Comparison Between 3-element & 5-element Yagi-Uda Antenna for Power Harvesting from Radio Frequency Signal

Lasker, Md. Minhaz Zaman,[a] Chisty, Nafiz Ahmed[b]

[a] Student, Dept. of EEE —American International University - Bangladesh, 82/B Kemal Ataturk Avenue, Banani, Dhaka 1213, Bangladesh

zamanminhaz@yahoo.com

[b] Asst. Prof., Dept. of EEE—American International University - Bangladesh, 82/B Kemal Ataturk Avenue, Banani, Dhaka 1213, Bangladesh

chisty@aiub.edu

Abstract. This paper discusses a comparison between 3-element and 5-element Yagi-Uda antenna to find out the best antenna for power harvesting from available RF waves in urban areas. The antenna will extract available RF waves from environment. The harvested energy from the chosen antenna, which of very low magnitude is later amplified to a suitable value for the use in consumer appliances, especially for mobile devices. It will increase the mobility of the device and allow using the unused electromagnetic wave for daily purposes, thus reducing the pressure on national power grid in a broad sense. Additionally, this paper discusses the antenna structure and methods for extracting DC power from electromagnetic radiation.

Keywords: Yagi-Uda antenna, CST software, RF signal, Energy harvesting device

1 INTRODUCTION

The process of extracting power from radio frequency is one of the latest innovations of modern science to make the best use of propagating electromagnetic waves. There are abundant unused energy waves in surroundings. Yagi-Uda antenna with different element number can be used to extract those electromagnetic waves. Electromagnetic fields and waves are generated around overhead lines, vibrating machines and Wi-Fi routers etc. Those frequencies are usually in Ultra High Frequency (UHF) band and remaining unused in environment. These unused electromagnetic waves can be harvested to produce power. This technology will add a new dimension to the sources of power and reduce pressure from national grid.

1.1 Methodology

The paper aims to find out the best Yagi-Uda antenna structure by comparing between 3-element and 5-element Yagi-Uda antenna by considering their characteristics and radiation pattern and later using the chosen one with a prototype circuit that will harvest the available RF waves from 700 MHz to 6 GHz for use in urban area. The bandwidth has been chosen keeping in mind that the band of spectrum covers all communication standard interfaces. Figure 1 shows the block representation of the whole process.

RF signal extracted through receiver will convert RF signal power into DC power (Lasker, Mojumdar, Chowdhury, Ferdous & Chisty, June 2014). The output power is very low, usually in mV range, which is not sufficient to drive any device even low power devices. In order to amplify the voltage, an AC amplifier circuit has been used. A full bridge rectifier circuit can be used to convert the AC voltage into DC voltage. Then a DC adjustable circuit will provide a constant +5V DC voltage.

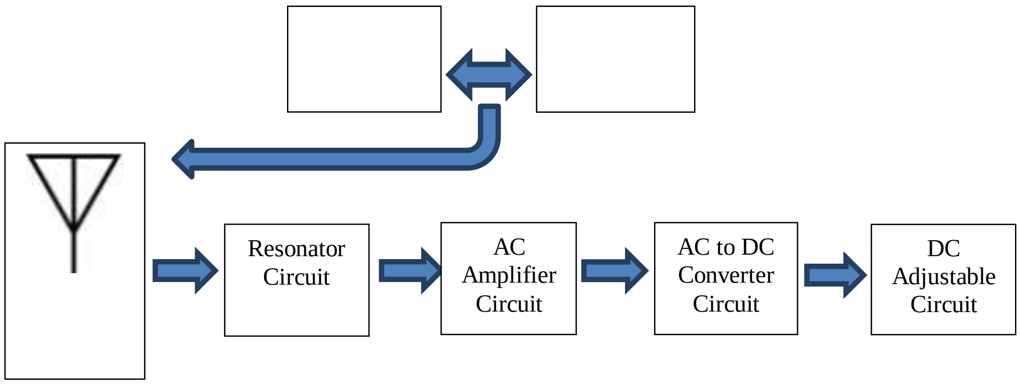

Fig. 1. Block diagram of experimental design

The resonance frequency of this resonator circuit is 0.2 GHz.
A comparison of different types of antennas considering their frequency range, gain, polarization, weight, electric field and magnetic field are shown in Table 1.

Table 1. Comparison among different types of antennas (Antenna, Antenna Masts and Pre-Amplifiers, n.d)

Antenna	Frequency range	Gain	Polarization	Weight	E.Field strength	H.Field strength
Log periodic Antenna	80MHz-4GHz	9 +/- 2 dBi	>30dB	11kg	60°-75°(3dB beam width typical)	50° - 65°3dB (beam width typical
Horn Antenna	14GHz-40GHz	15 - 20 dBi	>25dB	.3kg	13°-21°(3dB beam width typical)	14° - 23°3dB (beam width typical)
Loop Antenna	9KHz - 30 MHz	1.90-2.15dBi	>15dB	4kg	20dB/m	-31.5dB/Ωm
Yagi-Uda Antenna	30MHz - 7GHz	20dBi	>14dB	5kg	28.88dB/m	30.53dB/Ωm

1.2 Advantages of Yagi-Uda antenna

The Yagi antenna provides many advantages in a number of applications. This antenna has high gain allowing lower strength signals to be received. Yagi antenna has better directivity which enables interference levels to be minimized and have straight forward construction i.e; the Yagi antenna allows all constructional elements to be made from rods simplifying construction. The construction enables the antenna to be mounted easily on vertical and other poles with standard mechanical fixings.

2 3-ELEMENT AND 5-ELEMENT YAGI-UDA ANTENNA

The characteristics and radiation pattern of Yagi-Uda antenna changes according to its number of elements i.e. number of reflectors, driver element and directors. This paper discusses the radiation pattern, gain, VSWR, directivity, efficiency and bandwidth for both 3-element and 5-element Yagi-Uda antenna. A 3-element Yagi-Uda antenna consists of one reflector, one driven element and one director and a 5-element antenna consists of one reflector, one driven element and three directors.

3 YAGI-UDA ANTENNA DESIGN

In order to find out the characteristics of 5-element and 3-element antenna for comparing between them, designing of Yagi–Uda antenna is one of the most important issues of this paper. For better performance number, size and position of antenna elements (reflector, driven element, director) was in consideration.

CST Microwave Studio Software was used for antenna designing purpose. It is a fully featured simulation software for electromagnetic analysis and design.

In CST software, a 3-element and a 5-element Yagi-Uda antenna was designed with elements of same size and shape but different numbers. Port signal input for both antennas was given on driven element (Madhav & Venkata, n.d).

Scattering parameters or S-parameters (the elements of a scattering matrix or S-matrix) describe the electrical behavior of linear electrical networks when undergoing various steady state stimuli by electrical signals. S-parameter of designed antenna was observed in CST Microwave Studio software. Here S11 indicates the amount of power reflected by antenna.

The general guidelines for determining the size and shape of the Yagi antenna includes reflector length, driver length, director length, reflector to driver spacing, driver to first director spacing and spacing between directors (Delgadillo & Maringan, n.d.). Generally, the reflector length is slightly greater than $\lambda/2$, the driver and directors lengths are slightly less than $\lambda/2$, director lengths are typically between 0.4-0.45λ.

Range of working frequency: 700MHz to 6GHz

Center frequency: 3.35GHz

Electrical length, $\lambda = c/f = (3*10^8)/3350 = 89.55$mm

The reflector to driver spacing is about $\lambda/4$. The spacing between directors can be between 0.2-0.4λ. But be aware when the director spacing is greater than 0.3λ, the overall gain of the antenna is decreased by 5-7 dB (Delgadillo & Maringan, n.d.) .

A comparison between 3-element and 5-element Yagi-Uda antenna is shown in Table 2.

Table 2. Comparison between 3 & 5-element Yagi-Uda antenna (Lasker, Mojumdar, Chowdhury, Ferdous, & Chisty, June 2014; Madhav & Venkata, n.d)

	3-Element	**5-Element**
No. of Elements	One reflector, One driver, One director	One reflector, One driver, Three directors
Length of Elements	Reflector length = 0.7425m, Driven element length = 0.7095m, Director length = 0.66m	Reflector length = 60mm, Driver length = 38mm, Director 1 length = 36mm, Director 2 length = 36mm, Director 3 length = 36mm
Spacing between Elements	Spacing between reflector and driven element=0.2m, Spacing between Director and driven element =0.2m	Spacing between Reflector and Driver = 22mm, Spacing between Driver and Director 1= 11mm, Spacing between two Director = 18mm

Working Frequency	200 MHz	700MHz to 6GHz
Gain	At frequency 200 MHz gain is 7.14dBi	At frequency 3.0612 GHz gain is 10.2dBi
VSWR	1.62 at 200MHz	1.25 at 3.0612GHz
Reflected Power	For VSWR= 1.62, reflected power is 5.6% or -12.5 dB	For VSWR= 1.25, reflected power is 1.23% or -19.09 dB

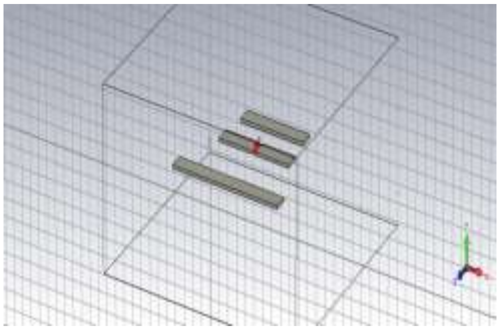

Fig. 2. 3-element Yagi-Uda antenna

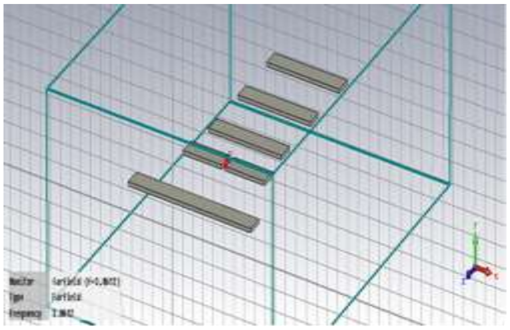

Fig. 3. 5-element Yagi-Uda antenna

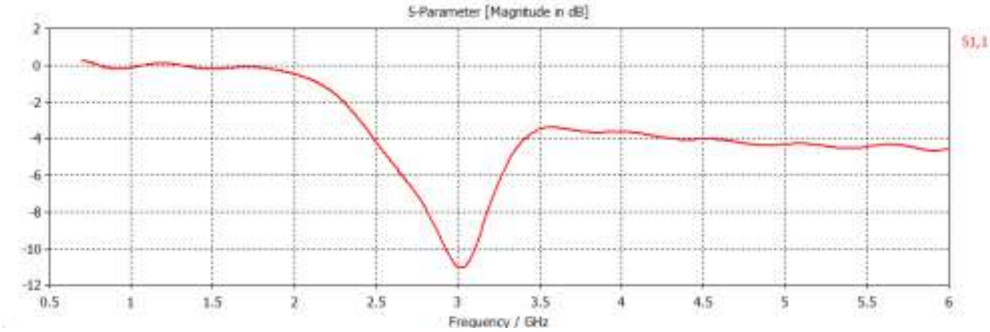

Fig. 4. S-parameter graph of 3-element Yagi-Uda antenna

From Fig. 3, S-Parameter graph, we get the resonance frequency of 3-element antenna is 3.0174 GHz. At resonance frequency, S11= -11dB (approx.). Our antenna's working bandwidth is 0.186 GHz.

Here, f1 = 2.9244 GHz

f2 = 3.1104 GHz

Bandwidth,

$\Delta\omega$ = f2 – f1

= (3.1104 – 2.9244) GHz

= 0.186 GHz

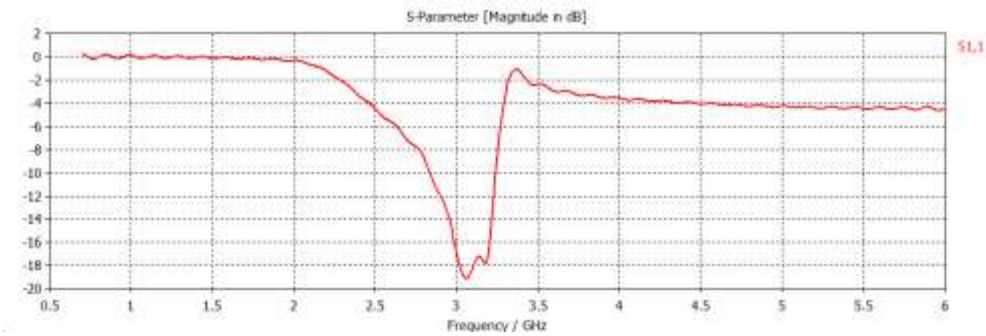

Fig. 5. S-parameter graph of 5-element Yagi-Uda antenna

From Fig. 3, S-Parameter graph, we get the resonance frequency of 5-element antenna is 3.0612 GHz. At resonance frequency, S11= -19dB (approx.). Our antenna's working bandwidth is 0.394 GHz.

Here, f1 = 2.8478 GHz

f2 = 3.2418 GHz

Bandwidth,

$\Delta\omega$ = f2 – f1

= (3.2418 – 2.8478) GHz

= 0.394 GHz

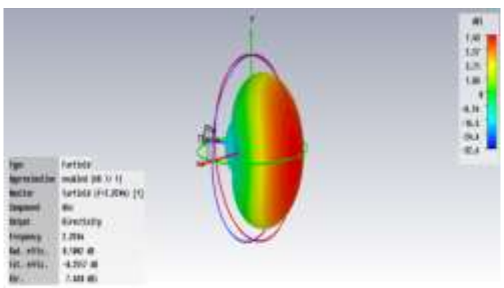

Fig. 6. 3D radiation pattern for 3-element antenna (f= 2.9244GHz)

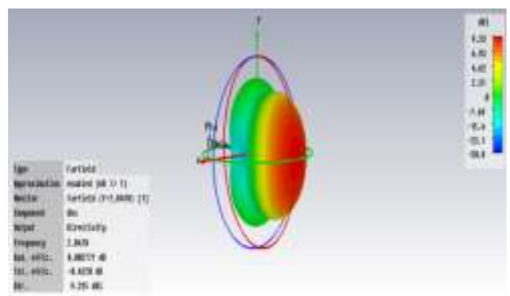

Fig. 7. 3D radiation pattern for 5-element antenna (f= 2.8478GHz)

From Fig. 6, at frequency 2.9244 GHz antenna gain is 7.43dBi, radiation efficiency is 0.1042dB, total efficiency is -0.3557dB and directivity is 7.430dBi.

From Fig. 7, at frequency 2.8478 GHz antenna gain is 9.23dBi, radiation efficiency is 0.002771 dB, total efficiency is -04220 dB, and directivity is 9.235 dBi.

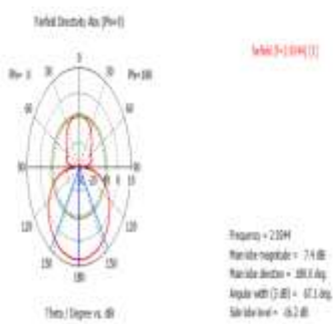

Fig. 8. Farfield Polar plot for 3-element antenna

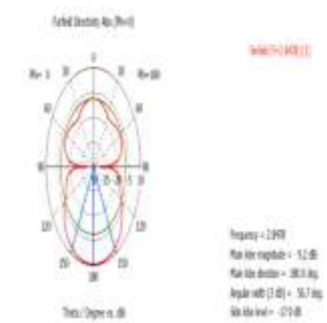

Fig. 9. Farfield Polar plot for 5-element antenna

(f= 2.9244GHz) (f= 2.8478GHz)

From figure 8, antenna main lobe magnitude is 7.4 dBi, main lobe direction is 180.0 degree, angular width (3 dB) is 67.1 degree and side lobe level is -16.2 dB.
From figure 9, antenna main lobe magnitude is 9.2 dBi, main lobe direction is 180.0 degree, angular width (3 dB) is 56.7 degree and side lobe level is -17.9 dB.

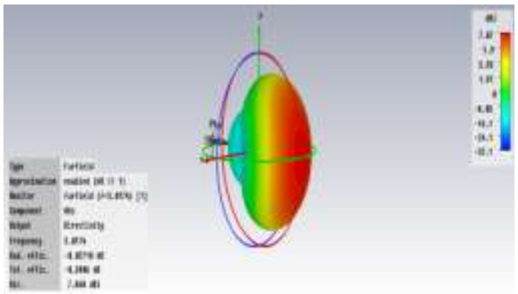

Fig. 10. 3D radiation pattern for 3-element antenna (f= 3.0174 GHz)

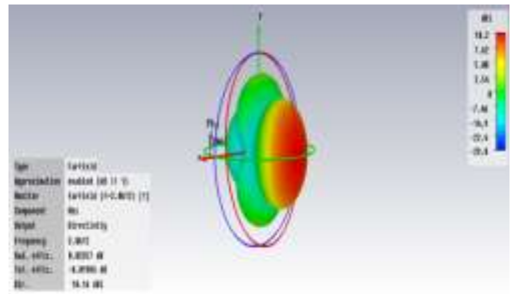

Fig. 11. 3D radiation pattern for 5-element antenna (f= 3.0612 GHz)

From Fig. 10, at resonance frequency 3.0174 GHz maximum gain is 7.87 dBi. Radiation efficiency is -0.02718 dB, total efficiency -0.3806 dB and directivity 7.868 dBi.
From Fig. 11, at resonance frequency 3.0612 GHz maximum gain is 10.2 dBi [8]. Radiation efficiency is 0.03357 dB, total efficiency -0.01986 dB and directivity 10.16 dBi.

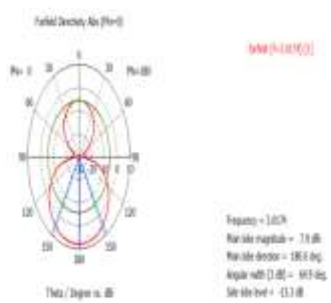

Fig. 12. Farfield Polar plot for 3-element antenna (f= 3.0174 GHz)

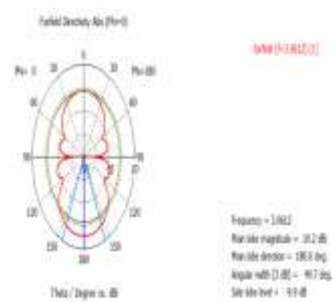

Fig. 13. Farfield Polar plot for 5-element antenna (f= 3.0612 GHz)

From figure 12, at resonance frequency antenna main lobe magnitude is 7.9 dBi, main lobe direction is 180.0 degree, angular width (3 dB) is 64.9 degree and side lobe level is -13.3 dB.
From figure 13, at resonance frequency antenna main lobe magnitude is 10.2 dBi, main lobe direction is 180.0 degree, angular width (3 dB) is 49.7 degree and side lobe level is -9.9 dB.

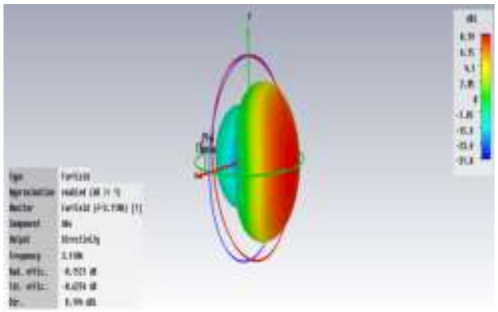

Fig. 14. 3D radiation pattern for 3-element antenna (f= 3.1104 GHz)

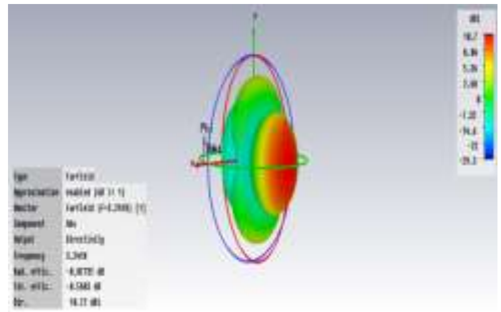

Fig. 15. 3D radiation pattern for 5-element antenna (f= 3.2418 GHz)

From Fig. 14, at frequency 3.1104 GHz maximum gain is 8.19 dBi. Radiation efficiency is -0.1521 dB, total efficiency -0.6254 dB and directivity 8.194 dBi.

From Fig. 15, at frequency 3.2418 GHz maximum gain is 10.7 dBi. Radiation efficiency is -0.07735 dB, total efficiency -0.5683 dB and directivity 10.72 dBi.

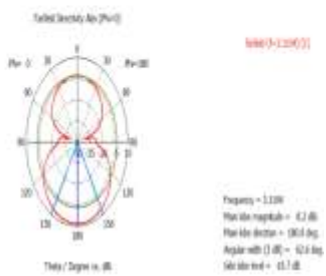

Fig. 16. Farfield Polar plot for 3-element antenna (f= 3.1104 GHz)

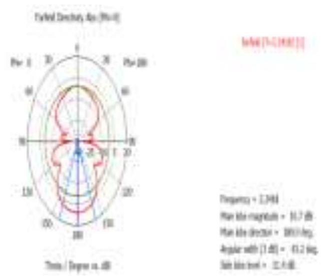

Fig. 17. Farfield Polar plot for 5-element antenna (f= 3.2418 GHz)

From figure 16, at frequency 3.1104 GHz antenna main lobe magnitude is 8.2 dBi, main lobe direction is 180.0 degree, angular width (3 dB) is 62.6 degree and side lobe level is -10.7 dB.

From figure 17, at frequency 3.2418 GHz antenna main lobe magnitude is 10.7 dBi, main lobe direction is 180.0 degree, angular width (3 dB) is 43.2 degree and side lobe level is -11.4 dB.

From experimental results, a comparison between 3-element and 5-element Yagi-Uda antenna is shown in Table 3.

Table 3. Comparison between 3 & 5-element Yagi-Uda antenna based on experimental results

	3-Element	**5-Element**
No. of Elements	One reflector, One driver, One director	One reflector, One driver, Three directors
Length of Elements	Reflector length = 60mm, Driver length = 38mm, Director 1 length = 36mm, Director 2 length = 36mm, Director 3 length = 36mm	Reflector length = 60mm, Driver length = 38mm, Director 1 length = 36mm, Director 2 length = 36mm, Director 3 length = 36mm

Spacing between Elements	Spacing between Reflector and Driver = 22mm, Spacing between Driver and Director = 11mm	Spacing between Reflector and Driver = 22mm, Spacing between Driver and Director 1= 11mm, Spacing between two Directors = 18mm
Working Frequency	700MHz to 6GHz	700MHz to 6GHz
Bandwidth	0.186 GHz	0.394 GHz
Resonance Frequency	3.0174 GHz	3.0612 GHz
Gain	At resonance frequency 3.0174 GHz gain is 7.87dBi	At resonance frequency 3.0612 GHz gain is 10.2dBi
VSWR	At resonance frequency VSWR is 1.78	At resonance frequency VSWR is 1.25
Reflected Power	For VSWR= 1.78, reflected power is 7.87% or -11.05 dB	For VSWR= 1.25, reflected power is 1.23% or -19.09 dB

4 CIRCUIT DESIGN

In this paper, an electronic circuit was designed for successful completion of power harvesting from radio frequency signal. The whole circuit was designed and simulated in Proteus Design Suite Software. A resonator circuit is designed which is able to extract frequency ranges from 700MHz to 6GHz. The output voltage of resonator circuit is very low that's why an additional AC amplifier circuit is used at the output of resonator. Then a bridge rectifier circuit also used to make AC voltage into DC (Circuits Today, August, 2009). But the voltage at the output of bridge rectifier is sometime more than +5V whereas we need a constant +5V always. To overcome this problem, IC 7805 was used as DC adjustable circuit to supply +5V always across the load (Analog Devices, Inc. 2009, & Burris, n.d).

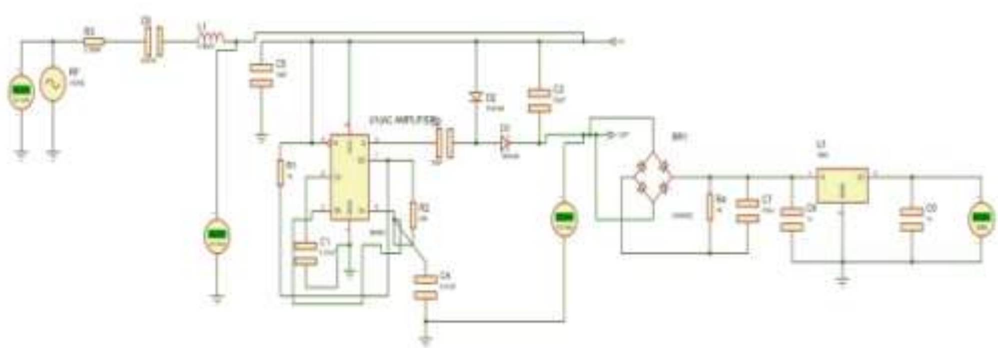

Fig. 18. Full Circuit Layout in Proteus

5 RESULTS AND DISCUSSIONS

Based on experimental results [Table 3], it is clear that 5 element Yagi-Uda antenna has larger bandwidth than 3 element Yagi-Uda antenna. At their resonance frequency, 5 element antenna has better gain than 3 element antenna. As 5 element antenna has smaller VSWR, this antenna reflects less power than 3 element antenna and delivers more power to the antenna. Thus 5 element Yagi-Uda antenna has small mismatch loss.

From above discussions, 5-element Yagi-Uda antenna can be considered as better antenna than 3-element Yagi-Uda antenna for power harvesting from radio frequency signal.

In case of designed circuit in Proteus, a small voltage was given at the input of resonator circuit to observe the performance of whole circuit. Input voltage at resonator was 430mV (AC) and output voltage across load is 5V (DC).

6 CONCLUSION

By observing the parameters it has been concluded that 5-element Yagi-Uda antenna can perform better than 3-element Yagi-Uda antenna and also able to accomplish the target. Its gain, directivity, efficiency, bandwidth, VSWR and delivered power is very much satisfactory.

Acknowledgement

First of all, we want to show our gratitude towards the almighty God for giving us the knowledge, opportunity and time to complete this work. We cannot forget the relationship that has built up with the faculties and professors who gave us advice whenever we came to halt during the completion of this work.

We are very grateful to the former faculties of AIUB, Mr. D.M.S Sultan and Mr. Rashedul Haque for their help. They were very helpful and supportive throughout this work.

Special thanks to Mojumdar, Md. Shahadat Hossain; Chowdhury, H.M. Ashiqur Rahman and Ferdous, Jannatul who encouraged and helped us a lot in every stage of this paper with their support, encouragement and affection. Without their friendly co-operation this paper would remain a dream.

References

Lasker, M. M. Z., Mojumdar, M. S. H., Chowdhury, H. M. A. R., Ferdous, J., & Chisty, N. A. (2014). *Design of a Device for Power Harvesting From Radio Frequency Signal*. Bhopal, India:International Journal of Engineering and Advanced Technology (IJEAT). http://ijeat.org/attachments/File/v3i5/E3225063514.pdf

Antenna, Antenna Masts and Pre-Amplifiers (n.d). Retrieved from http://www.frankoniagroup.com/.../Antennas/Antennas%20Komplett.pdf

Delgadillo, M., & Maringan, P. P.. *2.4GHz Yagi-Uda Antenna*. EE 172 Extra Credit Project. SAN JOSE STATE UNIVERSITY.

Madhav, B. T. P., & Venkata, K..K. *Design and Analysis of 3-Element yagi-uda Antenna for Wind Profiling Radar*. International journal of Computer Science and Communication Network (pp. 242-246)

Circuits Today (2009). *Full wave bridge rectifier*. Retrieved from http://www.circuitstoday.com/full-wave-bridge-rectifier

Analog Devices, Inc. (2009). *Voltage Regulator General Design Fundamentals.* http://www.analog.com/static/imported-files/pwr_mgmt/PM_vr_design_08451a.pdf

Burris, Matthew, (n.d). *Types of Voltage Regulators*. Retrieved from http://www.components.about.com/

Lasker, Md. Minhaz Zaman has completed Bachelor of Science in Electrical & Electronic Engineering (EEE) from American International University-Bangladesh (AIUB). He has completed major in Optoelectronic devices, Cellular Mobile Communication, Power system Protection, Computer System Architecture. His research interest covers electronic and telecommunication.

Chisty, Nafiz Ahmed has completed his Bachelor of Science in Electrical and Electronic Engineering (EEE) from American International University-Bangladesh (AIUB). He started his teaching career as a Lecturer of Electrical and Electronic Engineering Department of American International University-Bangladesh (AIUB), Banani, Dhaka in January 2006. Since then he has been teaching as a Full-time faculty, conducting both theory and laboratory classes for the undergraduate and graduate Engineering students. He has also supervised several final year graduate and undergraduate thesis groups.

After working for 2 and half years, he took study leave and went to Lund University (LTH), Sweden for his Master's in System on Chip (SOC) design. After the successful completion of his Master's program, Mr. Chisty has returned to Bangladesh and currently working as an Assistant Professor and Special Assistant in the Department of EEE at AIUB. His research interest is on ASIC implementation of wireless technologies (MIMO, OFDM) and on Antenna design.