ENERGY HARVESTING FROM RADIO FREQUENCY AND MICROWAVE SIGNALS

Mohammed Abdul Rahman Uzair[1], Mohammed Abdul Ahad Yahiya[2]

[1] *Associate Professor, Nawab Shah Alam Khan College of Engineering and Technology, Malakpet - Hyderabad, T.S., INDIA.*

[2] *Under Graduate, Nawab Shah Alam Khan College of Engineering and Technology, Malakpet - Hyderabad, T. S., INDIA.*

ABSTRACT—The aim of this paper is to illustrate the possibility of recovering electrical energy by using the concept of energy harvesting from signals around i.e., to receive Radio Frequency (RF) and Microwave signals present in the atmosphere and converting these signals into DC, in order to store it or power some circuit like charging a cell phone. To implement this concept, a receiver or an antenna is required to capture RF and microwave frequencies of Wi-Fi and GSM signals in the atmosphere. Designing an antenna is the main objective in realization of wireless cellular charging device. RF signals cannot be used directly to drive a load such as a mobile phone battery. Therefore, rectification and a boost up is done as Voltage Rectification and Boosting. A complete system is being proposed in this paper using GSM-900 and GSM-1800 signals for charging a cellular phone. The research paper is a contribution towards the concept of wireless energy transmission at the same time it proves the idea of collecting, converting and utilizing.

Keywords: Energy Harvesting, Radio Frequency (RF), Global System for Mobile, Wi-Fi, Voltage Doublers, Charge Pump, Computer Simulation Technology (CST), EMC, EMI, Digital Network.

I. INTRODUCTION

The main sources of electricity production available are natural resources like coal, natural gas, petrol, etc. The world is running short of all the natural resources due to their continuous utilization around the globe. So, there is a need for an alternate way for the production of electricity. RF energy in the ambient or the areas close to transmission towers or Wi-Fi hotspot provides an opportunity to harvest that energy. Some of the most prominent sources are FM radio systems (transmitted power is few tens of KW), TV Transmission (transmitted power is few tens of KW), Cell Tower Transmission (10 to 20 W per carrier), Wi-Fi and AM Transmission (transmitted power is few hundreds of KW), etc. Energy harvesting from RF and microwave signals is meant for the extraction of energy from the surrounding and then transforming it into some usable form. Atmosphere is filled with wide range of frequency signals which are used for different purposes. By capturing them and converting to a useful form, we would be able to achieve enough power to drive a relatively low power circuit.

II. SOURCES OF RF AND MICROWAVE SIGNALS

There are different types of electromagnetic waves including RF and Microwaves which exist with different frequencies in this world. Radio frequencies are between 3KHz to 300GHz and Microwaves frequencies are between 300MHz (0.3GHz) to 300GHz. RF frequencies used for AM and FM radio waves, microwaves used by mobile phone networks, for television channels broadcast, Wi-Fi, Bluetooth transmission are commonly used ones present in environment. Cell towers can be used as continuous sources of renewable energy as they transmit for full 24 hours a day. A cell tower transmits 10 to 20W per carrier; there may be 3 to 4 carriers and 3 to 4 operators on a single tower or they may spread over the roof top of buildings.

A. Free Space Path Loss:

Path Losses are the losses in transmission from transmitter to receiver given by the Equation (1).

$$FSPL = \left(\frac{4\pi d}{\lambda}\right)^2 \qquad (1)$$

Where,
$\lambda = \frac{c}{f}$' the signal wavelength
f = frequency
d = distance between transmitter and receiver
c = speed of light.

III. ANTENNA DESIGN

To receive the RF signals and Microwave signals from the air, a receiver or an antenna with appropriate gain is required. The received signal from the antenna is passed through a charge pump in order to convert it to DC and make its level sufficient enough to charge a small circuit (cell phone, in our case). Design of all the required equipment is discussed in detail in this section.

A. Antenna:

'Rectangular Patch Antenna' was designed in our case, as this type of Antenna is easy to design and fabricate. It is low profile and has a very low fabrication cost. Main parameters of the patch antenna depend on the substrate used in the fabrication, dielectric constant and height of the substrate. Using this information, the width and length of the patch at a

ISSN: 2278 – 7798

desired frequency can be calculated. For an efficient radiator, the width can be found using Equation (2).

$$w = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \quad \text{... (2)}$$

Where,
v_0 = free space velocity of light
f_r = resonant frequency of the micro strip patch antenna.
It is the function of antenna length given in Equation (3).

$$f_r = \frac{v_0}{2L\sqrt{\varepsilon_r}} \quad \text{... (3)}$$

IV. VOLTAGE DOUBLER

Antenna captures high frequency RF signal. RF signal is rectified to charge a device. To generate high DC voltage from low voltage AC, charge pump is used. Thus charge pump has two main functions: it rectifies the AC signal and generates high voltage DC signal at output. Charge pump is not an amplifier but has stages of voltage doublers. The basic schematic of a voltage doubler is shown in Figure2.

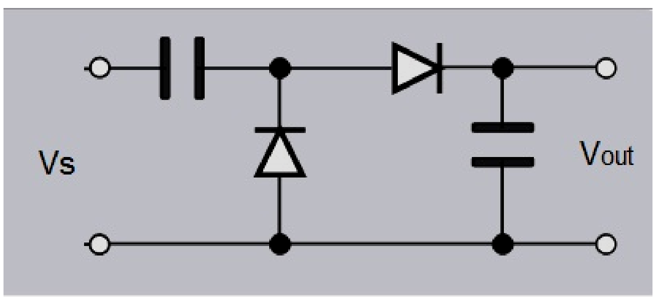

Figure1: Voltage doubler

During the positive half cycle, RF signal is rectified by the upper diode. The first capacitor is charged to peak AC voltage. During the negative half cycle, RF signal is rectified by the lower diode and the second capacitor is charged to peak AC voltage. But, during the negative half cycle, there is series combination of first capacitor and input signal. Thus, the total voltage across the second capacitor during negative half cycle is twice the input voltage.

$$V_{out} = 2V_m \quad \text{... (4)}$$

Output voltage is directly proportional to the number of stages in the charge pump. In general, **N** stages of voltage doubler can be cascaded to produce an output voltage of $2N*V_{in}$. Charge pump has network of diodes and capacitors and increased output voltage is achieved by charge transfer to capacitive load. More stages can be combined to produce three and four times the input voltage to produce the triple and quadruple voltage respectively. There are different types of charge pump circuits like Cockcroft-Walton, Dickson and Villard voltage multipliers. Output voltage is given by the relation given in Equation (5), when n-stages are connected in series

$$V_{out} = \frac{nV_o}{nR_0 + R_L}R_L = V_0\frac{1}{\frac{R_0}{R_L}+\frac{1}{n}} \quad \text{... (5)}$$

Where,
V_o = open circuit voltage
R_L = load voltage
R_o = internal resistance
N = number of stages

When load is connected at output, the voltage drop is given by Equation (6).

$$V_{drop} = \frac{1}{6f_c}(4n^3 + 3n^2 - n) \quad \text{... (6)}$$

Where,

f = operating frequency

c = stage capacitance

n = number of stages

Equation shows that number of stages can be increased to specific number as voltage drop becomes more significant at stages.

V. ENERGY HARVESTING PERFORMANCE

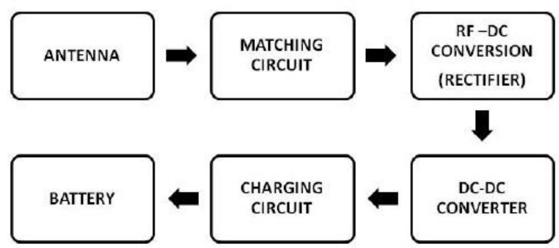

Figure2: Block diagram of the system

As in the block diagram of the system shown in Figure2, RF signals generated by multiple RF sources are captured by antenna. Using matching circuits for the antenna along with a rectifier, generated DC power is used by charging controller to run mobile device terminal functions or recharge its battery. This circuit will charge the battery by utilizing the ambient RF signal. Circuit will convert the RF signal to DC output to charge the battery. An energy harvesting system was studied through simulation and experimentally obtained data for practical design of the Smart energy harvesting circuit.

VI. RESULTS

The first step was designing the antenna. Secondly, voltage doubler was implemented and a small Seven-Stage Voltage Multiplier was developed to demonstrate the concept of Voltage multiplication.

ISSN: 2278 – 7798

A. Antenna Results

Radiation Pattern of the antenna after simulations is shown in Figure3.

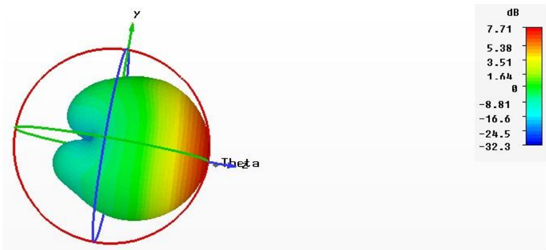

Figure3: Antenna Radiation Pattern

B. Single Stage Charge Pump:

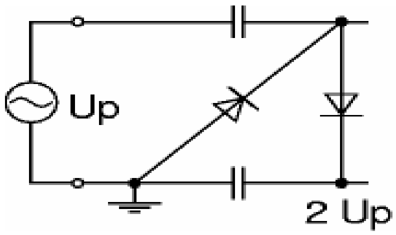

Figure4: Single-stage Voltage-doubler

The single stagvoltage doubler are shown in Figure5, where the input voltage was 5V and an output is around 8.9V was obtained almost double of the input value.

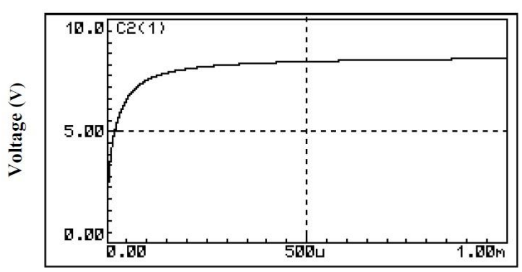

Figure5: Output Voltage of a single stage voltage doubler

Then the stages were increased to 2 and the voltage results were found to be four times the input as shown in Figure6.

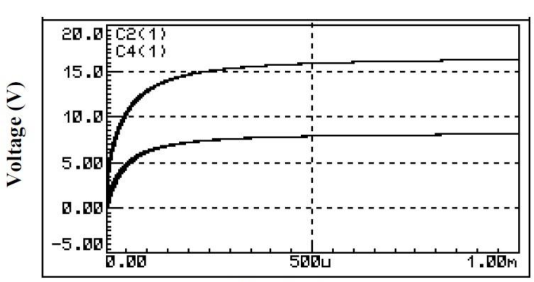

Figure6: Output Voltage of a two stage voltage doubler

Further, when the stages were increased to five, all the results obtained across different capacitors are shown in Figure7.

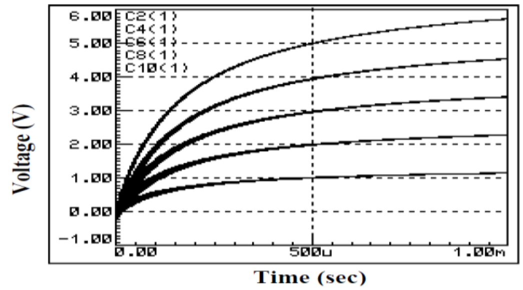

Figure7: Output Voltage of a five stage voltage doubler

From the simulated results, it can be clearly seen that when a voltage of 700mV was provided in the first stage the voltage became 1.19V i.e., double of the input. In the second stage, it rose to 2.7V and then 3.6V, 4.9V and 5.92V in the 3^{rd}, 4^{th} and 5th stages respectively.

C. Seven-Stage Charge Pump:

Since output voltage is too small for the desired goal, a charge pump with seven stages was used. The charge pump was designed for 500mV AC signal and frequency of 1GHz. The simulated design and simulation results of the charge pump model are shown in Figure8 and Figure9.

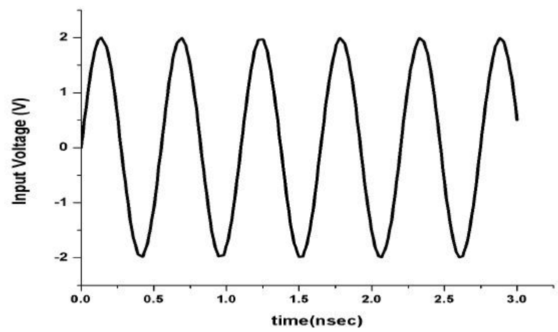

Figure8: Input Voltage given to charge pump

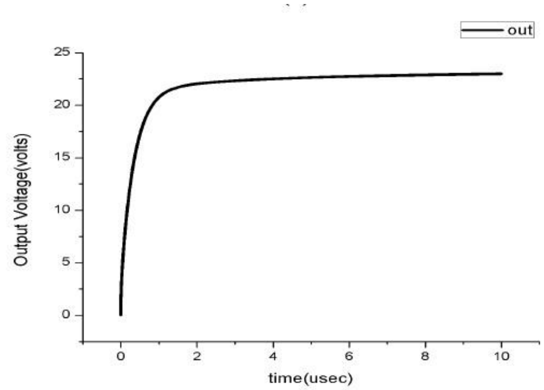

Figure9: Output voltage of Seven-Stage charge pump

After the simulated results, the Seven-Stage charge pump was fabricated and the results of the charge pump model are shown in Figure10.

ISSN: 2278 – 7798

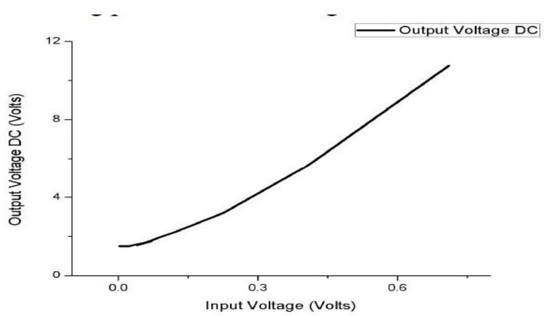

Figure10: Input-Output voltage graph for different power levels given to charge pump

Behavior of charge pump was tested by varying the frequencies and voltage levels at the input and the procedure was repeated by applying different terminations at the output of the charge pump.

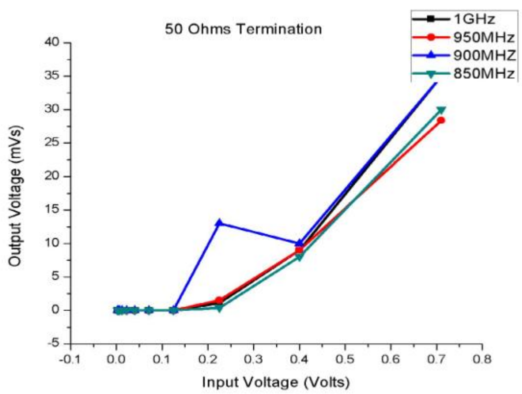

Figure11: Input-Output voltage for 50 Ohm termination attached at output port

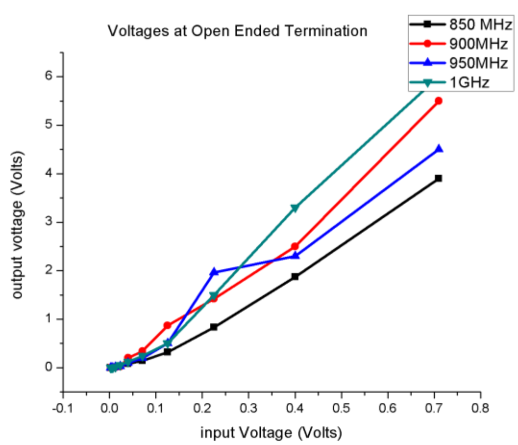

Figure12: Input-Output voltage with open ended terminations

In order to prove the concept of energy harvesting, the signal from a source of 1GHz was provided as input and was received by a receiver antenna of the same frequency at 1GHz. The initial testing of the transmitter as well as the receiver antenna for the purpose of calculating Free Space Path Loss gave results shown in Table-I.

Table-I: Fabrication results of charge pump model

Table-1 Free Space Loss		
d (m)	Pr-Pt (dBm)	FSL(dBm)
0.03	-10	1.979792788
0.06	-14.5	8.000392701
0.08	-16.25	10.49916743
0.1	-17.72	12.43736769
0.12	-18.2	14.02099261
0.14	-18.5	15.35992841
0.16	-19	16.51976735
0.18	-21	17.5428178
0.2	-24	18.45796761

Finally, the Antenna was integrated with the Charge Pump and tested before obtaining the resultant voltages at the output due to the increase in the distance and corresponding increase in the Free Space Path Loss, which is shown in Table-II.

Table-II: Distance-Voltage Comparison

Table-2 : Distance Vs Received voltage at the output	
Distance(cm)	Voltage(V)
10	1.67
20	1.6
30	1.54
35	1.5
40	1.39
50	1.3

VII. CONCLUSIONS

The aim of the proposed paper was to extract energy from the atmosphere to operate Charge Pump. Using the charge pump, RF signals that are present in surroundings, were converted to DC Voltage. This voltage was used to power electric circuits. In this way energy can be harvested from the atmosphere and it was used for some supplying power. In the proposed paper, the concept of utilizing the energy in order to charge a cellular phone has been successfully implemented and results have been presented. The Charge Pump is operational at the minimum power level of 0dB-m (0.221V) which cannot be easily obtained from the surroundings. However, this problem can be solved if high gain receiving antennas are designed to provide sufficient voltage to drive charge pump.

ACKNOWLEDGMENT

Mohammed Abdul Rahman Uzair thanks Mohammed Abdul Ahad Yahiya and other people for coming up with such a creative paper.
Mohammed Abdul Ahad Yahiya thanks Mohammed Abdul Rahman Uzair and all the people responsible for making this publication possible.

ISSN: 2278 – 7798

REFERENCES

[1] Energy Extraction from RF/ Microwave Signal, U. Batool, A. Rehman, N. Khalil, M. Islam, M. U. Afzal and T. Tauqeer,IEEE International Conference.

.[2] M. Arrawatia, M. S. Baghini, and G. Kumar, "RF energy harvestingsystem from cell towers in 900MHz band," 2011, pp. 1-5.

[3] H. Jabbar, Y. S. Song, and T. T. Jeong, "RF energy harvesting system and circuits for charging of mobile devices," *Consumer Electronics,IEEE Transactions on*, vol. 56, pp. 247-253, 2010.

[4] M. Al-Lawati, M. Al-Busaidi, and Z. Nadir, "RF energy harvesting system design for wireless sensors," 2012, pp. 1-4.

[5] P. T. A. (PTA). (2012, 28th June). *Spectrum Occupancy Rate ofCellular Mobile Operators*. Available:
http://www.pta.gov.pk/media/Annex_C_GSM_optrs.pdf

[6] R. L. Freeman, *Radio System Design for Telecommunication*: John Wiley & Sons, 2006.

[7] Balanis, *Antenna Theory: Analysis and Design, 2nd Ed*: Wiley IndiaPvt. Limited, 2007.

[8] (29th June 2012). *Microstrip patch Antennas*. Available:http://www.antenna-theory.com/antennas/patches/antenna.php

[9] (29th June 2012). *Computer Simulation technology*. Available:http://www.cst.com/Content/Products/TechnicalSpecification.aspx?product=CST%20EMS.

[10] "Voltage Doubler Circuits," ed, 2009.

[11] (29th June 2012). *DAEnotes*. Available:http://www.daenotes.com/electronics/devices-circuits/voltagemultipler#axzz1o3yuXWKL.

[12] D. W. Harrist, "Wireless Battery Charging System Using RadioFrequency Energy Harvesting," Engineering, BS, University ofPittsburgh,, University of Pittsburgh, 2004.

[13] S. Davis. *Power electronics Technology, Schottky Diodes: the Old OnesAre Good, the New Ones Are Better*. Available:http://powerelectronics.com/images/SchottkyDiodes.pdf

[14] (29th June 2012). *The Schottky Diode Power Rectifier*. Available:http://www.radioelectronics.com/info/data/semicond/schottky_diode/power-rectifier.php.

[15] *Network Analyzer | Agilent*. Available:http://www.home.agilent.com/agilent/product.jspx?nid=-536902444.0.00&lc=eng&cc=US.

[16] *Advanced Design System (ADS) Bundles | Agilent*. Available:http://www.home.agilent.com/agilent/product.jspx?nid=-34335.0.00&lc=eng&cc=PK.

Mohammed Abdul Rahman Uzair was born at Nalgonda, a district headquarter nearly 100kms from Hyderabad, India. He completed his BTech in Electrical and Electronics Engineering, from JNTU Hyderabad in the year 2003. He completed his MTech in Electrical Power Engineering, from JNTU Hyderabad in the year 2012. Currently, he is pursuing PhD from GITAM University, Hyderabad campus on the topic 'Failure Analysis of Power Transformers'. He is working as Associate Professor in the Department of EEE at Nawab Shah Alam Khan College of Engg & Tech, Hyderabad. His fields of interest are Power Systems and Power Electronics. He has published three papers so far- one in a National Journal (2011), one in an International Journal (2013) apart from an IEEE paper (2015).

Mohammed Abdul Ahad Yahiya was born at Hyderabad, India. he is in the finale of his B.Tech in Electrical and Electronics Engineering from JNTU, Hyderabad. He is a brilliant student in his batch from the very beginning of his Graduation. He has overall 70 percent in BTech so far. His fields of interest are Power Systems, Electrical transmission and Distribution Systems, Power Electronics, Renewable Energy Sources and Electrical Machines.

ISSN: 2278 – 7798