International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-3 Issue-5, June 2014

Design of a Device for Power Harvesting From Radio Frequency Signal

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Abstract— This paper discusses a prototype that will harvest available RF waves in urban areas especially from 700 MHz to 6 GHz. The harvested energy, 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 to use the unused electromagnetic wave for daily purposes, thus reducing the pressure on national power grid in a broad sense. In addition describes efficient methods for extracting DC power from electromagnetic radiation.

Index Terms— Yagi-Uda antenna, CST software, RF signal, Energy harvesting device

I. 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. 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 are being 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 build a prototype that will harvest available RF waves in urban area especially from 700 MHz to 6 GHz. 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 [1]. The output power is very low usually in mV range which is not sufficient to drive any device even low power device. 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.

Manuscript published on 30 June 2014.
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Batteries from low power devices can be omitted, a coil or super capacitor can be used to store energy where sufficient waves are not available in the environment (usually in rural area).

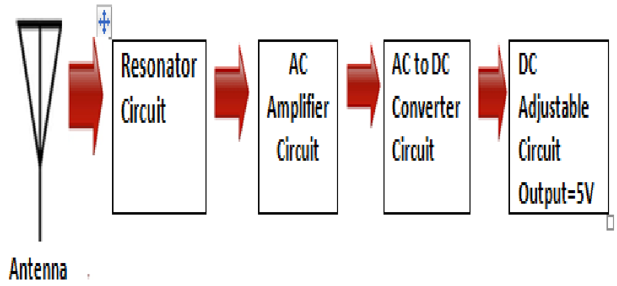

Fig. 1: Block Diagram of Experimental Design

A resonator is a device or system that exhibits resonance or resonant behavior at some specific frequencies called the resonance frequency. Resonators are used to generate waves with particular frequency or to capture some specific frequency. Usually, a resonator can be designed using resistor, capacitor and inductor. The resonant frequency of this design is 0.2 GHz. Amplifiers can be considered as a block containing the amplifying device which has two input terminals and two output terminals with the output signal being much greater than that of the input signal as it has been "Amplified" A rectifier is an electrical device composed of one or more diodes that converts alternating current (AC) to direct current (DC).

II. ANTENNA

An antenna is a device which is normally used in order to transmit or receive electromagnetic waves [2]. Antennas demonstrate a property known as reciprocity, which means that an antenna will maintain the same characteristics regardless if it is transmitting or receiving. Antennas are usually used for signal transmitting and receiving purpose. There are different types of antennas for different ranges of frequency, gains, radiation and directivity. Antenna is one of the most important portions of this paper. Comparison among different types and parameters of antenna are shown in Table I. By comparing different antennas based on their parameters, Yagi–Uda antenna has been found to be best for the mentioned frequency range.

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TABLE 1: Comparison among Different Types of Antennas [3]

Antenna	Frequency Range	Gain	Polarization	Weight	E. Field Strength	H. Field Strength
Log periodic Antenna	80MHz - 4GHz	9 +/- 2dBi	>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

2.1 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.

III. YAGI-UDA ANTENNA DESIGN

Designing of a 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. It is used to design the structure of a device (connectors, micro strip coplanar lines, monopole, dipole antenna etc.) and to find out the characteristics of the device.

In this paper a 5 element Yagi-Uda antenna was designed with one reflector, one driven element and three directors. Port signal input was given on driven element [7]. 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. 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 [xx]. 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 [yy].

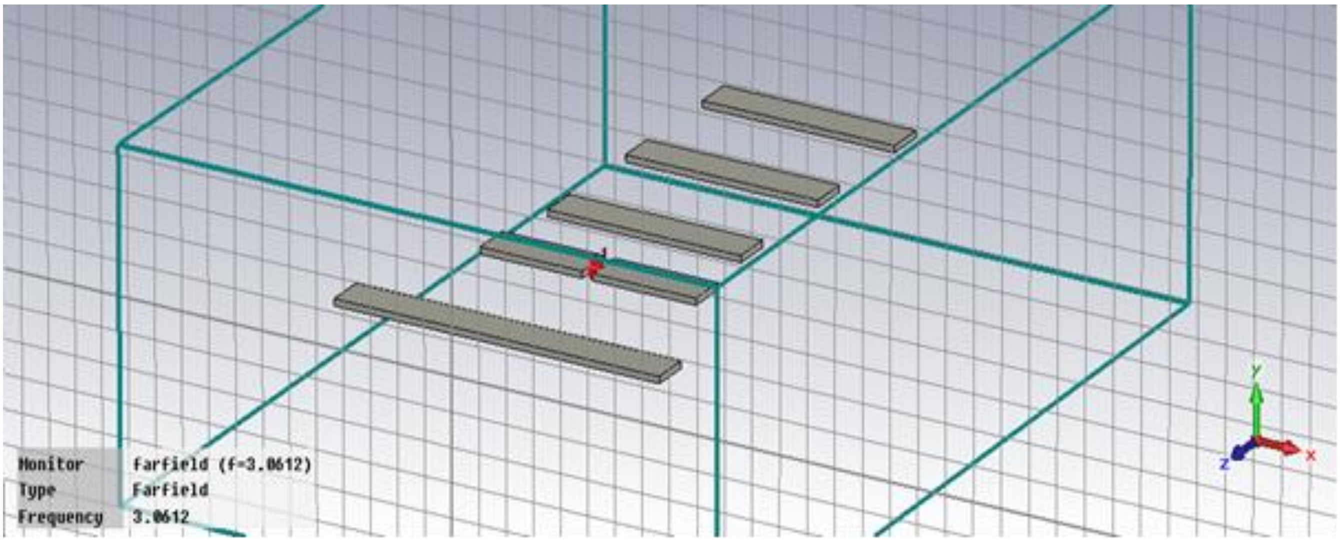

Fig. 2: 5-Element Yagi-Uda Antenna in CST Studio Software

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International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-3 Issue-5, June 2014

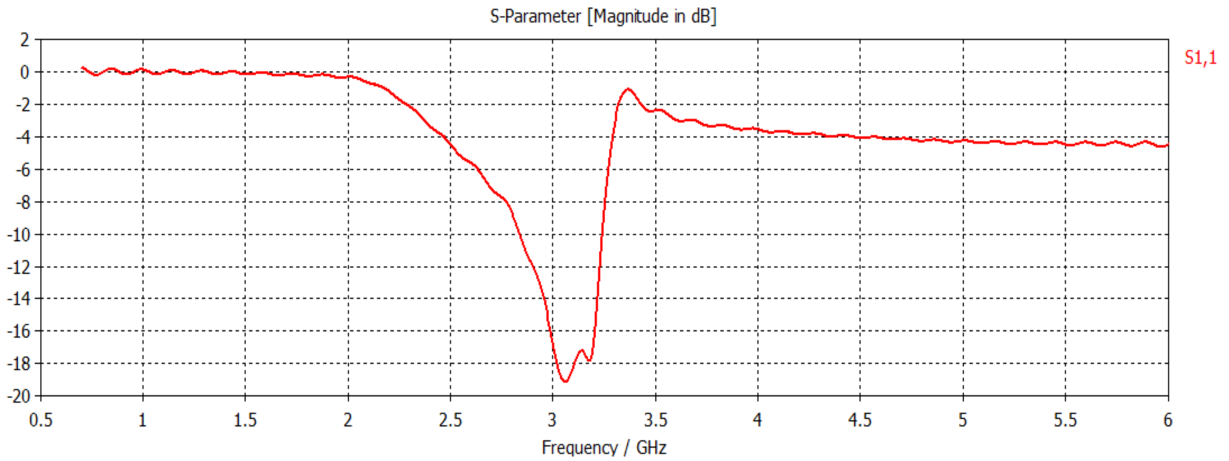

Fig. 3: S-Parameter of 5 Element Yagi-Uda Antenna

From Fig. 3, S-Parameter graph, we get the resonance frequency of our antenna is 3.0612 GHz. 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

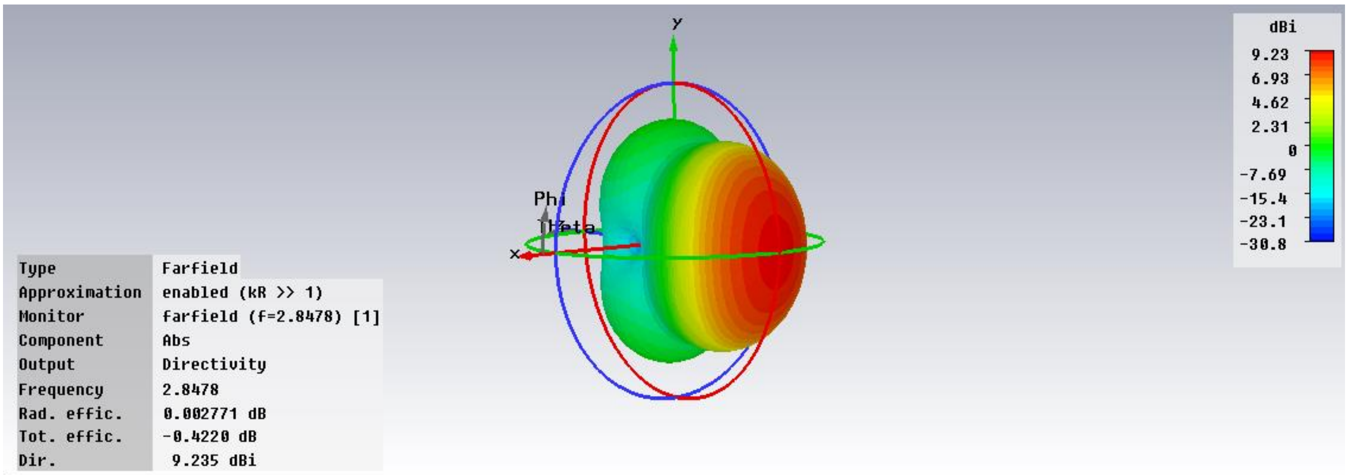

Fig. 4: Farfield 3D Plot (f = 2.8478 GHz)

From figure 4, 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.

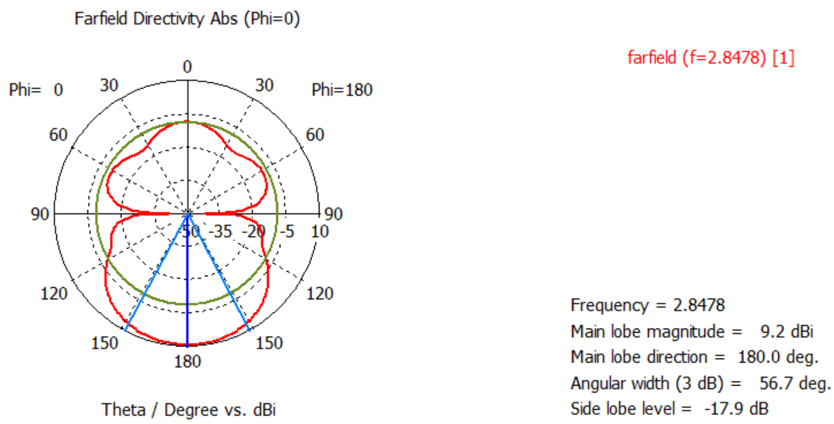

Fig. 5: Farfield Polar Plot (f = 2.8478 GHz)

From figure 5, 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.

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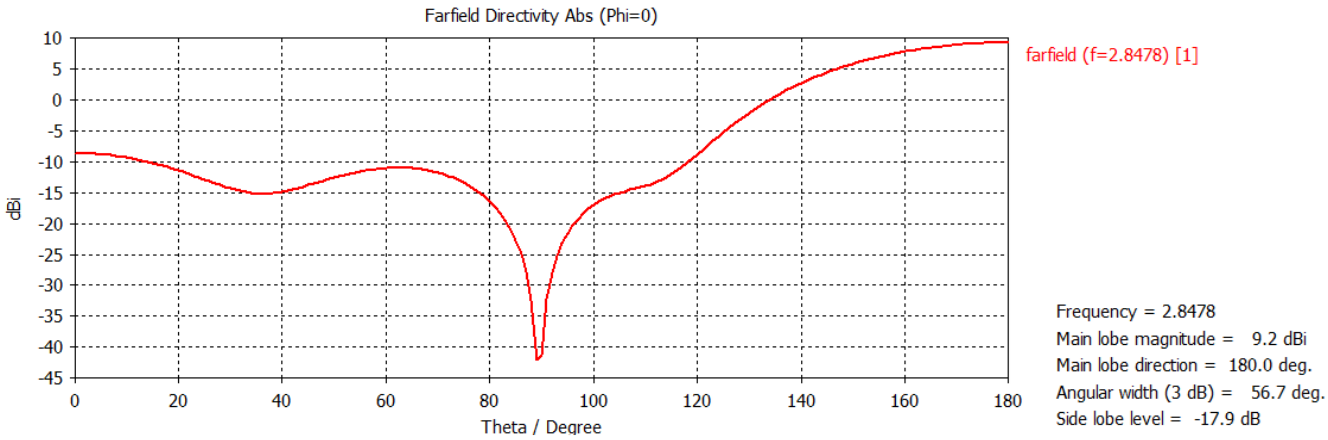

Fig. 6: Farfield Cartesian plot (f = 2.8478 GHz)

At resonance frequency 3.0612 GHz maximum gain is 10.2 dBi [8]

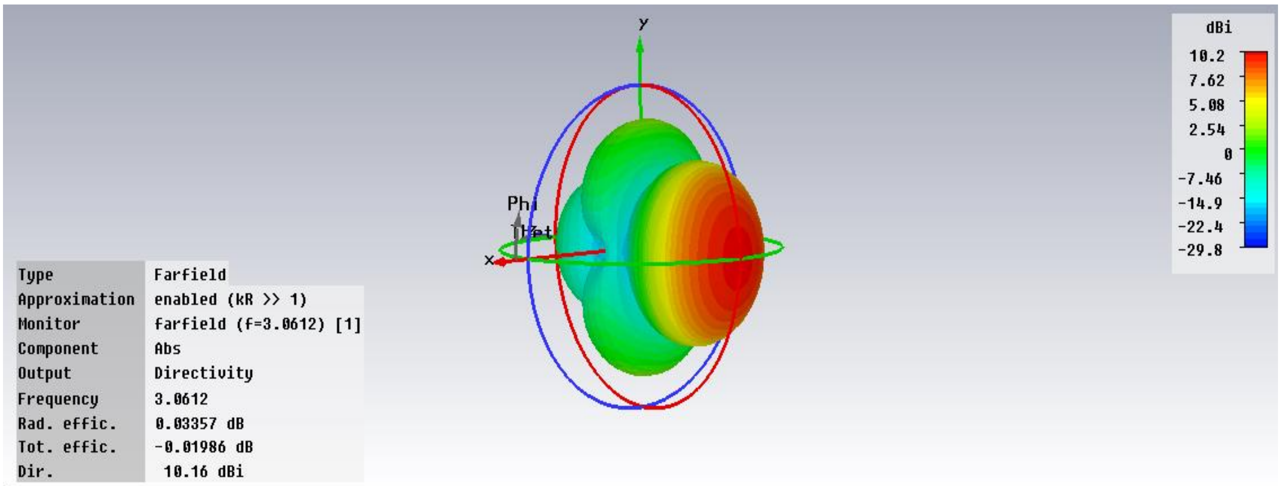

Fig. 7: Farfield 3-D Plot (f=3.0612GHz)

From figure 7, radiation efficiency is 0.03357 dB, total efficiency -0.01986 dB and directivity 10.16 DBI.

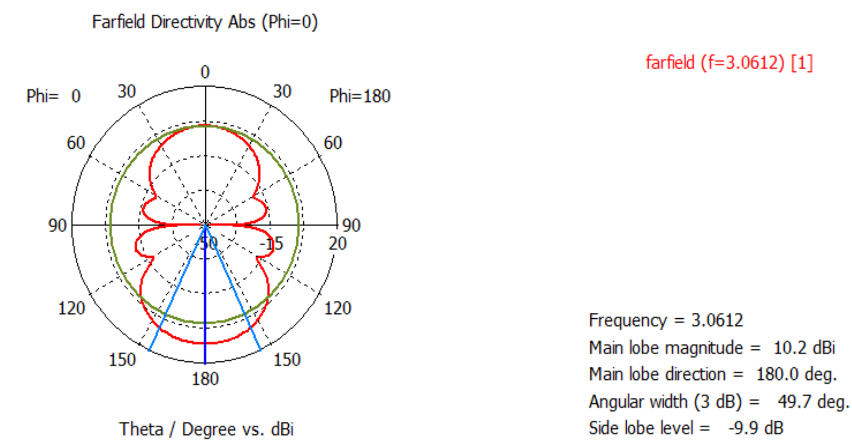

Fig. 8: Farfield Polar Plot (f=3.0612GHz)

From figure 8, antenna main lobe magnitude is 10.2 DBI, main lobe direction is 180.0 degree, angular width 49.7 degree, Sidelobe level is -9.9 dB.

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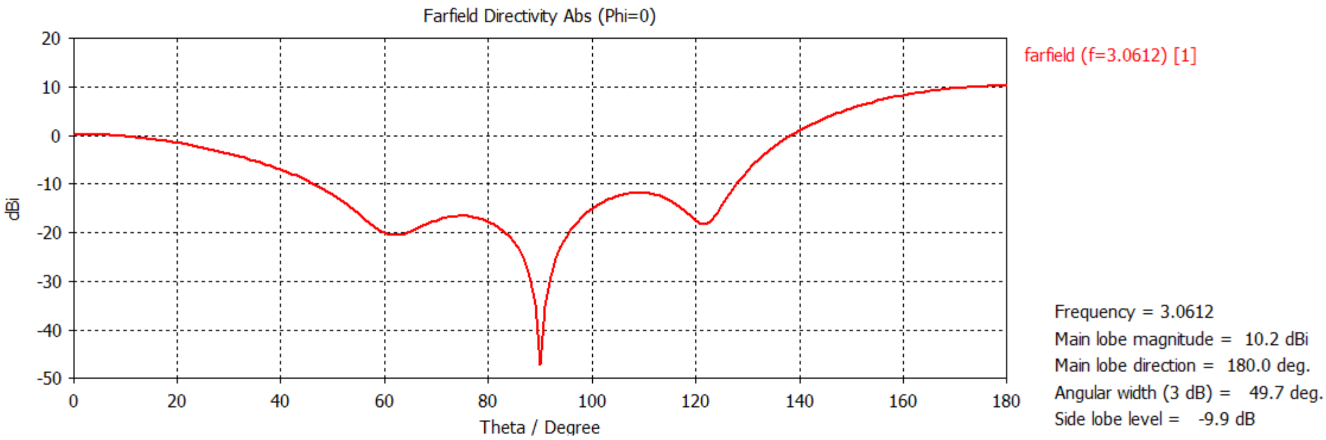

Fig. 9: Farfield Cartesian Plot (f=3.0612GHz)

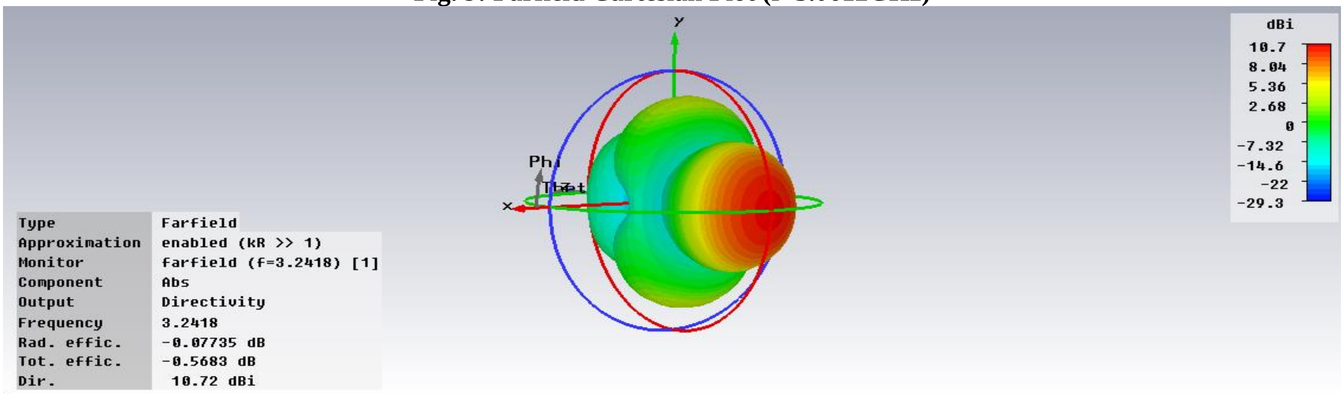

Fig. 10: Farfield 3D Plot (f = 3.2418 GHz)

From figure 10, radiation efficiency is -0.07735 dB, total efficiency -0.5683 dB and directivity 10.72 DBI.

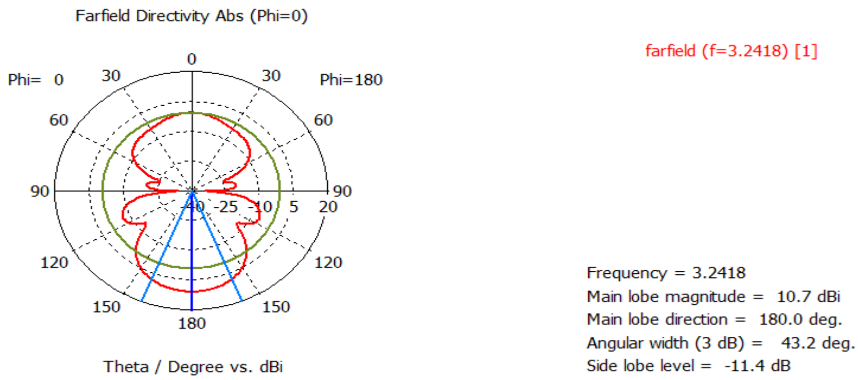

Fig. 11: Farfield Polar Plot (f = 3.2418 GHz)

From figure 11, antenna main lobe magnitude is 10.7 dBi, main lobe direction is 180.0 degree, angular width 43.2 degree, side lobe level is -11.4 dB.

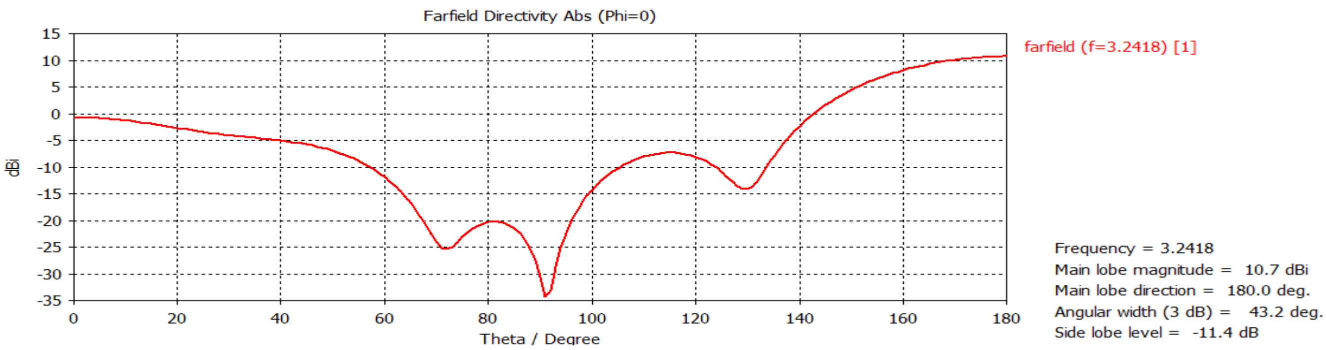

Fig. 12: Farfield Cartesian Plot (f = 3.2418 GHz)

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IV. CIRCUIT DESIGN

The successful design and implementation of any device depend on the best selection of electronic components and accurate circuit design. Different circuits can have same function but considering the efficiency, gain, loss etc. the most efficient electronic components and circuits has been chosen for the best performance of any device. Resonator, AC amplifier, Rectifier, DC adjustable circuit can be designed in different ways but considering the efficiency and complexity of circuit one should choose the best way. 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 700 MHz to 6 GHz. The output 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 [4]. 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 [5]-[6] As our thesis aim is to extract frequency ranges from 700 MHz to 6 GHz, we designed a series resonator circuit by further calculation. So the bandwidth $\Delta\omega$=5.3x10^9 = 5.3GHz

We know,

$\Delta\omega = R/L$……………………………….(18)

Let, R=3.5ohm

$L = R/\Delta\omega$ = 6.6x10^-10 H = 0.66 nH

Let, Central frequency, ω_0 = 1.5 GHz

$\omega_0 = 1/\sqrt{LC}$ …………………………….. (19)

So, $C = 1/(L \times \omega_0{}^2)$

= 1/[(0.66 x 10^-9) x (1.5 x 10^9)^2]

= 0.67nF

So, R = 3.5ohm

L = 0.66nH

C = 0.67nF

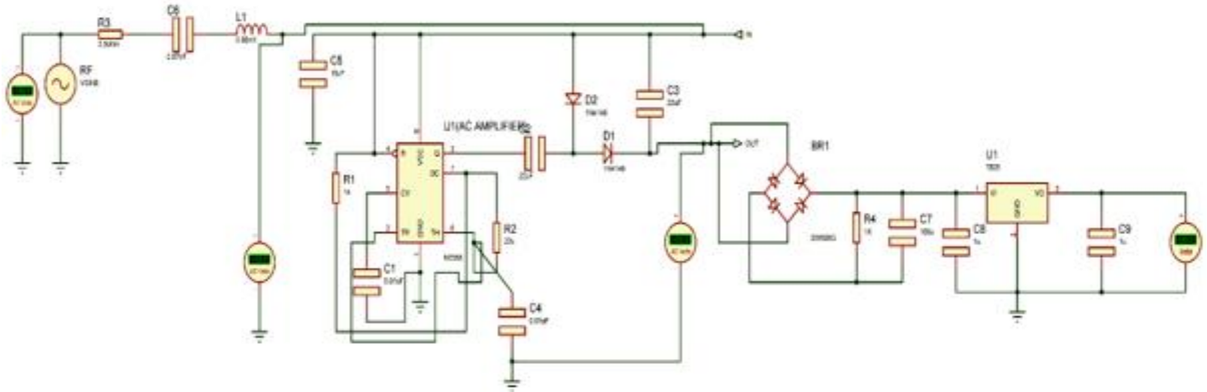

Fig. 13: Full Circuit Layout in Proteus

V. RESULTS AND DISCUSSIONS

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). For the extraction of radio frequency, antenna was designed in CST software. From the observation of different parameters it has been found that this antenna is able to extract signal ranges from 2.8478 GHz to 3.2418 GHz and its bandwidth is 0.394 GHz. The signal extracted by Yagi-Uda antenna has voltage in mV range.

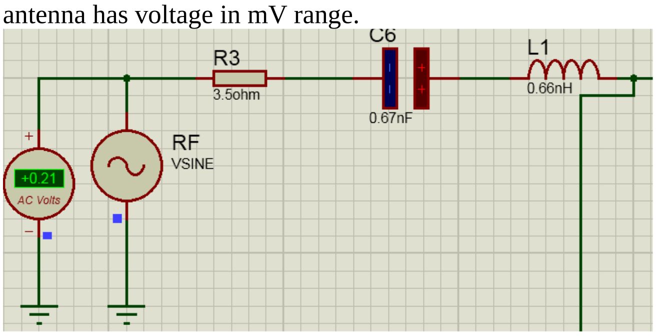

Fig. 14: Input at Resonator Circuit

Figure 14, Shows Input Voltage at Resonator Circuit.

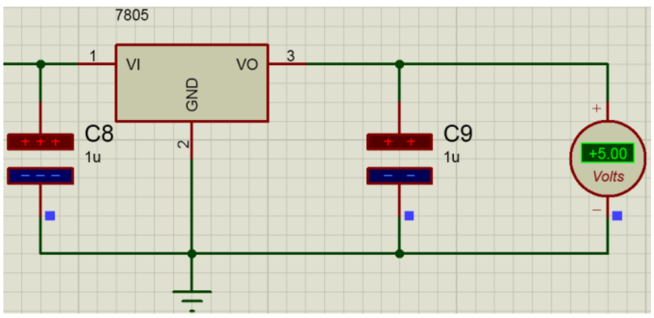

Fig. 15. Output at DC Adjustable Circuit

Figure 15, Shows output voltage at DC Adjustable Circuit.

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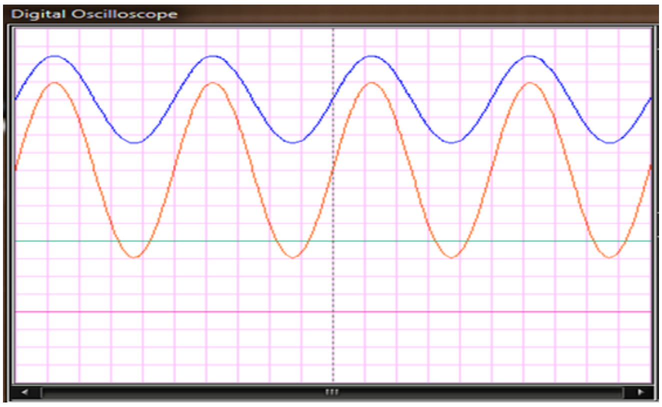

Fig. 16: Input – Output of AC Amplifier Circuit

Figure 16, shows the input (Blue) and output (Red) of AC amplifier circuit. The output is much amplified.

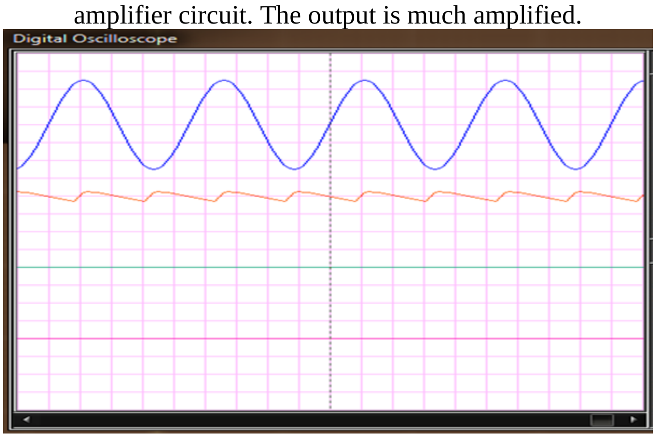

Fig. 17: Input-Output wave Shape of full Bridge Rectifier

Figure 17, shows the input (Blue) and output (Red) of rectifier circuit. The input AC signal is converted into DC signal.

VI. CONCLUSION

By observing the parameters it has been concluded that Yagi-Uda antenna can perform very well and also able to accomplish the target. Its gain, directivity, efficiency is very much satisfactory. Another important portion of this paper is circuit which was being used specially for amplification and rectification. This circuit is also able to perform these both function perfectly.

Acknowledgement

This paper is a reflection of the teamwork of four friends. 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. At every moment we remember all of our friends and peers who encouraged and helped us a lot in every stage of this paper, with their support, encouragement, affection and suggestions. Without their guidance and friendly co-operation this paper would remain a dream. At last we want to show our gratitude towards the almighty God for giving us the knowledge, time and opportunity of completing this work.

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