHz. The authors in [11], present a 10-element (with 8 directors) conventional yagi-uda antenna for WLAN applications. The proposed antenna is covering frequencies ranging from 1.8GHz to 2.4GHz with a gain of 13dBi. They carried out simulation using method of moments based EM simulation software called SuperNec v2.9. The proposed antenna in [11] is also covering bands other than WLAN and moreover, it uses 8 directors to achieve a gain of 13dBi.



Figure 3: 10-element yagi-uda antenna [11].

In this paper, we discuss various yagi-uda antennas operating at 2.45GHz. Proposed antennas cover complete Wi-Fi 2.4GHz band along with few channels of Wi-MAX 2.3GHz and 2.5GHz bands. With the proposed gain enhancement approaches, we are able to achieve a maximum gain of 12.30dBi with 4 directors. Simulations of these antennas are performed on method of moments based EM structure simulator software called FEKO suite 6.3.

3. DESIGN OF CONVENTIONAL YAGI-UDA ANTENNAS

In this paper, we initially focus on the designs of conventional yagi-uda antennas with 4 directors as shown in figure 2. Here, we have selected 4 directors for better gain and bandwidth. First of all, we consider uniform spacing between the directors and then we focus on non-uniform spacing.

3.1. UNIFORM SPACING BETWEEN DIRECTORS

In this paper, for better understanding of the designs, we have mentioned all the dimensions in terms of ' λ '. Here, uniform spacing between the directors is denoted by 'Sad' and it is assumed as 0.35λ . Design of the proposed uniform spaced yagi-uda antenna with 4 directors in FEKO is shown in figure 4.

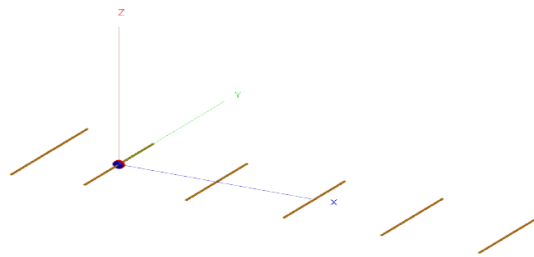


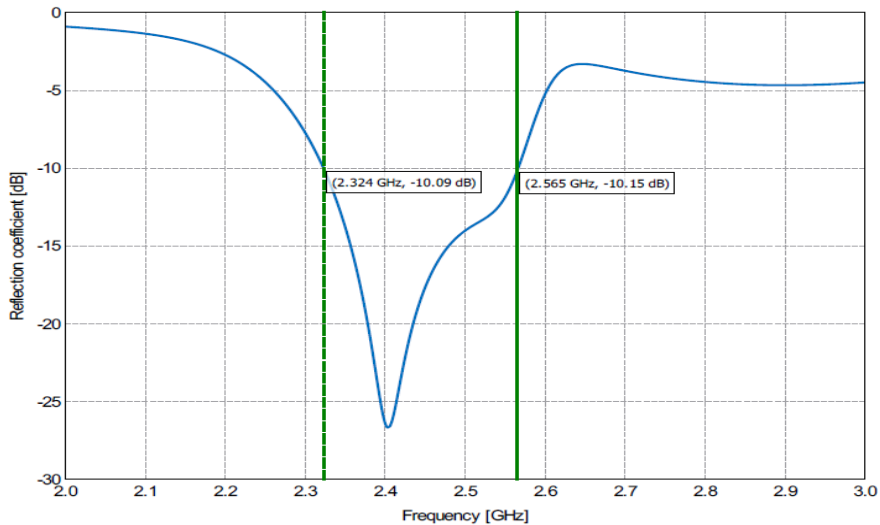
Figure 4: Conventional yagi-uda antenna with 4 directors.

Before discussing various yagi-uda antennas, initially we need to know the optimized dimensions of ' L_r ' ($\geq \lambda/2$), ' L_{ac} ' (0.45λ - 0.49λ) and ' L_d ' (0.4λ - 0.45λ) of a conventional yagi-uda antenna for Wi-Fi and Wi-MAX applications. From the basic knowledge of conventional yagi-uda antennas, we have tried different possible combinations with the lengths of reflector, active element and directors. Results of designs having different possible lengths are shown in Table I.

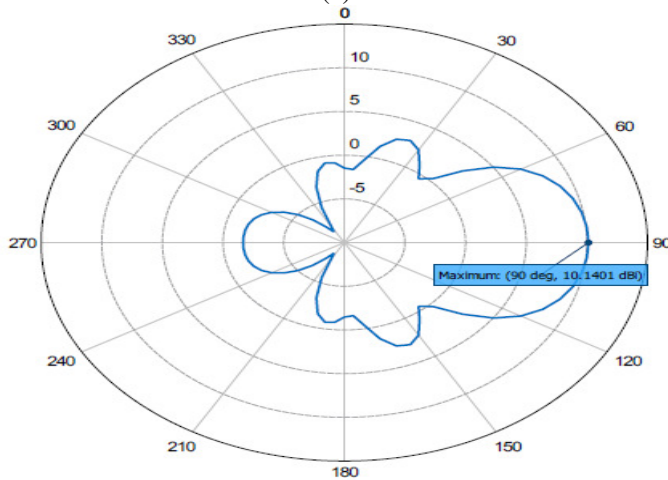
TABLE I. ‘Sra’=0.25*λ, ‘Sad1’=‘Sad2’=‘Sad3’=‘Sad4’=‘Sad’=0.35*λ, where ‘Lr’, ‘Lac’ and ‘Ld’ are varying

case	Lr	Lac	Ld	Gain	Gain (dBi)	-10dB ranges (GHz)	-10 dB Bandwidth (GHz)
I	0.55*λ	0.5*λ	0.4*λ	8.535	9.31	2.115-2.308	0.193
II	0.525*λ	0.5*λ	0.4*λ	9.246	9.66	2.143-2.298	0.155
III	0.525*λ	0.475*λ	0.4*λ	9.213	9.64	2.215-2.418	0.203
IV	0.5*λ	0.45*λ	0.4*λ	10.32	10.14	2.324-2.565	0.241
V	0.475*λ	0.425*λ	0.4*λ	11.60	10.64	2.440-2.600	0.160

If we look at the results shown in table I, designs with cases I, II, III and V are not suitable for our applications. Because, these designs are covering frequencies other than Wi-Fi and Wi-MAX bands. However, case V antenna design can be used only in Wi-MAX 2.5GHz band for few channels. So, for our applications, antenna presented in case IV is suitable because, it is covering complete Wi-Fi 2.4GHz band along with few Wi-MAX channels. Here, we got the dimensions of ‘Lr’, ‘Lac’ and ‘Ld’ as shown in table I case IV. Various plots of the proposed design having dimensions mentioned in table I case IV are shown in figures 5 (a) and (b).



(a)



(b)

Figure 5 (a): Reflection coefficient vs. frequency plot (b). Polar plot of the proposed antenna at 2.45GHz, for table I case IV dimensions.

From the results of table I, we get the dimensions of different element lengths. Now, let us see why we have considered the possible uniform spacing between directors (Sad) as 0.35λ . Results of designs having different uniform spacings are presented in table II.

TABLE II. 'Lr'= $0.5*\lambda$, 'Lac'= $0.45*\lambda$, 'Ld'= $0.4*\lambda$, 'Sra'= $0.25*\lambda$, where 'Sad' is varying

case	Sad	Gain	Gain (dBi)	-10dB Ranges (GHz)	-10dB Bandwidth (GHz)
I	$0.35*\lambda$	10.32	10.14	2.324-2.565	0.241
II	$0.38*\lambda$	10.81	10.34	2.316-2.52	0.204
III	$0.4*\lambda$	11.61	10.65	2.318-2.493	0.175
IV	$0.425*\lambda$	11.50	10.61	2.322-2.466	0.144

If we focus on the results shown in table II, it is clear that when 'Sad' is 0.35λ , then only we are able to achieve complete Wi-Fi 2.4GHz band along with few channels of Wi-MAX 2.3GHz and 2.5GHz bands. Note that, the antenna designs with dimensions discussed in table I case IV and table II case I are same. Here, as we keep on increasing uniform spacing, it is understood that, gain increases but the bandwidth decreases.

Therefore, we can highlight that, only the design discussed in table II case I is useful for Wi-Fi and Wi-MAX applications. However, case II and III designs can be used only for Wi-Fi applications. In table I and II, we present the results of possible uniform spacings between the directors. In these cases, it is observed that the antenna design with table II case I dimensions is most suitable for our applications. Now, let us consider non-uniform spacing between the directors.

3.2. NON-UNIFORM SPACING BETWEEN DIRECTORS

As discussed earlier, spacing between the directors and the spacing between a director and an active element lies between 0.35λ to 0.4λ . Previously, we focused only on uniform spacing between the directors. Here, we examine different possible non-uniform spacing combinations for our applications. Different non-uniform spacing outcomes are shown in table III.

TABLE III. 'Lr'= $0.5*\lambda$, 'Lac'= $0.45*\lambda$, 'Ld'= $0.4*\lambda$, 'Sra'= $0.25*\lambda$, where 'Sad1', 'Sad2', 'Sad3' and 'Sad4' are varying

case	Sad1	Sd	Sd1	Sd2	Gain	Gain (dBi)	-10dB Ranges (GHz)	-10dB Bandwidth (GHz)
I	$0.35*\lambda$	$0.73*\lambda$	$1.13*\lambda$	$1.53*\lambda$	11.350	10.55	2.334-2.519	0.185
II	$0.35*\lambda$	$0.73*\lambda$	$1.06*\lambda$	$1.46*\lambda$	10.233	10.10	2.321-2.549	0.228
III	$0.35*\lambda$	$0.73*\lambda$	$1.06*\lambda$	$1.39*\lambda$	10.556	10.235	2.328-2.549	0.221
IV	$0.35*\lambda$	$0.70*\lambda$	$1.03*\lambda$	$1.36*\lambda$	10.430	10.183	2.327-2.57	0.243
V	$0.40*\lambda$	$0.78*\lambda$	$1.13*\lambda$	$1.46*\lambda$	9.897	9.955	2.315-2.527	0.212
VI	$0.35*\lambda$	$0.73*\lambda$	$1.13*\lambda$	$1.48*\lambda$	11.17	10.48	2.325-2.527	0.202

Let us consider the results shown in table III. Design with table III case I dimensions can be used only for Wi-Fi applications. Antenna design with table III case VI dimensions has somewhat less gain but more bandwidth than the design with table III case I dimensions. Antenna design with table III case IV dimensions is providing similar results in terms of gain as

well as bandwidth, when comparing with the antenna discussed in table II case I. If we focus on the results discussed in table III, it is clear that the results are not better than the results obtained in table II case I. So, for our dual applications discussed non-uniform spacing designs are not giving proper gain, bandwidth and hence from the next discussion onwards our designs deal only with uniform spacings between the directors.

As per the designs with 4 directors (uniform spacing and non-uniform spacing) are concerned, design with table II case I dimensions is the best design for our application. So far, we have been dealing designs with 4 directors. In the next section, we observe the response of proposed design, when the number of directors is varied.

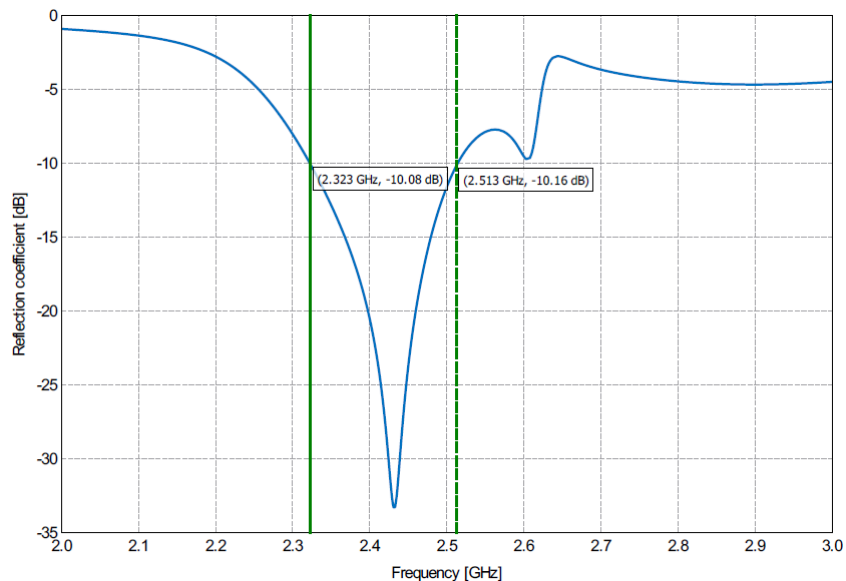
3.3. INCREASING NUMBER OF DIRECTORS

Here, our aim is to compare the results obtained in this section with the results obtained in the modified yagi-uda antenna design section. Design results of proposed antennas with a variation in number of directors are given in table IV.

TABLE IV. 'Lr'=0.5* λ , 'Lac'=0.45* λ , 'Ld'=0.4* λ , 'Sra'=0.25* λ , 'Sad'=0.35* λ , where the number of directors are varying

No. of Directors	Gain	Gain (dBi)	-10dB Ranges (GHz)	-10dB Bandwidth (GHz)
3	9.07	9.58	2.32-2.538	0.218
4	10.32	10.14	2.324-2.565	0.241
5	12.70	11.04	2.331-2.54	0.209
6	14.55	11.63	2.323-2.513	0.190
7	15.27	11.84	2.323-2.528	0.205
8	16.94	12.29	2.328-2.547	0.219

If we observe the results of designs shown in table IV, yagi-uda antenna with 3 directors is giving quite low gain. Proposed antenna with 6 directors is giving a maximum gain of 11.63dBi and a 10dB return loss bandwidth of 0.190GHz. Various plots of proposed yagi-uda antenna with 6 directors are presented in figures 6 (a) and (b).



(a)

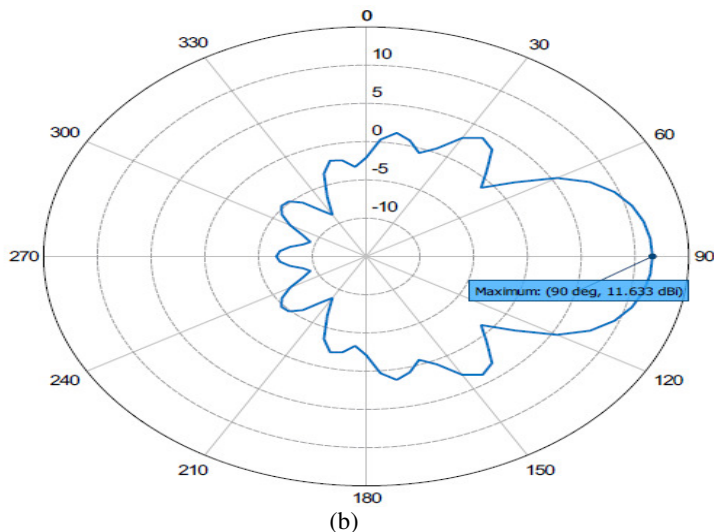


Figure 6 (a): Reflection coefficient vs. frequency plot (b). Polar plot at 2.45GHz of the proposed yagi-uda antenna with 6 directors.

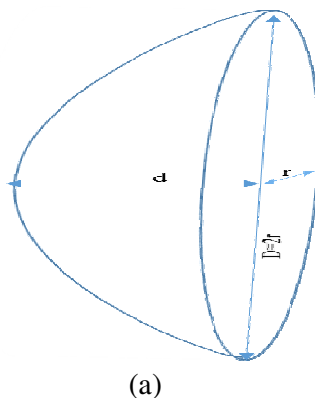
Design with 7 directors is providing a maximum gain of 11.84dBi and a 10dB return loss bandwidth of 0.205GHz. Obtained results in this case are better than the yagi-uda antenna with 6 directors. Yagi-da antenna with 8 directors is also yielding improved gain and bandwidth than all other cases as shown in table IV. From the observation, as we increase number of directors, gain as well as size of the antenna increases. In this paper, our focus is to enhance the gain by keeping same 4 directors as well as maintaining the same bandwidth (obtained in table II case I) as minimum bandwidth. At the same time, we need to maintain the same 2.3GHz and 2.5GHz - 10dB cut-offs as in the case of yagi-uda antenna with table II case I dimensions, so that it is useful for Wi-Fi and Wi-MAX applications.

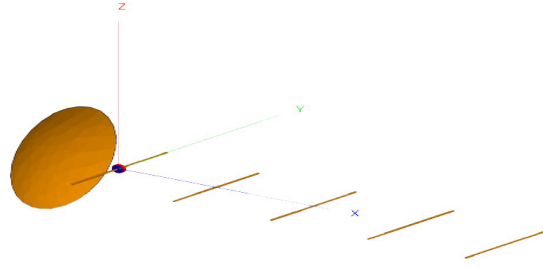
4. DESIGN OF MODIFIED YAGI-UDA ANTENNAS

In this section, we discuss different approaches to enhance the gain by not disturbing the bandwidth obtained in table II case I. To obtain better performance in terms of gain and bandwidth, we replace reflector element by better reflectors like parabolic plate or rectangular plate of good conducting material.

4.1. REPLACING REFLECTOR ELEMENT BY A PARABOLIC PLATE

Here, we present designs of modified yagi-uda antennas, in which the reflector element is replaced by a parabolic plate. In this case, 'Sra' is a distance between the centre of the parabolic plate to the active element, which is also $0.25*\lambda$. Proposed parabolic plate and modified antenna designs are shown in figures 7 (a) and (b).





(b)

Figure 7. (a): Proposed parabolic plate with a radius 'r' and depth 'd' in place of reflector element. Figure 7. (b): Proposed Modified yagi-uda antenna design with 4 directors in FEKO.

To have improved performance than the conventional yagi-uda antenna, diameter (D) of the parabolic plate must be greater than the length of active element. In the initial design, we assume radius (r) as ' $Lr/2$ ' and then we make changes in depth. In the next level of the design, we increase radius (r) and then we vary the depth as shown in below tables. To avoid complexity, here also we have mentioned parabolic structure dimensions in terms of ' Lr '. Different combinations of radius ' $Lr/2$ ' and depth (d) results are presented in table V.

TABLE V. ' $Lr'=0.5*\lambda$ ', ' $Lac'=0.45*\lambda$ ', ' $Ld'=0.4*\lambda$ ', ' $Sra'=0.25\lambda$ ', ' $Sad'=0.35*\lambda$ ', where 'r' and 'd' are varying

Radius (r)	Depth (d)	Gain	Gain (dBi)	-10dB Ranges (GHz)	-10dB Bandwidth (GHz)
$Lr/2$	$Lr/5$	13.00	11.14	2.348-2.476	0.128
$Lr/2$	$Lr/10$	12.50	10.97	2.348-2.530	0.182
$Lr/2$	$Lr/30$	12.19	10.86	2.345-2.546	0.201

If we look at results shown in table V, it is clear that by replacing a reflector with a parabolic plate, there is enhancement in gain than the conventional yagi-uda antenna discussed in table II case I. There is one more point to observe is that, as we decrease the depth (d), gain decreases slightly but the bandwidth increases considerably. Modified yagi-uda antenna with radius ' $Lr/2$ ' and depth ' $Lr/5$ ' is achieving a maximum gain of 11.14dBi, which is higher than the gain of yagi-uda antenna with 5 directors (11.04dBi). But, the proposed antenna design is not covering Wi-Fi and Wi-MAX bands. Antenna design with radius ' $Lr/2$ ' and depth ' $Lr/30$ ' is also yielding higher gain but less bandwidth than the yagi-uda design discussed in table II case I. This design is providing better bandwidth than the design with radius ' $Lr/2$ ' and depth ' $Lr/5$ '. Here, we need a modified yagi-uda antenna with higher gain and bandwidth than the antenna discussed in table II case I. To achieve the required goal, let us increase the radius of parabolic plate. Design results of the antenna with increased radius and variation in depth are shown in table VI.

TABLE VI. ' $Lr'=0.5*\lambda$ ', ' $Lac'=0.45*\lambda$ ', ' $Ld'=0.4*\lambda$ ', ' $Sra'=0.25\lambda$ ', ' $Sad'=0.35*\lambda$ ', where 'r' and 'd' are varying

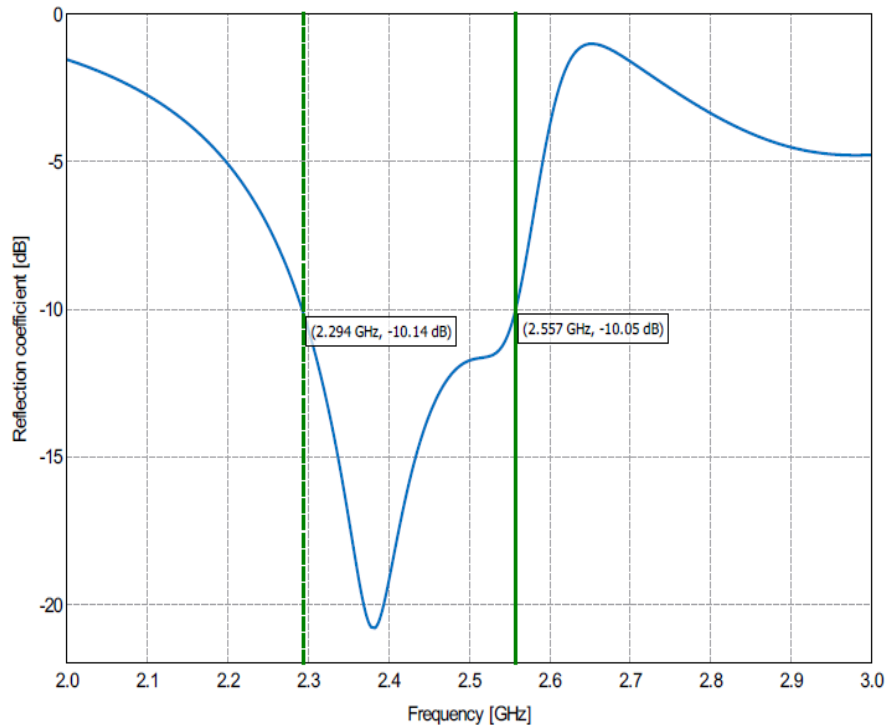
Radius (r)	Depth (d)	Gain	Gain (dBi)	-10dB Ranges (GHz)	-10dB Bandwidth (GHz)
$(2*Lr)/3$	$Lr/5$	14.80	11.70	2.28-2.479	0.199
$(2*Lr)/3$	$Lr/10$	14.50	11.61	2.295-2.531	0.236
$(2*Lr)/3$	$Lr/30$	14.22	11.53	2.297-2.545	0.248

In this case, with the increment in radius, gain as well as bandwidth increases. Design with radius $(2 \cdot L_r)/3$ and depth $L_r/30$ is giving a maximum gain of 11.53dBi, which is higher than the yagi-uda antenna discussed in table II case I (10.14dBi). At the same time, it is also higher than the yagi-uda antenna with 5 directors (11.04dBi). In this case, we are covering complete Wi-MAX 2.3GHz and Wi-Fi 2.4GHz bands, which are not covered by the conventional yagi-uda antenna discussed in table II case I. Here also we are getting improved gains and bandwidths. Let us increase the radius further. Design results the proposed antenna with radius L_r and different values of depths are presented in table VII.

TABLE VII. $L_r=0.5 \cdot \lambda$, $L_{ac}=0.45 \cdot \lambda$, $L_d=0.4 \cdot \lambda$, $S_{ra}=0.25 \lambda$, $S_{ad}=0.35 \cdot \lambda$, where r and d are varying

Radius (r)	Depth (d)	Gain	Gain (dBi)	-10dB Ranges (GHz)	-10dB Bandwidth (GHz)
L_r	$L_r/5$	17.00	12.30	2.287-2.552	0.265
L_r	$L_r/10$	16.60	12.20	2.291-2.554	0.263
L_r	$L_r/30$	16.20	12.10	2.294-2.557	0.263

Consider the design results shown in table VII. Design with radius L_r and depth $L_r/5$ is providing a maximum gain of 12.30dBi, which is more than the yagi-uda antenna with 8 directors (12.29dBi). In this case also, we are achieving complete Wi-MAX 2.3GHz and Wi-Fi 2.4GHz bands. The design with radius L_r and depth $L_r/30$ is giving a maximum gain of 12.10dBi, which is higher than the yagi-uda antenna with 6 directors (11.63dBi), 7 directors (11.84dBi). Even, it is almost maintaining the same 2.5GHz -10dB cutoff (2.557 GHz) with -10dB cutoff of the yagi-uda antenna (2.565GHz) discussed in table II case I. Various plots of the proposed antenna with radius L_r and depth $L_r/30$ are shown in figures 8 (a) and (b).



(a)

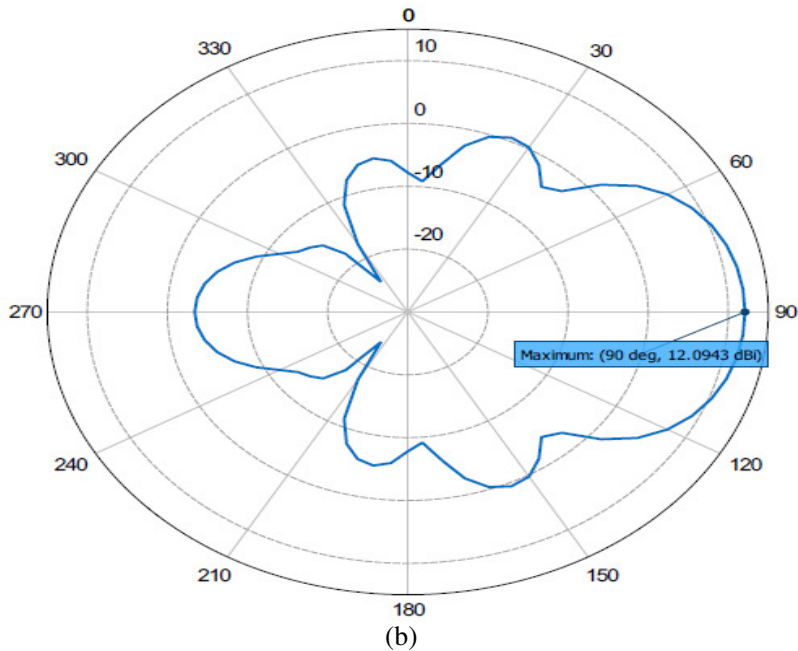


Figure 8 (a): Reflection coefficient vs. frequency plot (b). Polar plot at 2.45GHz, of the Modified yagi-uda antenna, when ‘r’ as ‘Lr’ and ‘d’ as ‘Lr/30’.

Here, we can state that, without increasing number of directors it is possible to enhance the gain as well as bandwidth. So, for our Wi-Fi and Wi-MAX applications proposed antenna designs discussed in table VII are most suitable. In the next discussion, we replace reflector element by a rectangular plate.

4.2. REPLACING REFLECTOR BY RECTANGULAR PLATE

Here, we discuss the response of modified yagi-uda antennas, when the reflector element is replaced by a rectangular plate having length (L) and width (W) as shown in figure 9 (a). In this case ‘Sra’ is simply a distance between the rectangular plate to the active element, which is also $0.25*\lambda$. Arrangement of the conventional yagi-uda antenna with rectangular plate is shown in figure 9 (b).

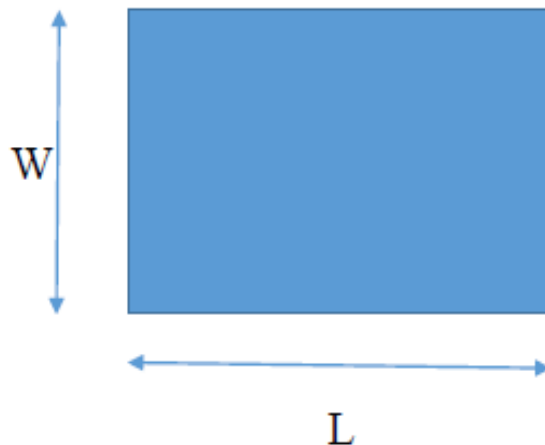


Figure 9 (a): Proposed rectangular plate with Length ‘L’ and width ‘W’ in place of reflector element.

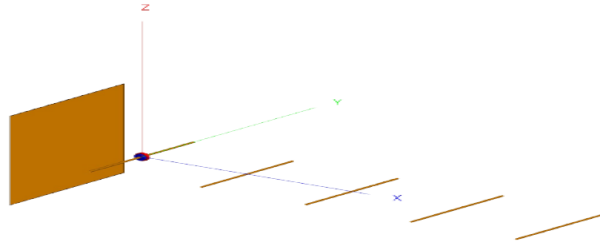


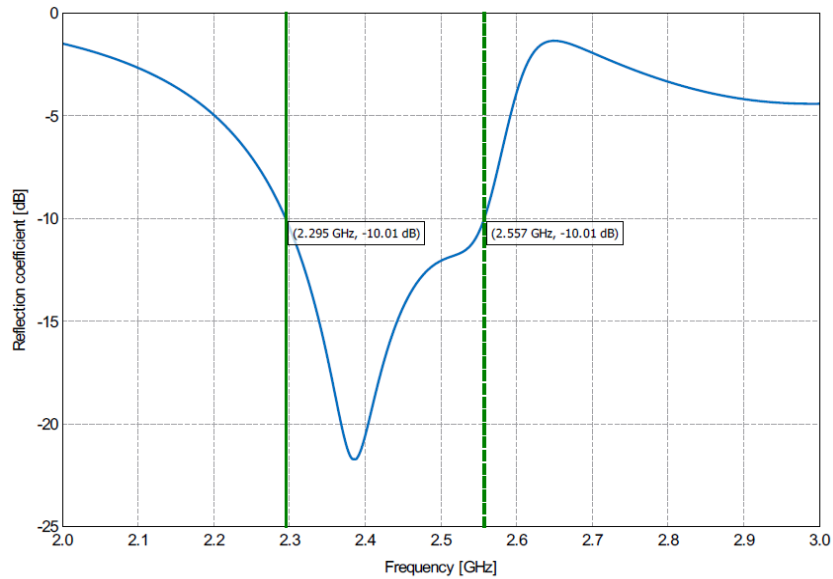
Figure 9 (b): Proposed Modified yagi-da antenna with rectangular plate.

Design results of the rectangular plate with possible combinations of Width (W) and Lengths (L) are shown in table VIII.

TABLE VIII. ‘Lr’=0.5λ, ‘Lac’=0.45*λ, ‘Ld’=0.4*λ, ‘Sra’=0.25*λ, ‘Sad’=0.35*λ, where ‘L’ and ‘W’ are varying

Width (W)	Length (L)	Gain	Gain (dBi)	-10dB Ranges (GHz)	-10dB Bandwidth (GHz)
Lr/2	Lr	11.80	10.72	2.315-2.556	0.241
Lr/2	Lr*1.5	10.40	10.17	2.31-2.563	0.253
Lr	Lr	12.90	11.11	2.311-2.548	0.237
Lr	Lr*1.5	12.80	11.07	2.30-2.557	0.257
Lr*1.5	Lr*1.5	14.48	11.61	2.295-2.557	0.262

If we look at the results shown in table VIII, we get a maximum gain of 11.61dBi, which is approximately equal to the conventional yagi-uda antenna with 6 directors (11.63dBi). In this case also, the design is achieving more bandwidth and almost maintaining the same 2.5GHz - 10dB cutoff (2.557 GHz) with -10dB cutoff of the yagi-uda antenna (2.565GHz) discussed in table II case I. Various plots of the proposed modified yagi-uda antenna with rectangular plate having width ‘Lr*1.5’ and length ‘Lr*1.5’ are shown in figures 10 (a) and (b).



(a)

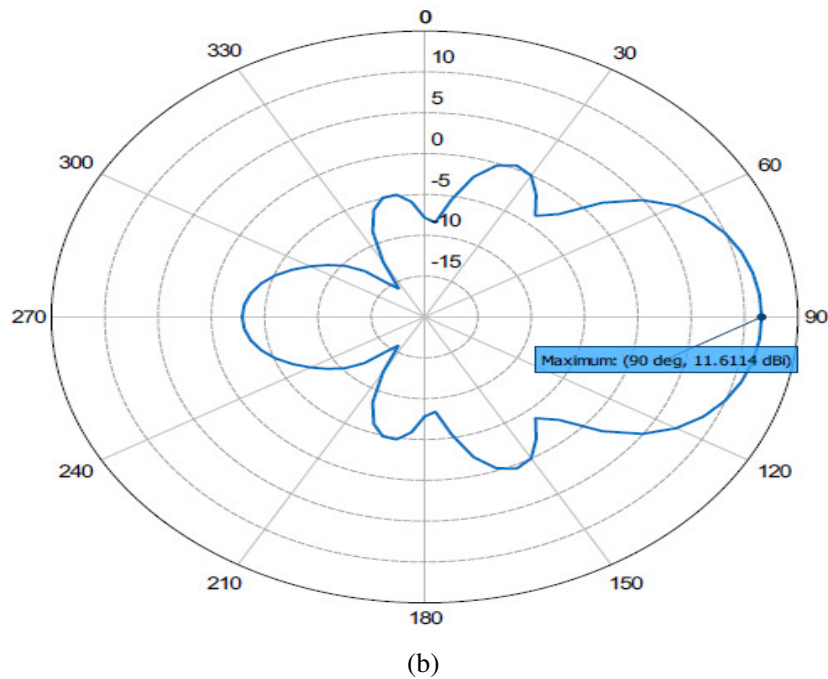


Figure 10 (a): Reflection coefficient vs. frequency plot (b). Polar plot at 2.45GHz, of the modified yagi-uda antenna, when 'L' and 'W' as $1.5 \cdot L_r$.

Here also, we can state that, the proposed antenna design with rectangular plate having length and widths as ' $1.5 \cdot L_r$ ' can also be used for our applications. Hence, we can conclude that, the proposed designs in table VII and the design with rectangular plate having length and widths as ' $1.5 \cdot L_r$ ' are most suitable antennas for Wi-Fi and Wi-MAX applications.

5. CONCLUSION

In this paper, initially we discuss conventional yagi-uda antennas by considering uniform, non-uniform spacing between directors. Here, we observed the problems associated with non-uniform spacings and concluded that, the antenna design presented in table II case I is suitable for our dual applications. Next, we varied the number of directors and noted that, as we increase number of directors, gain as well as size of the antenna increases. After that, we replace the reflector element by various structures. Out of this examinations, parabolic plate designs discussed in table VII and the design with rectangular plate having length and widths as ' $1.5 \cdot L_r$ ', are giving increased gain and bandwidth than any other yagi-uda antennas. Finally, we can state that, proposed designs in table VII and table VIII are most suitable antennas for Wi-Fi and Wi-MAX applications. These kinds of designs are mostly useful in areas, where Wi-Fi and Wi-MAX technologies are enabled.

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