

RF Energy Harvesting System from Cell Towers in 900MHz Band

Mahima Arrawatia

Electrical Engineering Department
Indian Institute of Technology Bombay
Powai, Mumbai-400076, India
Email: mahima87@ee.iitb.ac.in

Maryam Shojaei Baghini

Electrical Engineering Department
Indian Institute of Technology Bombay
Powai, Mumbai-400076, India
Email: mshojaei@ee.iitb.ac.in

Girish Kumar

Electrical Engineering Department
Indian Institute of Technology Bombay
Powai, Mumbai-400076, India
Email: gkumar@ee.iitb.ac.in

Abstract—An experimental RF energy harvesting system to harvest energy from cell towers is presented in this paper. An electromagnetically-coupled square microstrip antenna is designed and fabricated for deployment in the presented system. Antenna gain of 9.1dB and bandwidth from 877 MHz to 998 MHz is achieved. A Schottky diode-based single stage voltage doubler and six-stage voltage doubler has also been designed and fabricated for DC voltage generation. Measured results show that a voltage of 2.78V is obtained at a distance of 10m from the cell tower and a voltage of 0.87V is obtained at a distance of 50m.

I. INTRODUCTION

Available RF energy in the ambient or areas close to transmission towers provides an opportunity to harvest that energy. Some of the most prominent sources are FM radio systems ((88-108 MHz, transmitted power few tens of KW), TV Transmission (180-220 MHz, transmitted power few tens of KW), Cell Tower Transmission (10 to 20 W per carrier), Wi-Fi (2.45GHz, 5.8GHz), AM Transmission (540-1600 KHz, transmitted power few hundred KW) and mobile phones (transmitted power 1W to 2W), etc.

Cell towers can be used as a continuous source of renewable energy as they transmit 24 hours. In India cell towers transmit in the frequency range of 869- 890 MHz in CDMA, 935-960 MHz in GSM 900 and 1810-1880MHz in GSM 1800 bands. It transmits 10 to 20W per carrier; there maybe 3 to 4 carriers and 3 to 4 operators on a single tower or spread over the roof top of buildings. Gain of the cell tower transmitter antenna is typically 17dB. The half power beam width (HPBW) of the antenna in horizontal direction maybe between 60° to 90° and in vertical direction varies between 5° to 10°. Maximum power is received when the receiver is in the main beam. For cell site consisting of transmitting towers of GSM900 band, signal strengths are calculated in Table I at various distances according to Friis transmission equation.

$$P_r = P_t G_t G_r [\lambda / (4\pi R)]^2 \quad (1)$$

Where,

Pr = Received Power

Pt= Transmitted Power

Gt= Gain of the transmitted Antenna

Gr= Gain of the receiver Antenna

R= Distance between the transmitter and receiver antennas

TABLE I
POWER RECEIVED FROM CELL TOWERS (GSM 900 BAND)

Distance (m)	200	100	50	10	5
Number of Carriers	1	1	1	1	1
Number of Operators	1	1	1	1	1
Power Received(mW)	0.13	0.50	6.03	50.28	201.12
Power Received(dBm)	-9.01	-2.99	7.81	17.01	24.01

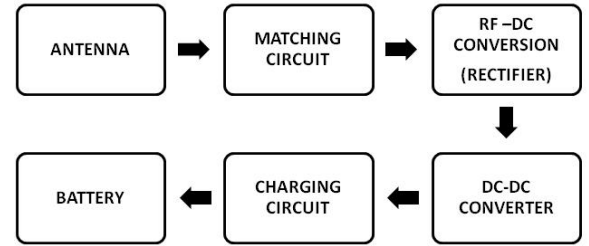


Fig. 1. Basic Block Diagram of RF Energy Harvesting System

The gain of the cell tower transmitter antenna is 17dB. Receiver antenna gain is taken as 9dB according to the fabricated microstrip antenna gain. Transmitted power is 20W from the cell towers. Frequency is taken as 950MHz which is approximately middle value of GSM 900 band.

For full signal strength, a cell phone requires only -69dBm power. In a radius within 50m from a cell tower, power level is very high. Such high power levels cause various health hazards, such as, headache, memory loss, nausea, dizziness, tingling, altered reflexes, muscle and joint pain, and ultimately leading to cancer [1].

There are more than 4 lakhs cell towers in India, therefore harvesting ambient RF energy would provide an alternate energy source for various applications and reduce radiation health hazards. Fig.1 shows the basic block diagram of RF Energy harvesting system.

However, harvesting energy from them poses several challenges.

1. Available power varies with distance, direction and gain of the receiver antenna; therefore high gain antenna for all frequency bands would be required.



(a) Side view of Electromagnetically Coupled SMSA (b) Top view of Electromagnetically Coupled SMSA

Fig. 2. (a) Side view of Electromagnetically Coupled SMSA (b) Top view of Electromagnetically Coupled SMSA.

2. Due to non-linear dependence of the rectifier impedance on the frequency and power, broadband impedance matching network is essential for maximum power transfer.
3. High efficiency of RF-DC conversion and low power DC-DC converter is required.

Minimum numbers of components are used in the design of the RF Energy harvesting system to reduce power dissipation in the circuit itself.

II. MICROSTRIP ANTENNA DESIGN

Antenna is one of the most crucial components in RF energy harvesting system to extract maximum power. Various antenna topologies have been reported in [2-4] for RF energy harvesting but high gain and bandwidth have not been achieved simultaneously.

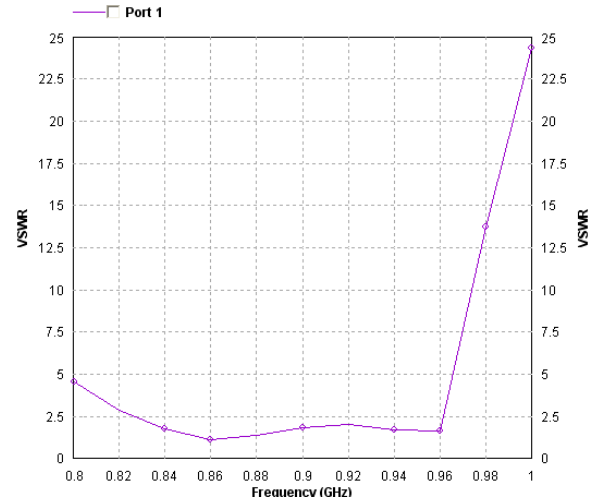
In this paper, broadband electromagnetically coupled Square microstrip antenna (SMSA) [6] is used for the proposed RF energy harvesting system. It uses stacked multi-resonator configuration for broadband operation. Only the bottom patch is fed and top patch is coupled electromagnetically.

Antenna has a stacked configuration. Two 2mm thick aluminum radiating patches are electromagnetically coupled through an air gap of 1.3cm. First and second square patch are of length 15.2cm and 12.8cm respectively. The ground plane size is 24 cm X 24 cm. The total height of the antenna is 2.6cm. Fig. 2 shows fabricated electromagnetically coupled SMSA designed for GSM 900 band using IE3D software from Zeland [7].

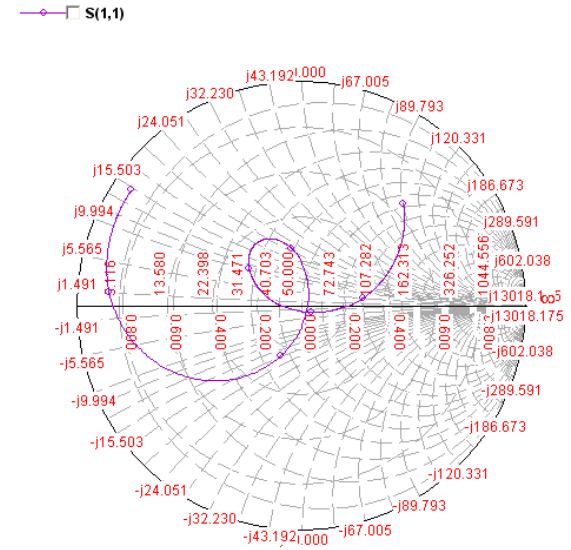
Simulated VSWR and input impedance plots of electromagnetically coupled SMSA are shown Fig. 3(a) and (b). Bandwidth for VSWR less than 2 is from 877 to 998 MHz. Fig. 4 shows the gain plot of the antenna. The gain of antenna is 9.1 dB. Fig. 5 shows measured VSWR plot and input impedance plot of SMSA. The antenna is designed for the 935-960 MHz (GSM 900) band but it can also covers part of CDMA transmission band (869-890MHz). To enhance the gain, array of SMSA can be used.

III. RF TO DC CONVERSION USING SCHOTTKY DIODES

A voltage doubler is designed using Dickson Multiplier topology. Silicon based Schottky diode having threshold voltage of 230 mV and diode capacitance of 0.26 pF is chosen.



(a) VSWR of Electromagnetically Coupled SMSA



(b) Input Impedance of Electromagnetically Coupled SMSA

Fig. 3. Simulated (a) VSWR and (b) Input impedance of Electromagnetically Coupled SMSA

At microwave frequency, the non-linear capacitance of the diode governs the maximum power transfer to the load and amplitude of the rectified output as input impedance of the rectifier changes with frequency. Fig. 6 (a) and (b) shows a single stage voltage doubler and 6 stage voltage doubler.

Both single stage and 6 stage voltage doubler circuits are fabricated. Fig. 7 (a) and (b) show fabricated single stage voltage doubler and 6-stage voltage doubler circuits respectively. Six-stage voltage doubler is implemented to measure the power dependence of the rectifier for lower power level as the voltage measured at single stage is very low. Single stage voltage doubler is used for rectenna measurements inside the lab and near the cell towers as the power level are higher at these places.

Input impedance of the diode changes with the input power

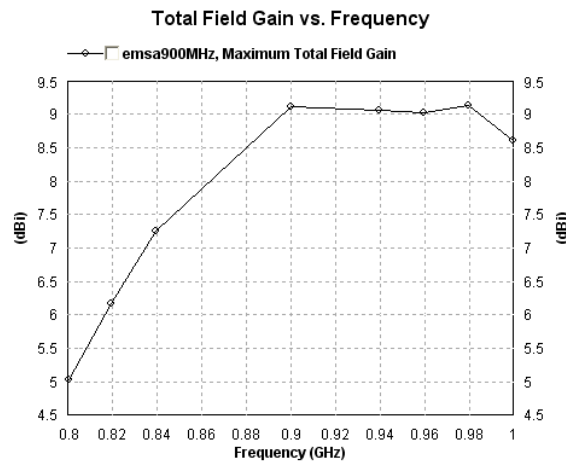


Fig. 4. Simulated gain plot of electromagnetically coupled SMSA

TABLE II

VOLTAGE AT VARIOUS STAGES OF SIX STAGE RECTIFIER WITH 2.2 KOHM LOAD AT 900 MHZ FOR DIFFERENT INPUT POWER LEVELS

Power (dB)	6th stage voltage (V)	5th stage voltage (V)	4th stage voltage (V)	2nd stage voltage (V)	1st stage voltage (V)
15	4.83	3.89	3.92	3.63	2.53
10	2.32	2.08	2.10	2.0	1.40
5	0.95	0.95	0.95	0.96	0.68
0	0.30	0.31	0.31	0.33	0.25

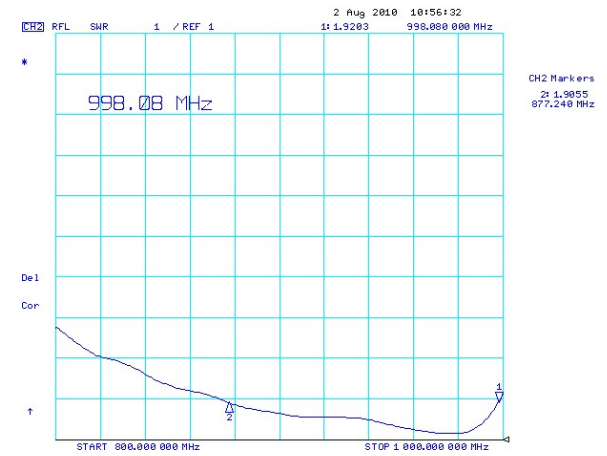
as the dc operating point of the I-V curve moves in a non-linear fashion [5]. The impedance variation of a six stage rectifier at 900 MHz with change in power level is shown in Fig.8. Impedance variation is taken at 900MHz as it is the approximate middle value of the CDMA and GSM 900 bands.

Large variation of input impedance with input power and frequency makes designing a broadband conjugate matching network complex. Therefore, a resistive impedance matching network, as shown in Fig.9, is used to allow maximum power transfer.

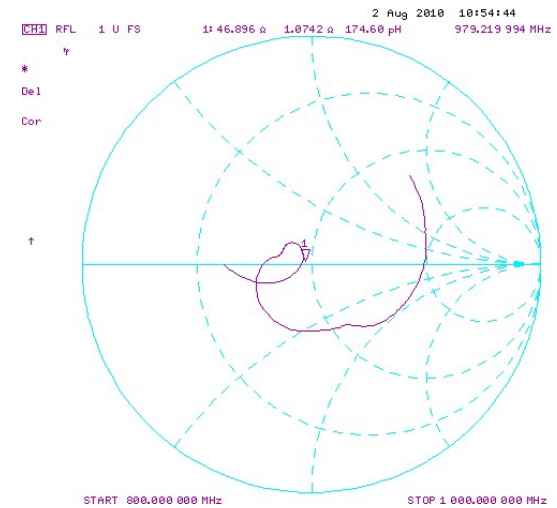
The value of R_{match} depends on the input impedance of the antenna. This approach provides an approximate and simple matching between the antenna and rectifier.

The 6- stage rectifier is tested for its performance by feeding it directly from a RF source. Table II shows output voltage variation of six stage voltage doubler with 2.2 Kohm load at 900 MHz using a RF source at various power levels. Table III shows the output voltage variation of six stage voltage doubler for no load condition.

Rectenna is a combination of rectifier and antenna. Fig.10. shows the experimental setup of rectenna. It consists of an RF source transmitting 900 MHz (approximately middle value of CDMA and GSM 900 band) with output power of 17dBm (50mW). A horn antenna with a gain of 11dB is connected to the RF source to simulate cell towers inside the lab, and voltages at output of rectenna at various distances are measured. Table IV summarizes the measured results at 900MHz using a single stage voltage doubler with 100K ohm and 10uF load.

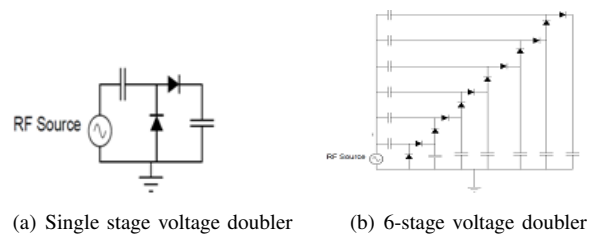


(a) Measured VSWR of Electromagnetically Coupled SMSA



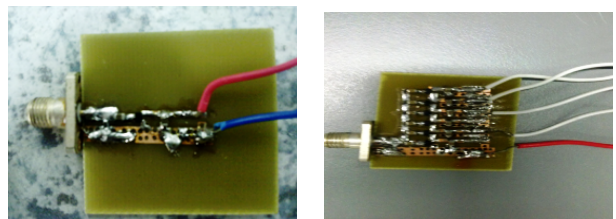
(b) Measured Input Impedance of Electromagnetically Coupled SMSA

Fig. 5. Measured (a) VSWR and (b) Input impedance of Electromagnetically Coupled SMSA



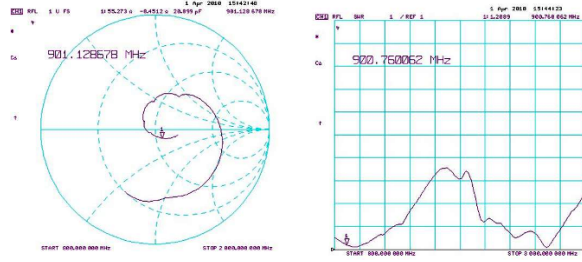
(a) Single stage voltage doubler (b) 6-stage voltage doubler

Fig. 6. (a)Single stage voltage doubler and (b) 6-stage voltage doubler

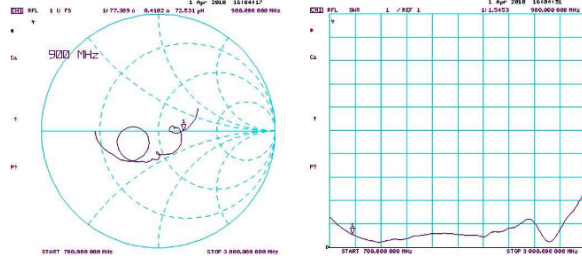


(a) Fabricated Single stage voltage doubler (b) Fabricated 6-stage voltage doubler

Fig. 7. Fabricated (a) Single stage and (b) 6 stage voltage doubler circuit



(a) Input impedance and VSWR plot of six stage rectifier for an input power of -10dBm



(b) Input impedance and VSWR plot of six stage rectifier for an input power of 10dBm

Fig. 8. Input impedance and VSWR plot of six stage rectifier for an input power of (a) -10dBm (b) 10dBm

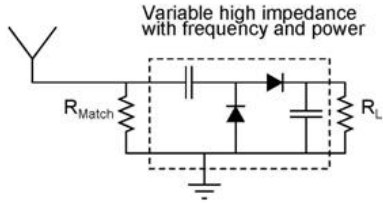


Fig. 9. Approach used for resistive impedance matching

IV. MEASUREMENT AT ACTUAL SITE

Voltage levels are measured at actual site consisting of transmission cell towers at Indian Institute of Technology Bombay (IIT-B) using the fabricated electromagnetically coupled microstrip antenna and single stage voltage doubler. Figs.11 and 12 show the experimental setup for rectenna measurement at 50 m and 10 m from cell towers respectively.

The voltage obtained at 50 m was 0.87V. This voltage can be stepped up using a boost converter. A stand alone boost converter from Texas Instrument TPS61220 has been designed to work from an input voltage of 0.7V. Voltage at 50m after

TABLE III
VOLTAGES AT 4TH - 6TH STAGES OF SIX STAGE VOLTAGE DOUBLER FOR LOW INPUT POWER LEVELS FOR NO LOAD AT 900 MHz

Power (dB)	6th stage voltage (V)	5th stage voltage (V)	4th stage voltage (V)
-1	1.34	0.88	0.65
-2	1.10	0.72	0.54
-5	0.60	0.39	0.32
-10	0.21	0.14	0.16

TABLE IV
RESULTS OF RECTENNA WITH SINGLE STAGE VOLTAGE DOUBLER AT 900MHz WITH 17dBm TRANSMITTED POWER

Distance (dB)	Voltage(V) no load	Voltage(V) 100K load
60	3.45	3.38
80	2.31	2.27
100	1.67	1.52
120	1.48	1.34
140	1.14	1.02
160	0.83	0.68
180	0.58	0.46



Fig. 10. Experimental setup for Rectenna measurement at 900MHz



Fig. 11. Experimental setup for Rectenna measurement at 50m from cell tower (IIT-B)

stepping up can be used to charge a battery using a charging circuit.

At a distance of 10m voltage of 2.78V is obtained. This large voltage can be used to charge a battery using a charging circuit.

The power level observed using a hand-held radiation monitor was 4dBm and 5dBm at 50m and 10m respectively.

Lower power levels are observed as the rectenna is not in the main beam of the cell towers antenna.



Fig. 12. Experimental setup for Rectenna measurement at 10m from cell tower (IIT-B)

V. CONCLUSION

In this paper, a RF energy harvesting system from cell towers is presented. A high gain electromagnetically coupled antenna is developed. A silicon based schottky diode single stage and 6 stage rectifier are also designed. A voltage of 2.78V is measured at a distance of 10m from the cell tower. Due to the increase in the population density, many people live within 10m from the cell tower. RF energy harvesting from cell towers would therefore provide two fold benefits: provide an alternative source of energy and protect people living in close vicinity of the tower from radiation health hazards.

ACKNOWLEDGMENT

We would like to thank Department of Science and Technology, Government of India for financial support of this research on RF Energy Harvesting under the project 10DST026.

REFERENCES

- [1] N. Kumar and G. Kumar, Biological Effects of Cell Tower Radiation on Human Body, *IEEE Conf. ISMOT*, pp.1365-1368, Dec. 2009.
- [2] Z. W. Sim, R. Shuttleworth, and B. Grieve Investigation of PCB Microstrip patch receiving antenna for outdoor RF energy harvesting in wireless sensor networks, *IEEE Conf. Antenna and Propagation Conference, Loughborough*, pp.129-132, Nov. 2009
- [3] A.C. Patel, et al, Power Harvesting for Low Power Wireless Sensor Networks. *IEEE Conf. Antenna and Propagation Conference, Loughborough*, pp.633-636, Nov. 2009
- [4] V.Rizzoli, et al, CAD Multi-Resonator rectenna for micro power generation. *Proc. of 4th European Microwave Conference*, pp.1684-168, Sep. 2009.
- [5] J.A. Hagettry, et al, Recycling Ambient Microwave Energy With Broad-Band Rectenna Arrays. *IEEE Trans. Microw. Theory. Tech* vol. 52, no 3, pp.1014-1024, Mar. 2004
- [6] G. Kumar and K. P. Ray Broadband Microstrip Antenna, Artech House, USA 2003.
- [7] IE3D software from Zealand ,USA