Wireless RF Energy Harvesting Using Inverted F Antenna

Pratima Ghattarki[1], Anilkumar V Nandy[2]

[1]*Student, School of Electronics, KLE Technological University, Hubli, Karnataka, India*
[2]*Dr. Anil V Nandy, School of Electronics, KLE Technological University, Hubli, Karnataka, India*

Abstract - *This project proposes to develop an Energy harvesting system using RF radiations with the aid of Inverted F antenna. With the help of survey we recognized that energy harvesting using RF has higher efficiency than the other natural resources [1]. Because of rapid increase in the usage of communication devices like, mobile phones, internet modem and Bluetooth, our surrounding environment is enclosed by RF signals, hence we can harvest sufficient amount of energy further which can be used for micro devices like IOT's and other automations.*

With the help of survey outcome recognize that Inverted F antenna is have higher gain, easy feeding, and small size compared with the spiral antenna, directional antenna, patch antenna, etc. In this project array of 20 antennas are used to harvest the energy. Output of the antenna will be in the form of AC that will be converted to DC by using rectifier diode (Schottky diode). To remove AC noise low pass filter is used, subsequently the output energy is stored in the battery for further applications. For the antenna design KiCad software tool is used. We got maximum of 1.4V from single antenna. HFSS is used for simulation purpose.

Key Words: *RF Energy harvesting, Inverted F Antenna, Schottky diode, Super capacitor, HFSS, KiCad*

1. INTRODUCTION

Wireless systems are heart of the present technology. Many wireless systems had been developed in past two decades and are widely used in the market. Most usable and important wireless systems are mobile phone, radio and WiFi modems. Broadcasting systems radiate Electromagnetic rays in the air, in that, most of the energy get wasted, to reuse that energy harvesting systems are developed.

Nikola Tesla described the transformation of energy from one point to the other point without physical connection with the power source in the late 19th century. Subsistence of Electromagnetic wave is discovered by Heinrich Hertz. In 1901 Tesla wanted to transmit the electrical power across the Atlantic, but in 1914 project was failed. In 1930's some experiments are conducted in westinghouse laboratory, and they succeeded in transmitting 100 watts of power among two dipole antennas of 100MHz which are placed 1.5m apart from each other [3].

Energy can be harvested by using many energy resources, unaltered energies are solar energy, wind energy, sea waves, etc. And other natural resources like natural oil, and natural gas, because of human usage these natural energy resources are reducing day by day. By considering some survey I can tell that energy harvesting using RF radiations will give higher efficiency than the other natural and artificial energy sources. When we consider RF radiation TV, WiFi model, internet modem, mobile, and microwave will come into picture. In this modern era usage of mobile and internet is increasing rapidly, so we can harvest sufficient amount of energy from our surrounding environment for the micro devices.

In RF technology Rectenna is the essential element, it is a combination of antenna and rectifying circuit. Antenna will help to receive or transmit the radiations emitted by the source of electromagnetic spectrum. Rectifying diode will convert the antenna AC output into DC form. We can find n number of antennas nowadays, so antenna selection and designing is the difficult task in this project. After with lots of study on antennas I have selected Inverted F Antenna for our energy harvesting system which has a gain of 3.3dBi. For the energy harvesting system selection of omni-directional antenna is much better than the directional antennas, directional antennas will receive or transmit the energy from all the directions. Where in directional antennas will receive or transmit the energy only with the specific direction.

1.1 Solar Energy

Solar energy is traditional, widely used energy source, compared to other ambient energy sources, solar energy has highest power density, and its key component is photovoltaic cell. This system has been used in many applications, but the main drawbacks of solar energy are, we can use only in day time, and also it is depends upon the weather, even solar cells are costlier and we have to maintain them [1].

1.2 Wind Energy

Wind energy is also the widely used method for energy harvesting. Energy can be harvested even in summer, winter and rainy season with day and night. Availability of wind energy source is more compared t solar energy, but power density is poorer than the solar energy. It has been used in many applications like in communication field and other systems. It harvested enough energy to drive wireless sensor Imote2, and also in some other wireless applications. But the wind turbines will be in big size, it occupies large area, it has high cost to build, and it should be constructed in hill stations [1].

1.3 Mechanical Vibration

In mechanical vibrations there are two types, electromagnetic generator vibrations and piezoelectric material vibrations. The energy generated due to relative motion of the coil and magnet is the electromagnetic vibration, and the energy generated due to vibration or mechanical rotation of the piezoelectric material is called piezoelectric energy. This system was developed by a research group, it has charged a battery with capacity of 40mAh in 60 minutes, and that can be improved further. Piezoelectric energy harvester has to be attached to the moving or vibrating systems like motor, machines, vehicles and even in human bodies, but its power density is very low and movement has to be in continues. MEMS piezo materials are available but they will generate less energy and manufacturing of MEMS device is complex and maintenance is difficult [1].

1.4 Thermal Energy

Energy harvesting using thermal energy is the other method, in this method thermoelectric generators convert's thermal energy into electric energy based on Seebeck effect. It has no kinetic energy compared to vibration energy, conversation efficiency is less under vary in temperature. Due to its size and construction it is difficult to merge with MEMS devices. TEG technology can generate output in µW form [1].

1.5 RF Energy

Last method for energy harvesting is using 1.5 RF Energy RF radiations, which is presently ongoing technology, it's frequency in energy band is between 3000Hz and 300GHz.Billions of radio stations are transmitting the RF radiations. RF energy is independent on climatic conditions compared with all other ambient energy like climate, weather, and temperature hence the author has concluded that energy harvesting using RF waves has higher efficiency than the other energy forms [1].

1.6 Battery management using RF source

Main components used in this projects are square antenna, RF source, impedance matching circuit, rectifier diode, chopper circuit, microcontroller, adc, relay, lcd display,etc. In this model when antenna receives the RF signal it captures the signal and converts electromagnetic wave into AC signal, Ac signal will next goes to the impedance matching circuit, then the signal will be converted into DC form through the rectifier, then DC signal enters the chopper circuit for boosting the power. This model has designed for the 900MHz GSM band, and produces the output voltage in the range of 1V-2V [2].

1.7 Rectenna based approach

In this method author has used array of 64 spiral antenna to increase the output power, in 324 cm^2 area 64 array of spiral rectenna elements are distributed with different orientation, so energy can be harvested from different polarized sources. In this paper author has considered effective area Aeff =25cm^2, then the RF input power will vary between 250nW and 2.5mW, so the rectification efficiency will vary between η=1% and η=20% respectively, and DC output power will be in the range between 2nW and 450 µW [3].

1.8 Inverted F antenna with extended slit

This antenna is easy to design, its extended slit has inner diameter of 0.8mm and outer diameter 1.2mm. In simulation result they got antenna gain as 2.4dBi and had return loss of -42.5 dB, but measured return loss was 33.4 dB, simulated 10dB bandwidth was 300 MHz and measured bandwidth was 390 MHz. Due to increase in the slit resonant frequency was not much shifted, and also return loss has changed [4].

2. TOOLS

2.1 Inverted F Antenna

This antenna has overall size of 25.7 × 7.5 mm, this can be used in all kinds of 2.45GHz transmitters and transceivers, it has maximum gain of +3.3dBi.This antenna can directly matches with 50Ω impedance device, no need to add external impedance matching circuit. Gain of the antenna will vary due to change in the position of the feed point. It has bandwidth in the range 2.3GHz to 2.7GHz with center frequency 2.45GHz. It has 10% reflection, it will give high performance.

2.2 Schottky Diode

Antenna will capture the electromagnetic waves then converts that into AC signal, to convert AC to DC we have to add rectifying circuit after the antenna, instead of adding Rectifier Bridge we can add schottky diode ,which will be consists of half bridge, this will convert AC signal to DC signal. Schottky diode's maximum operating frequency is 5THz.

SMS7630-079LF is a part number of the schottky diode which I used as a rectifier for this project. It is a surface mount, microwave and RF detector and mixer, its resistance can be matched with impedance of the antenna, so no need to add additional impedance matching circuit.

2.3 Super Capacitor

Rectified output power has to be stored in next step. Initially a super capacitor is used after the rectifier to store the DC power or it acts like secondary battery, then that power can be transferred into the external attached battery.

FG0H225ZF is part number of the selected super capacitor. It is used as secondary storage battery. It will take few seconds to charge, it can be used for 5.5V DC circuit, it has a nominal capacity of 2.2F for charging and 2.8F dir discharging. It has capacity to hold minimum 4.2V.

2.4 KiCad

KiCad is open source software, which is used to design electronic circuits. It suits for Electronic Design Automation (EDA), it has feature of schematic capturing, PCB layout design, and also it has facility to create Gerber file, bill of material and has facility for 3D view of the PCB design and the components. It has a special feature of library editing which is the main requirement for the designers. I have done the complete circuit of this project in PCB with the layout by using this tool.

2.5 EAGLE

EAGLE (Easily Applicable Graphical Layout Editor) is Electronic Design Automation (EDA), it is it is applicable with schematic design, PCB layout design and also for CAM (Computer Aided Manufacturing) features. In this tool schematic file will be in .SCH extension and library files will be in .LBR extension. It saves postscript and Gerber layout with Sieb & Meyer and Excellon drill files.

2.6 ANSYS HFSS

High Frequency Structure Simulator is a commercial too, which is used for many designing applications like antenna design, connector design, UHF system design, filters, PCB design and complex RF circuits. It is also helpful for electromagnetic design applications. It introduced to the market in the year of 1989. It also has facility of DC circuit design and simulation, transient design, 3-D simulation, 3-D model design, and solid designs. Most of the designing companies use HFSS tool for antenna design and simulation. We can get accurate values in 3-D patterns, VSWR, Elevation pattern, etc.

3. DESIGN AND IMPLEMENTATION

To design wireless RF energy harvesting system we need antenna, rectifier diode, and super capacitor.

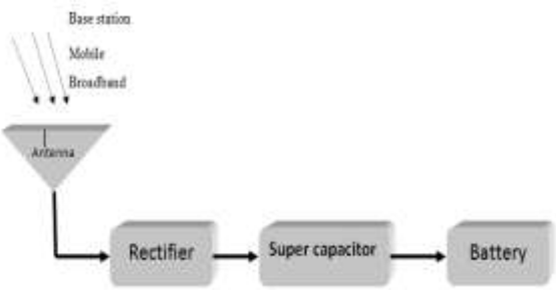

Fig.1 Block diagram for Energy harvesting system

In this block diagram first block is antenna. Omnidirectional antenna will capture the electromagnetic radiations from the RF sources like base station, mobile, broadband, etc. Ac signal will be fed to the rectifier block from the output of the antenna. Rectifier diode will converts AC signal into DC signal. Further output of the rectifier diode will be stored in the super capacitor for the initial storage, then that can be transferred into the battery.

3.1 Antenna design in HFSS

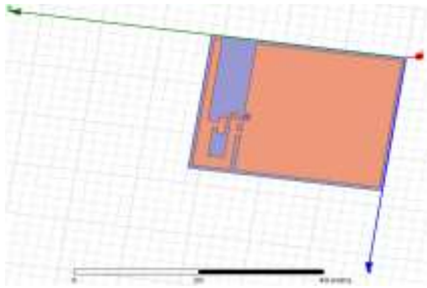

Fig.2 Inverted F antenna

Following image is the design of inverted F antenna which is used in our project. It has dimension of 25.7 ×7.5 mm.

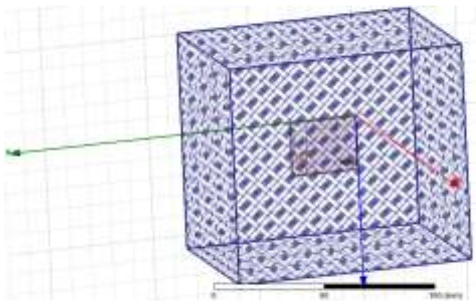

Fig.3 Boundary

Boundary has been created for the design to minimize the losses from the external sources. Addition of the boundary will reduce the entering and loosing of radiations from in out of the box which will reduce the loss of radiations. Following figure shows the antenna with boundary.

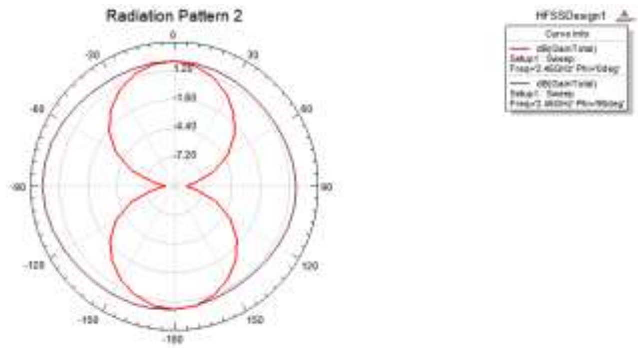

Fig.4 2D Pattern

3D pattern will help to understand the directivity of the radiation pattern along X,Y and Z axis with the help of angles θ and φ . θ Will help to find the directivity along Z axis, and it will vary from 0° to 360°. φ(Cut angle) will be constant and is related to X axis, this is called as Planar Cut.

In Conical Cut φ will vary from 0° to 360° along X axis and θ will be constant. Following figure shows the 3D pattern of inverted F antenna. It has maximum gain of 3.1dB and minimum of -1.09dB.

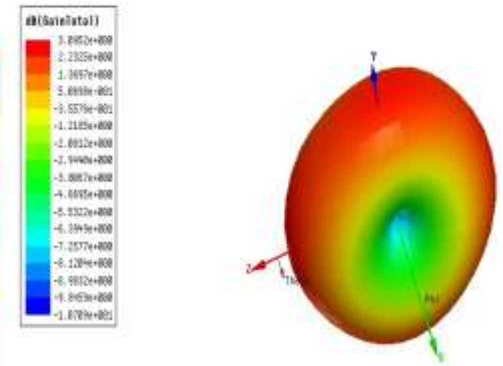

Fig.5 3D pattern

VSWR

VSWR will tell about amount of power received by the antenna and how amount of power reflected back to the feed of transmitted antenna. To get good VSWR the impedance between transmitter and the transmitting path should be same, usually the radio transmitter impedance will be of 50Ω.

From the figure we can find VSWR=3 according to simulation results, hence magnitude of reflection coefficient will be 0.5. For VSWR=3 return loss will be 6.02 and reflected power in terms of percentage is 25%. SO, it tells that antenna will works efficiently for 2.45GHz frequency.

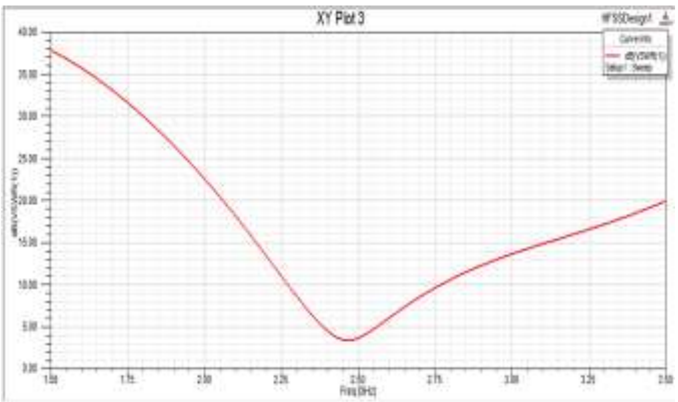

Fig.6 VSWR graph

3.2 PCB Design:

3.2.1 Schematic Design

After creating the antenna library in Eagle tool, I designed complete energy harvesting circuit design in KiCad tool, there antenna library has been used, KiCad has more features than eagle and it is an open source too and easy to work. But it has same steps as Eagle has to design an antenna. Following is the design of the complete circuit.

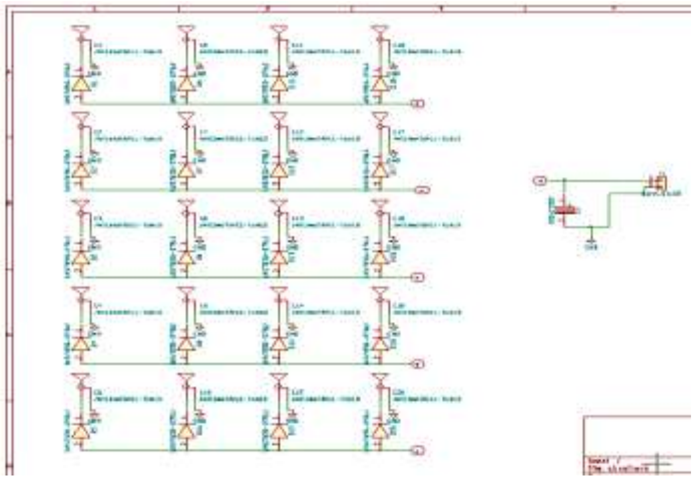

Fig.7 Schematic

In this schematic 20 antennas have been used in array form, and then those are connected to the rectifier. All antennas rectifiers are sorted and connected to super capacitor.

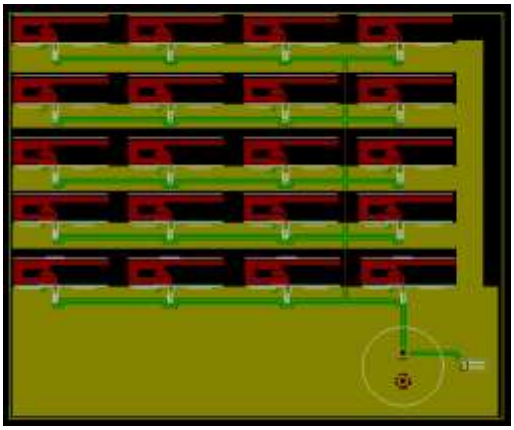

Fig.8 Layout

4. RESULTS AND DISCUSSION

After fabrication process smd diodes has been assembled, which will use to convert AC signal into DC. First, we kept the board nearer to the router to check whether it is capturing signal or not, for that we were getting voltage in mV and as we increase the distance between source and the receiver antenna voltage was reducing.

Practical experiment has been conducted in 2 types of environments, one is noisy environment and other is without noise. In without noise condition we conducted experiment in a room where only the selected transmitting router signal is present. In noisy environment there were many signals available, that experiment has been conducted in college and in company.

In without noise environment D-Link DIR 600M router has been used as a transmitting source, it's antenna has 5dBm gain and has maximum transmitting power 62mW. By using multi meter voltage across the antenna feed point has been calculated, 50Ω is the radiation resistance of both transmitting and receiving antenna. By using $P = \frac{V^2}{R}$ power is measured, below table is the data for theoretical and practical values for power, dBm and dBW with respect to the distance from 1meter to 4 meters. Same experiment is conducted for 4 regions. Readings and respective graphs are plotted for the same.

Table-1: Readings for the first experiment is as shown in the table.

Column1	**1**	**2**	**3**	**4**	**5**
Power – Theoretical (µW)	156	39	17	9.7	6.266
Power – Practical (µW)	112.5	32	12	2	0.2

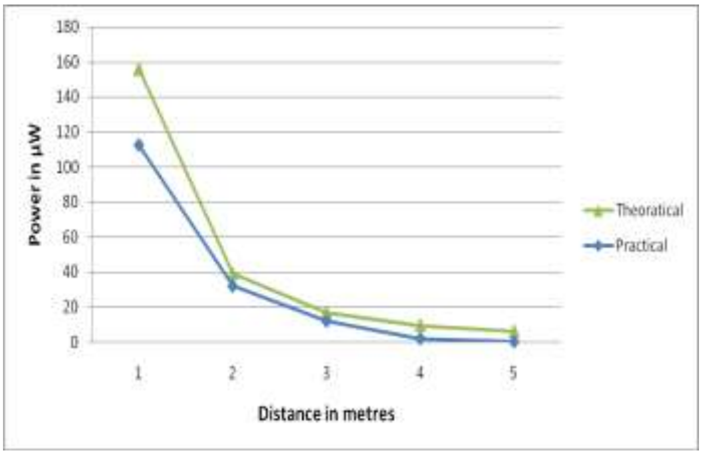

Fig.9 Result Graph

In this experiment we got nearer values for the theoretical values, this is happened because of high transmitting signal.

Table-2: Results in noisy environment

Column1	1	2	3	4	5	6	7
Power – Practical (mW)	42	30.7	16	9.8	1.15	0.018	0.0005

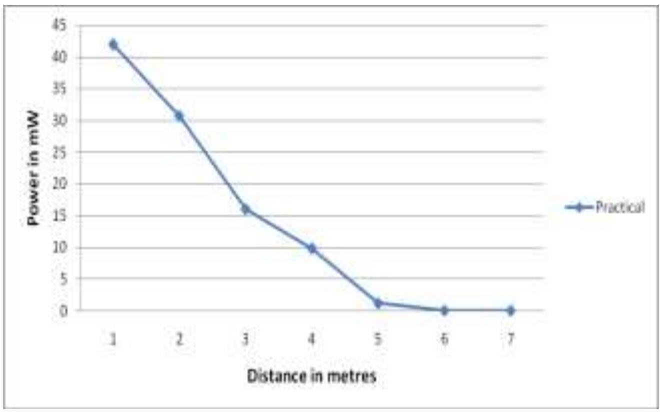

Fig.10 Power vs Distance graph

In this graph we can't see much distortion, because of less noise, and maximum voltage is 1.4V in noisy environment.

5. CONCLUSION

As per the literature RF energy harvesting method has 50% accuracy, by observing our experimental results we are getting good accuracy. Inverted F antenna has higher gain compared to other antennas so we can harvest more energy further. From simulation results we got less than 10% reflection and have 1.8 VSWR value. As per the practical experiment results we got maximum 1.4V AC which is a good result for RF radiation source. In future miniaturized RF connectors have to be used at the end of the antenna, which will reduce the manual loss while testing. KiCad is very easy to work and inverted F antenna is also easy to design.

6. FUTURE SCOPE

As it was a prototype model, we wanted know how much energy we can harvest by using single inverted F antenna. From this design we got good accuracy, as it has some drawbacks, to overcome those in next design we are going to use connectors and angle variation facility. This will capture and store sufficient energy in the battery. This we are using in the IOT kisan sensor network. Where drone can spray pesticides to the field automatically with the help of sensor network, for such system battery plays major role to make sensors working continuously. This project has been done to charge the battery automatically with the aid of power management system.

REFERENCES

[1]. Shihua Cao and Jianqing Li, "A survey on ambient energy sources and harvesting methods for structural health monitoring applications" Advances in Mechanical Engineering

2017, Vol. 9(4) 1–14_ The Author(s) 2017, DOI: 10.1177/1687814017696210

[2]. M Nalini1, J V Nirmal kumar2, R Muthu kumar2, M Vignesh2. "Energy Harvesting And Management From Ambient Rf Radiation", vol. 978-1-5090-5778-8/17/$31.00©2017 IEEE

[3]. Gabriel Abadal, Javier Alda and Jordi Agustí. "Electromagnetic Radiation Energy Harvesting – The Rectenna Based Approach" Published by INTECH open science/open mind

[4]. Ali Javed Hashmi, Atif Mehmood, Touseef Ali, Syed Arsalan Ali. "Design of 50 Ohm Microstrip Monopole Inverted F Antenna With Extension Slits For 2.4 GHz" vol. 978-1-5090-4300-2/16/$31.00 ©2016 IEEE

[5]. Antenna Theory Analysis and Design by Constantine A. Balani

[6]. Application Report *SWRU120C–April 2007–Revised February 2017* 2.4-GHz Inverted F Antenna (texas).

[7]. IEEE Standard for Definitions of Terms for Antennas, Sponsored by the Antennas Committee. IEEE 3 Park Avenue New York, NY 10016-5997 USA

[8][. Antenna basics by Christof Rohner