International Journal of Advance Research in Engineering, Science & Technology(IJAREST),
ISSN(O):2393-9877, ISSN(P): 2394-2444,
Volume 2, Issue 7, July- 2015, Impact Factor: 2.125

DESIGN DEVELOPMENT AND FABRICATION OF PRINTED Yagi-Uda ANTENNA

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Abstract -*The Yagi-Uda antenna was invented in 1926 by Shintaro Uda of Tohoku Imperial University, Sendai, Japan, with the collaboration of Hidetsugu Yagi, also of Tohoku Imperial University. Yagi-Uda antennas are routinely made with high gains (over 10dB) making them a common choice for directional antennas especially in VHF and UHF communications systems where a narrowband antenna is acceptable. In the recent years, Printed circuit antennas have been receiving much attention owing to their light weight, low cost, small size, easy fabrication, and ease of installation. The Printed Yagi Uda Antenna is designed for the frequency range 4.0 GHz – 4.4GHz. This range of Radio Frequencies lies in the C (4 to 8GHz) band. C Band frequencies are used for many satellite communication transmissions, some Wi-Fi devices, cordless telephones, and weather radar systems. For satellite communications, the microwave frequencies of the C-band perform better under adverse weather conditions. This paper provides the steps to design, simulate and fabricate a Printed Yagi-Uda Antenna which may be used in satellite communication or radar system applications*.

I. INTRODUCTION

To meet the intended applications in Satellite Communication, the following specifications, listed in Table I are chosen:

Table I : Specifications

Parameter	Specifications
Frequency Range	4.0 GHz - 4.4 GHz
Gain	6 dB
Beamwidth	Min 70^{o} in both planes
Return loss	Better than 10dB
Polarization	Linear
Connector type	SMA Tab type
Physical Dimensions	50x70 (mm)
Weight	< 100g

The different design parameters of the antenna are calculated by using the design equations. In the design, one reflector, single dipole and three directors are used to meet the desired gain, polarization and return loss requirement. The simulation studies are carried out using Ansoft HFSS Simulation tool. The simulation results are obtained and optimization of different parameters are carried out for achieving aimed specifications.

The effect of change in the length of dipole, directors, reflectors and the spacing between them, on the Gain and Return loss is also studied.

II. Yagi-Uda Antenna

Most Yagi's are for TV-reception and they are also used for more specialized purposes with transmitting too. It is the most popular directional array antenna on the radio amateur bands from 14 MHz through VHF and UHF. It is sometimes seen on the 30 and 40 meter bands too.

The driven element in a parasitic array, always resonant at the operating frequency. The parasitic elements are usually (but not always) slightly off resonance; the directors are generally tuned to a higher frequency than that of the driven element, and the reflector is generally set to a lower frequency (thus longer). The impedance of the driven element, at the feed point, is a pure resistance when the antenna is operated at its resonant frequency. When parasitic elements are near the driven element, the impedance of the driven element is low compared to that of a dipole in free space. The basic design uses a dipole as a driven element. It is resonant when the electrical length is 1/2 of the wavelength, for the used frequency, applied to the feed point. Folded Dipoles are commonly used in Yagi design.

A. Working Principle of Yagi Uda Antenna

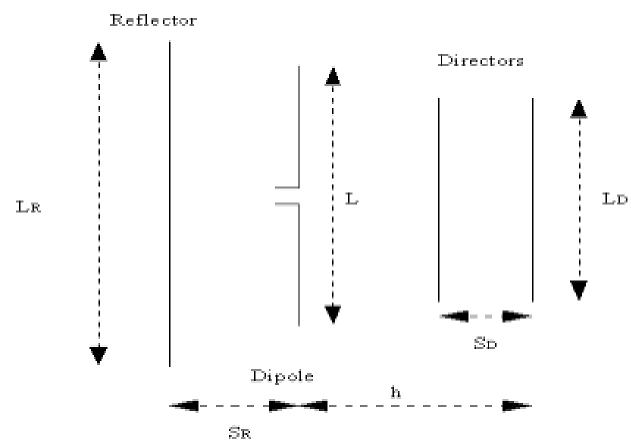
The objective of the design is to make a "travelling wave" structure with currents in the elements all contributing to the far field in the forward direction. The contributions are designed to add up in phase in the forward direction, and to cancel in the reverse direction. The director elements are cut shorter than the driving element, which is itself a little shorter than a half wavelength at the design frequency. The reflector is cut to be about a half wavelength and it is longer than the driving element, and spaced closer than are the directors. The directors present a capacitive impedance, acting like two lengths of open circuit transmission line each a little shorter than a quarter wavelength to a hypothetical generator at the center formed from the "induced emf" set up by the impinging fields. Similarly, the reflector presents an inductive impedance to a hypothetical emf generator at its center. The effects of the spacing's and the current progressive phase shifts mean that the contributions of the current in the various elements to the radiated fields all add up in phase.
If the director elements are cut a little short, their self-impedance is capacitive and they have to be spaced a little closer than a half-wavelength in order to maintain equality of phase in the radiation contribution with the wave arriving from the previous director. The currents in successive elements thus roughly have the pattern ....up down up down up down....but will all be nearly equal in magnitude to each other. There is also some progressive phase shift as the wave advances, caused by the fact that the directors are cut short (capacitive).
The field pattern on the Yagi directors therefore advances as a travelling wave in the forward direction, with wavelength approximately equal to three director spacing's. So the travelling wave structure supports a non-attenuating wave in the forward direction, and the currents in the directors are all approximately the same size, although with a progressive phase delay. It is for this reason that, for moderate numbers of elements, the forward gain is proportional to the number of elements.

The reflector has an induced current in it that contributes a wave in the backwards direction that just cancels the backward wave from the driven element. Only a little power is radiated backwards. The net power radiated by the reflector current has to go somewhere, so it appears as a contribution in the forward direction. The length and the spacing of the reflector have a strong influence on the residual backward radiation from the Yagi-Uda. Typically the reflector will be spaced by 1/8 to 1/4 of a wavelength, and the directors by about 1/3 wavelength each.

The array factor gain of a Yagi-Uda is therefore limited to the number of elements, and the element gain is that of a dipole of length about half a wavelength, which is 1.66. Therefore the maximum gain we can reasonably expect from the Yagi-Uda is 1.66 times the number of elements, over isotropic, (or just a factor [equal to the number of elements] over the gain of a single half-wave dipole).

B. Design specifications for Yagi-Uda antenna

FIGURE 1 : Structure



The theoretical parameter limits have been summarized as follows:

- Reflector Length: L_R = 0.47 - 0.52 λ
- Driven Element Length: L = 0.45- 0.49
- Director's length: L_D = 0.4-0.45 λ

- Separation between Directors: S_D = 0.2-0.35 λ
- Separation between driven element and reflector: S_R = 0.2-0.35 λ

All of the above variables will affect the output of the antenna. Optimization can be achieved by simulating the radiation patterns for varying values of the above variables.

C. *Design specifications for Printed Yagi-Uda antenna*

FIGURE 2 : Top Side

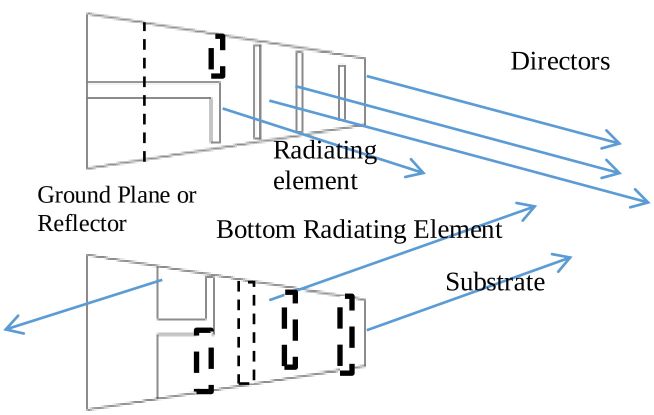


FIGURE 3 : Bottom Side

The Printed Yagi antenna is designed on the Rogger's RT Duroid 5880 card with three directors, top feed and half of the dipole on the top side (Fig 5.2) and the bottom side (Fig 5.3) consisting of the reflector (ground plane) and the bottom portion of the radiating element (dipole). A 0.8mm thick Rogger's RT duroid 5880 substrate is used as the Circuit board. The antenna is excited at the wave port by a coaxial cable. Feed input impedance is 50Ω.

Table II lists the design formulae and the calculated measurements of all the elements of the Antenna. If the Printed Circuit antenna radiates into a dielectric filled atmosphere of relative permittivity E_r=2.2, the wavelength, and hence the electric dimensions need to be scaled down by a factor $(Er)^{1/2}$ to obtain similitude with the propagation in free space.

Table II: Design formulae and calculated values

PARAMETERS	FORMULA	Calculated Values (mm)
S_{12}	0.2λ-0.35 λ	9.4-16.45
$S_{23}=S_{34}=S_{45}$	0.2 λ -0.35 λ	9.4-16.45
W_2	0.015 λ -0.025 λ	0.7-1.1
$W_3=W_4=W_5$	0.015 λ -0.025 λ	0.7-1.1
L_2	0.45 λ -0.49 λ	21.15-23.03
$L_3=L_4=L_5$	0.4 λ -0.45 λ	18.8-21.15

D. *Optimised value*

- The results obtained after optimization met our required specifications. Hence we fixed all our parameters accordingly. They are listed in the Table III.
- A Roger's RT Duroid 5880 substrate board having a dielectric constant of 2.2 was used in the project. This was chosen because the lower the dielectric constant, more will be the propagation of the EM Waves through the substrate. Hence a low dielectric constant substrate was chosen.
- Its thickness is kept to be 0.8mm and the perfect electric conductors are Copper.
- The feed line used is a microstrip line having a thickness of 4.8 mm, which matches the input impedance of the antenna and the feed.

PARAMETERS	FORMULA	CALCULATED VALUES (mm)	
		Theoretical	**Optimized**
Distance between Reflector and Dipole	0.2λ-0.35 λ	9.4-16.45	**10.55**
Distance between the successive directors	0.2 λ -0.35 λ	9.4-16.45	**D1-D2 = 10.47 D2-D3 = 9.60 D3-D4 = 8.45**
Width of Dipole	0.015 λ -0.025 λ	0.7-1.1	**1.5**
Width of Directors	0.015 λ -0.025 λ	0.7-1.1	**1.5**
Length of Radiating element	0.45 λ -0.49 λ	21.15-23.03	**30.0530**
Length of directors*	0.4 λ -0.45 λ	18.8-21.15	**D1=23, D2=18.2, D3=15.6**

Table III: Theoretical and Optimized values

III.FABRICATION

Fabrication is a process in which the designed antenna is realized. Flow graph for the design process is given in Table IV. Fabrication of the antenna is carried out on the substrate material metalized on both the sides using photolithographic process as described below.

Table IV: Fabrication Process

DESIGN
MASTER DRAWING ART WORK LAY OUT
ART WORK LAY OUT
PHOTO REDUCTION
NEGATIVE DEVELOPMENT
LAMINATE CLEANING
RESIST APPLICATION
RESIST EXPOSURE
RESIST DEVELOPMENT
INSPECTION
ETCHING
BONDING
FINISHING

IV. RESULTS & DISCUSSION

After the model is simulated, and optimized, the results are obtained using Ansoft HFSS software, and noted. Then the antenna is realized and physical measurement of the antenna parameters is done. These results are then compared with the simulated ones, discussed in this chapter.

A. Simulation Results

1) Radiation Pattern

A power gain of 6.9 dB is obtained after optimization of the parameters. The radiation pattern plots are shown in figures 4 and 5.

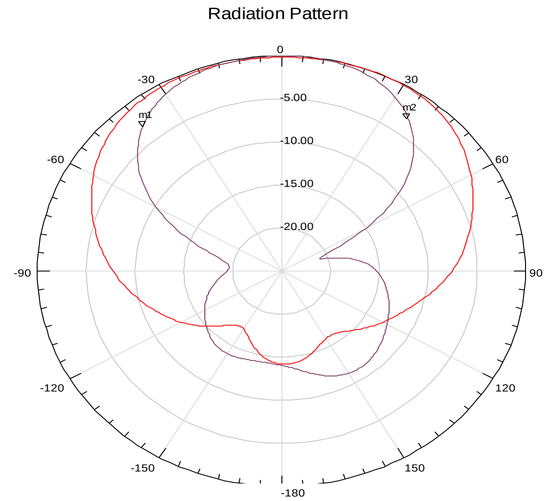


FIGURE 4 : Radiation Pattern (10 dB Normalize)

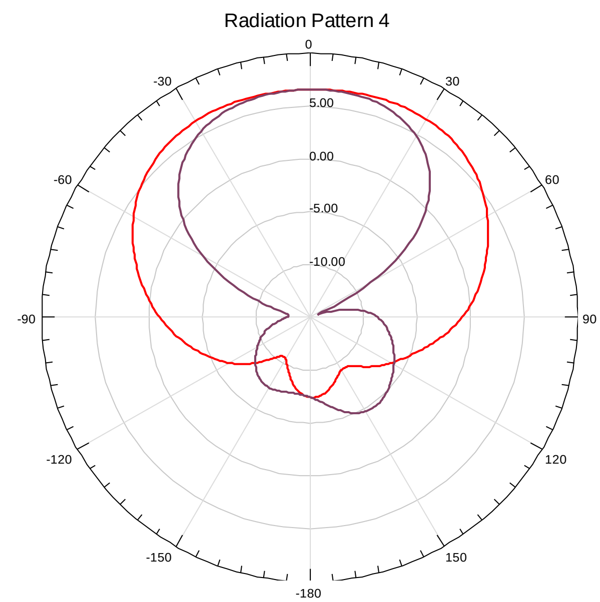


FIGURE 5: Radiation Pattern

2) Return Loss

The return loss of less than -10 dB is successfully obtained throughout the frequency band of 4.0 GHz to 4.4 GHz and the resonant peak of -16.50 dB is seen at 4.2 GHz. This is depicted in figure 6.

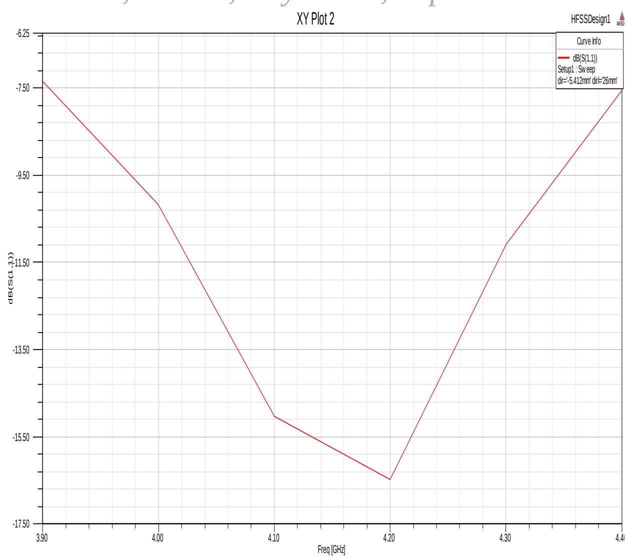


FIGURE 6 : Return loss

3) VSWR

The simulated VSWR plot of the designed Yagi Uda antenna is shown in fig 7.

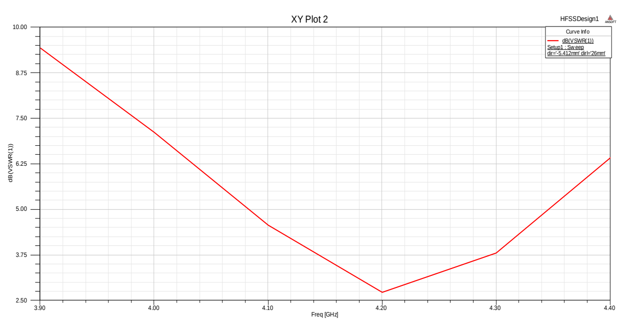


FIGURE 7 : VSWR Plot

4) Effect of number of directors, on Gain and Return Loss.

As shown in the Table V, we conclude that as the number of directors is increased, the Gain increases and the return loss improves. However the magnitude of increase in gain reduces as the number of directors is increased.

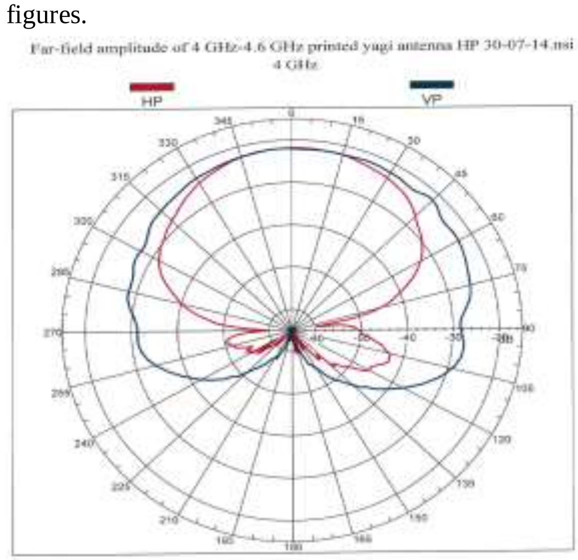
Table V : Effect of number of directors, on Gain and Return Loss

Elements	**Gain (dB) at 4.2 GHz**	**Return Loss**
Director 1	5.736	Resonant Freq: 4.3 GHz
		Peak : -17.86 dB
Director 1 and 2	6.5118	Resonant Freq: 4.2 GHz
		Peak : -18 dB
Director 1, 2 and 3	6.9056	Resonant Freq: 4.2 GHz
		Peak : -18.74 dB

B . Results of Fabricated antenna

1) Radiation Pattern

The radiation patterns at the frequencies in the range 4.0 GHz to 4.6 GHz is obtained and shown below. The corresponding gains and beamwidth values are plotted in Table VI given below, which summarizes the observations from the given below figures.



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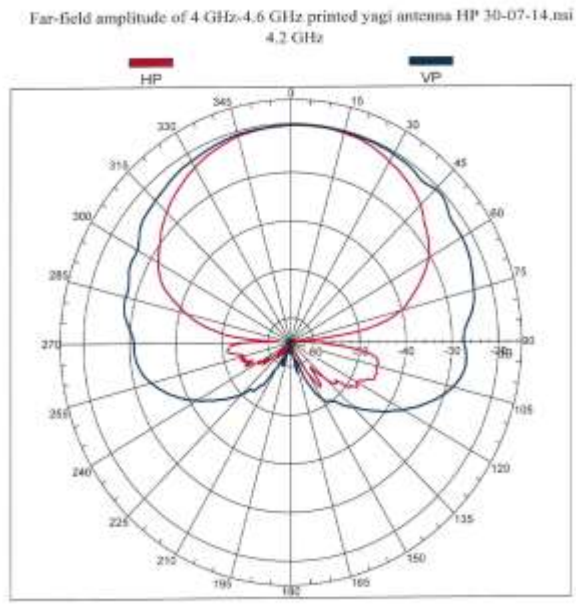
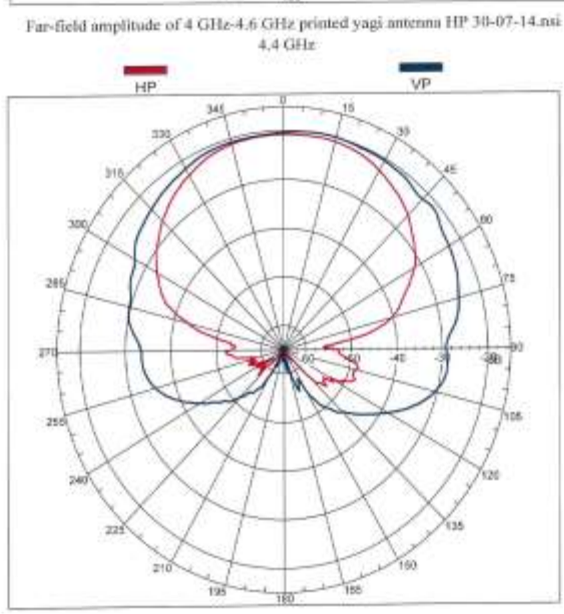




Frequency (GHz)	Gain (dB)	Beamwidth in HP (dB)	Beamwidth in VP (dB)
4	4.22	69.39	120.74
4.1	5.99	67.24	116.58
4.2	6.18	65.33	111.35
4.3	6.14	65.85	107.15
4.4	6.74	66.66	100.11
4.5	7.36	65.75	94.40
4.6	6.56	63.19	92.01

Table VI: Measured Results

2) Return Loss and VSWR

A return loss of -43.954 dB is measured, which is resonant at a frequency of 4.39GHz.
Its value is below the -10 dB mark in a bandwidth of 525 MHz over the range 4.1 GHz to 4.625 GHz, shown in the fig 9.5. The fig 9.6 shows the VSWR measured, and has a value of 1.02 dB at 4.39 GHz and is less than 2 over the bandwidth mentioned above.

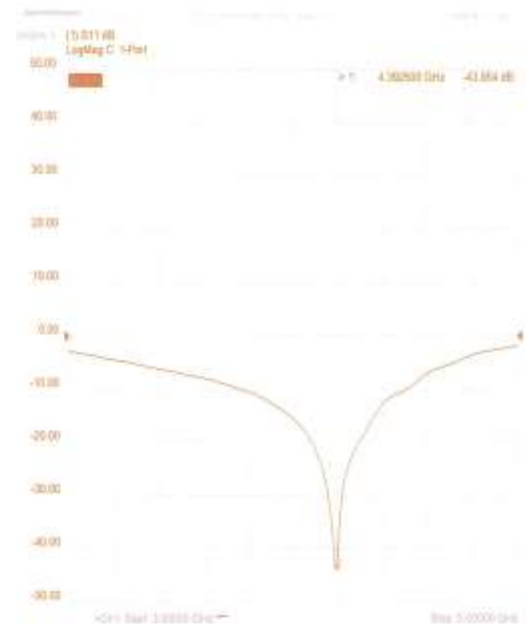


FIGURE 8: Return Loss

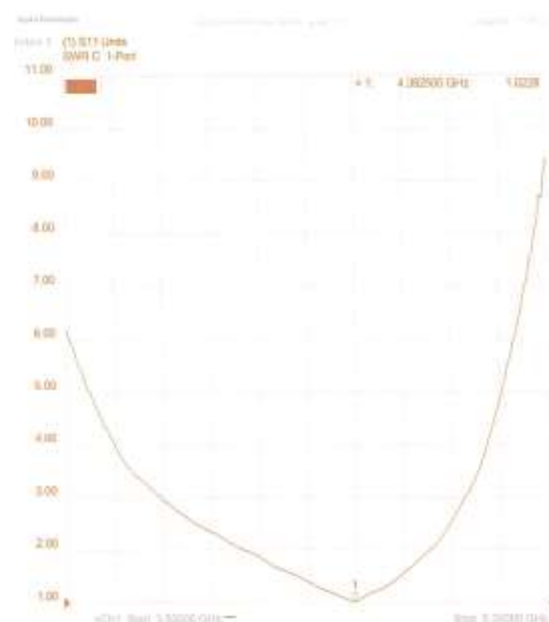


FIGURE 9 : VSWR

3) Comparison between the specifications, simulated and measured results.

Table VII compares the values of the specified parameters, the simulation results and the physically measured results.

Table VII: Comparison between the specifications, simulated and measured results

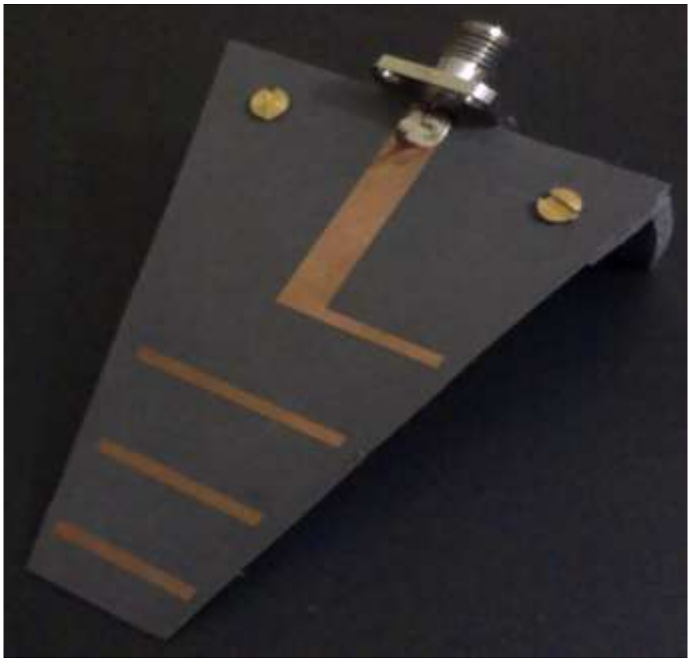
Specifications	**Results**	
	Simulated	**Realized**
4-4.4GHz	3.9-4.4 GHz	4.1 GHz-4.6GHz
400 MHz	500 MHz	525 MHz
Less than 10dB	Less than 10 dB	Less than 10 dB
6 dB	6.9dB	6.18 dB
70^{o}	76^{o}	65^{o}
Linear	Linear	Linear
50mmX70mm (max)	48.6mmx66.4mm	48.6mmx66.4mm
Less than 100g	Less than 100g	Less than 100g

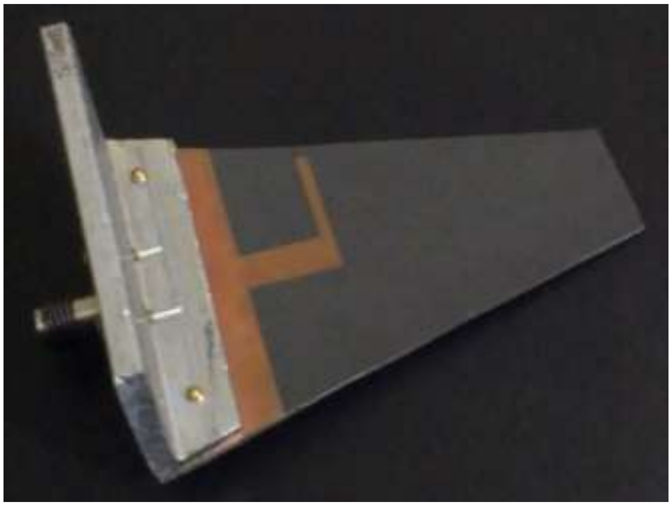
V. CONCLUSION

Thus the Printed Yagi-Uda antenna with the specified parameters is designed, realized and analyzed and found to be within the specified range, in terms of gain and return loss. A large bandwidth is obtained and a consistent gain and beamwidth is observed over the frequency range of 4.1 GHz to 4.65 GHz. The antenna may now be used for its intended applications.

VI. APPENDIX

A . Printed Yagi Uda Antenna Photographs





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