Design and Simulation of Energy Harvesting System Using GSM Signal

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Abstract-An experimental RF energy harvesting system to harvest energy from cell towers is presented in this paper. An electromagnetically-coupled E- Shapedmicrostrip antenna with an antenna gain of 4 dB is designed and fabricated for deployment in the presented system. A Schottky diode based seven-stage voltage doubler has also been designed and simulated for DC voltage generation. Simulated results show that 2.5 V is obtained at the output.

Index Terms- Electromagnetically coupled, E- Shaped microstrip patch, Schottky diode, Voltage doubler.

I. INTRODUCTION

Life without electricity is unimaginable nowadays. Electricity has become a part and parcel of our lives. The demand for electricity has been very high in the recent days and hence the electricity generated by usual means is not sufficient. On the other hand, the deposition of battery causes environmental pollution. Finite electrical battery life has encouraged companies and researches to come up with new ideas and technologies to drive wireless mobile devices for an infinite or enhanced period of time. A technology of capturing and storing the energy from external ambient sources is known as Energy Harvesting. Energy harvesters take fuel from ambient sources present around us and thus are free for the user. The various sources available are wind, solar, thermoelectric, heel strike, vibration, electromagnetic, temperature gradient, push buttons, radio frequency, acoustic etc. Energy harvesting using Electromagnetic energy presents a promising future in low power electronics and wireless sensor networks. Radio wave is ubiquitous in our daily lives in the form of signals transmission from TV, Radio, Wireless LAN, Mobile phone etc. The energy transmitted from these wireless sources is very high (KW) range but the receivers take in only a small amount of this energy. Rest of the energy is dissipated as heat or absorbed by other materials. This energy that is wasted can be harvested to generate electricity. RF sources in India are shown in the table.

Table 1. RF Sources

SOURCE	FREQUENCY	TRANSMITTED POWER	NUMBER OF TOWERS
AM	540-1600 MHz	100 Kw	197
FM	88-108 MHz	10 KW	503
TV	180-220 MHz	40 KW	1044
Wi-Fi	2.4-2.5 GHz	(10-100) Mw	Wi-Fi hotspots
Cell towers	800,900,1800 MHz	20 W	4.5 lakhs

The dominant radio frequencies available in the atmosphere are usually in the GSM-900 and GSM-1800 range. A GSM-900 base station antenna transmits in the frequency range of 935-960 MHz. This frequency band of 25 MHz is divided into twenty sub-bands of 1.2 MHz, which are allocated to various operators. There may be several carrier frequencies (1 to 5) allotted to one operator with upper limit of 6.2 MHz bandwidth. Each carrier frequency may transmit 10 to 20 W of power. So, one operator may transmit 50 to 100 W of power. The radiated power density is given as

$$P_d = \frac{\left(\frac{P_t \times G_t}{4\pi R^2}\right) Watt}{m^2}$$

The radiated power density at the transmitter side for GSM 900 is 4.7 Watts/m^2, and for GSM 1800 is 9.2 Watts/m^2. Hence by Friss Transmission formula the power density at the receiver end can be determined.

$$P_r = P_t \times G_t \times G_r \times \left(\frac{\lambda}{4\pi R}\right)^2$$

Hence at the receiving end the various power densities at a distance of R=50 m are:-

At 887 MHz (CDMA), P_r= -3.2 dBm

945 MHz (GSM 900), P_r = -3.8 dBm

1872 MHz (GSM 1800), P_r = -9.7 dBm

In our country we have adopted radiation norms are given by ICNIRP guidelines of 1998 for safe power density of f/200, where frequency (f) is in MHz. Hence, for GSM900 transmitting band (935-960 MHz), power density is 4.7W/m^2 and for GSM1800 transmitting band (1810-1880 MHz), it is 9 W/m^2.The power densities at various distances from transmitting tower are given below

Table 2. Power Densities

DISTANCE R(m)	POWER DENSITY P_d IN W/m^2	POWER DENSITY P_d IN µW/m^2
1	79.6	79600000
3	8.84	8840000
5	3.18	3180000
10	0.796	796000
50	0.0318	31800
100	0.008	7960
500	0.000318	318

It is clear that only the power of the channels in three bands GSM-900, GSM-1800, UMTS-2100, is dominant among the ambient RF energy. Hence we use broadband or wide band antennas for the reception of these signals. The key element of an energy harvesting system is rectenna, which is a combination of an antenna and a rectifier. The antenna receives the RF power, and the rectifier converts it into dc power.

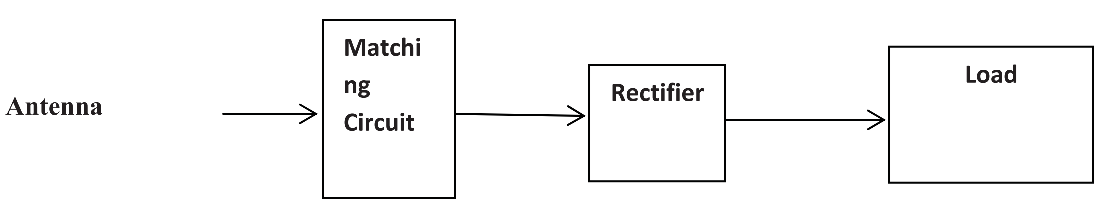

Figure1. Block Diagram

The key element of an energy harvesting system is Rectenna, which is a combination of an antenna and a rectifier.The antenna receives the RF Power. In this project the RF signals are GSM-900 and GSM-1800, so the requirement is dual-band antenna. The received ambient RF power level is normally in nW or μW range to increase the power. Therefore an array of dual-band antenna is needed. The received RF power is converted into dc power by using a rectifier circuit. Villard Voltage Multipliers are used to convert the high frequency AC signal into DC signal. The received RF power is low and the signal frequency is high so the diodes are required to have a very low turn ON Voltage and high operating frequency. Unlike normal diodes; Schottky diodes have high switching speed and low forward voltage which makes them efficient. At high frequencies the low values of inductors are difficult to construct but using an inductor along with capacitor at integrated circuit level greatly improves the performance.Matching Circuit is needed for matching the impedance of dual-band antenna array and the impedance of the rectifier circuit.Load may be a wireless sensor modes which consume dozens microwave in sleep mode and hundreds microwave in active mode and also we can use load as lowest power microcontroller.

II. MICROSTRIP ANTENNA DESIGN

A microstrip antenna consists of a radiating patch on one side of a dielectric substrate, which has a ground plane on the other side. Based on the given parameters an E Shaped microstrip patch antenna was designed with an overall good performance at the desired centre frequency of 900 MHz. The patch antenna is shown in the fig below.

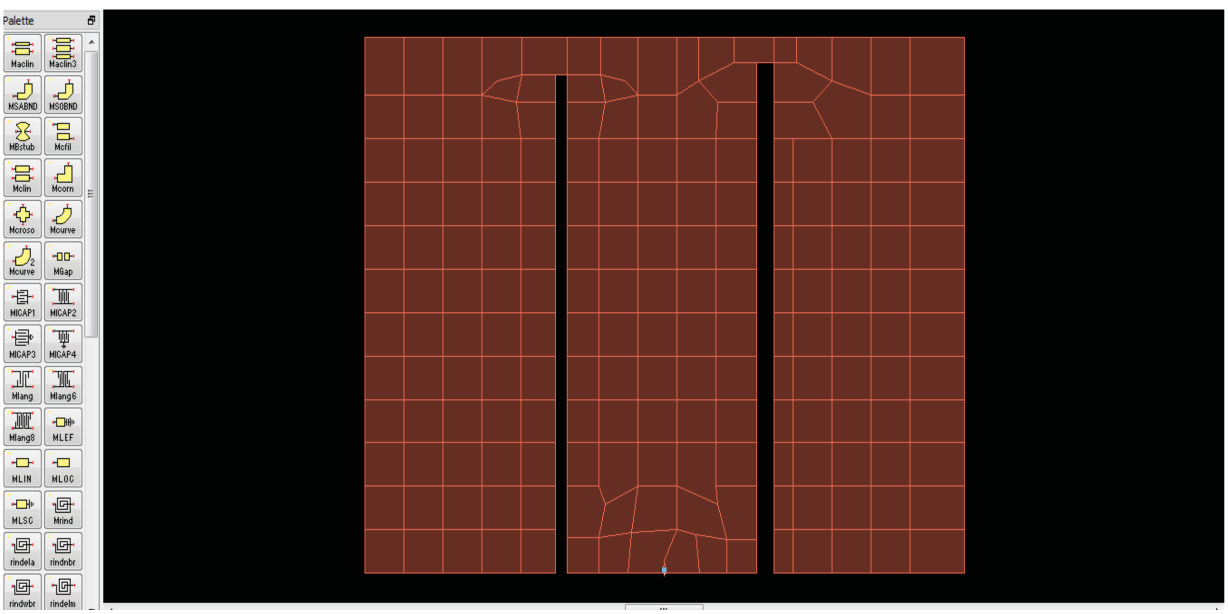

Figure 2.Layout of the E Shaped patch antenna

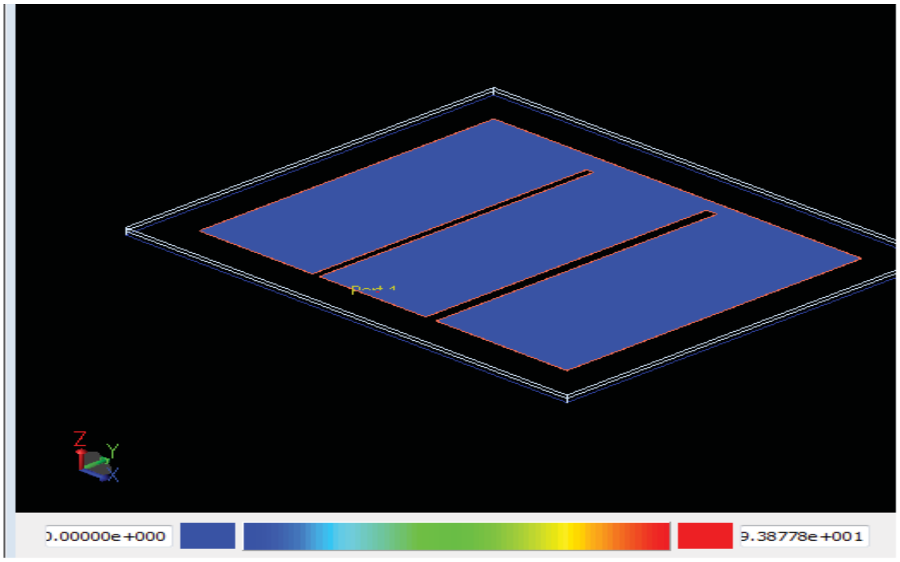

Figure 3. Tile view of the patch antenna

The patch conductor is made of copper on a FR4 substrate. The important specifications chosen in simulation for this design are: the thickness of substrate 1.6 mm, the thickness of copper 0.035 mm, the relative permittivity 3.9, and the loss tangent 0.01. Return Loss is the loss of signal power resulting from the reflection caused at a discontinuity in a transmission line or optical fiber. This discontinuity can be a mismatch with the terminating load or with a device inserted in the line. It is usually expressed as a ratio in decibels (dB).

RL (dB) =10 log10 Pi/Pr

The reflection coefficient S11 represents how much power is reflected from the antenna and hence is known as reflection coefficient or return loss. Whenever the return loss is 0 dB no reflection occurs and hence the RF signal of that particular frequency is completely captured by the antenna.

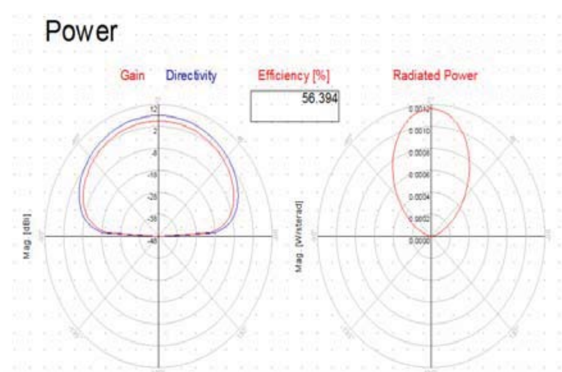

Figure 4.Gain and directivity

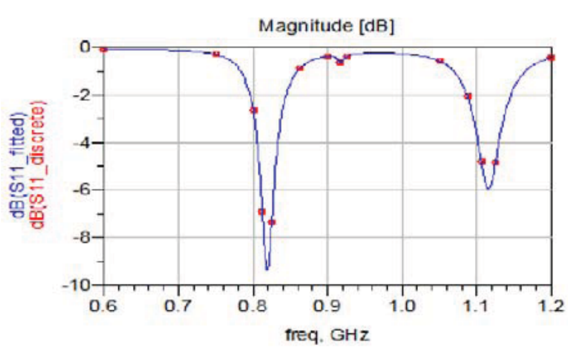

Figure 5. Return loss of the antenna

The return loss for the E shaped patch antenna for the given parameters was -9.5 dB.Directivity describes the direction in which the radiation intensity of the antenna is maximum. Radiation pattern defines the variation of the power radiated by an antenna as a function of the direction.

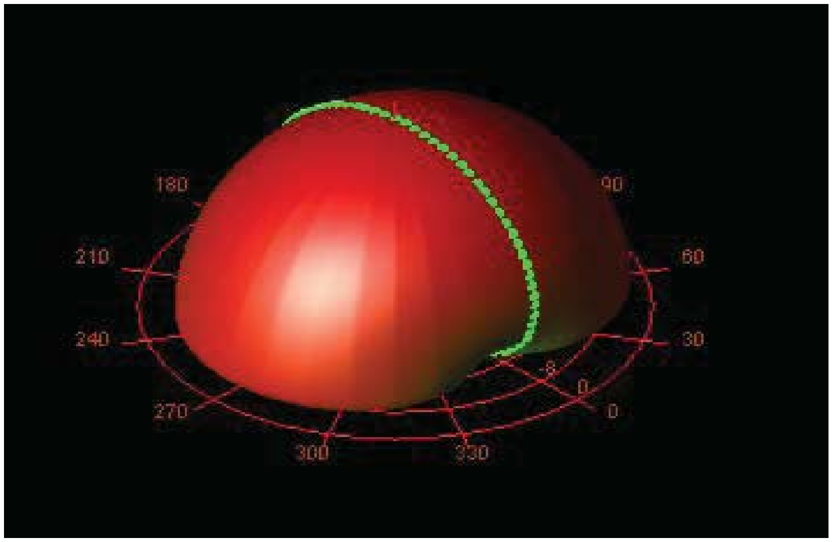

Figure 6. Radiation pattern of the antenna

This radiation pattern shows that the antenna radiated more power in a certain direction.

III. RECTIFIER DESIGN

A Seven stage Villard Voltage multiplier circuit was designed. HSMS2850 of Agilent Technologies was used as the diode for rectification.

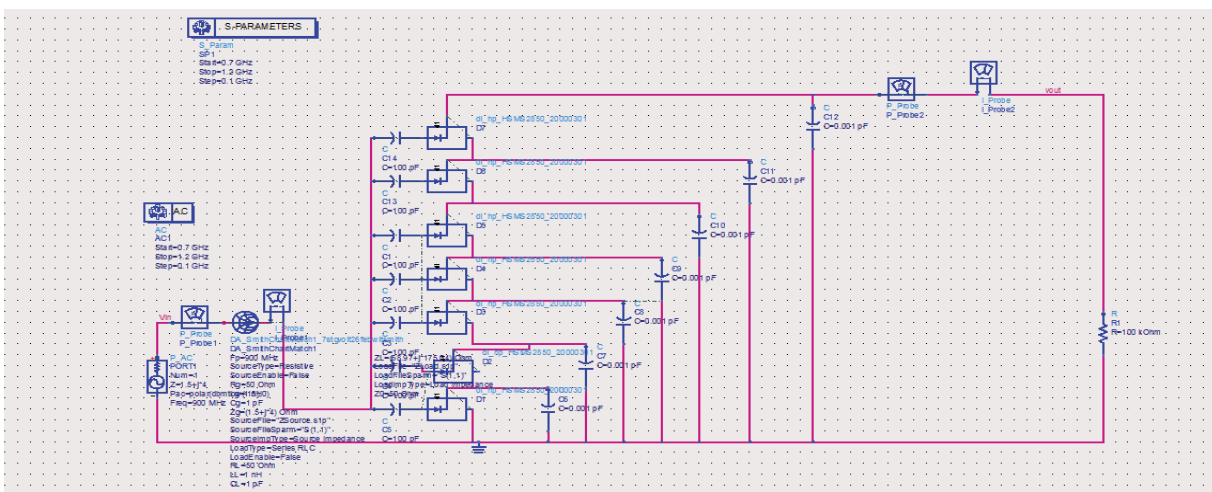

Figure 7. Seven stage rectifier circuit

Hence it is found that at 900 MHz frequency for an input voltage of 180 mV a output of 2.5 V is obtained. As per the relationship between power, current and voltage $P = V \times I$. As the voltage increases in a voltage multiplier the current drops down. The results of input and output current are shown in the Figure.

freq	Vin	vout
700.0 MHz	0.149 / -3.593	0.340 / -5.618
800.0 MHz	0.166 / -8.126	0.626 / -12.433
900.0 MHz	0.180 / -68.492	2.513 / -88.138
1.000 GHz	0.088 / 4.315	0.565 / -165.2...
1.100 GHz	0.109 / 3.296	0.274 / -172.0...
1.200 GHz	0.116 / 2.461	0.175 / -174.4...

Figure 8.Output of seven stage rectifier

The output voltage obtained is 14 times that of the input voltage.

IV. MATCHING CIRCUIT

A matching circuit is essential for the power from source (antenna) to be transmitted to the load (rectifier) completely without any return loss. With the help of ADS 2009, Smith chart matching method is employed to design the matching circuit. With the help of this smith chart a matching circuit is obtained with the transmission line values generated by the software itself.

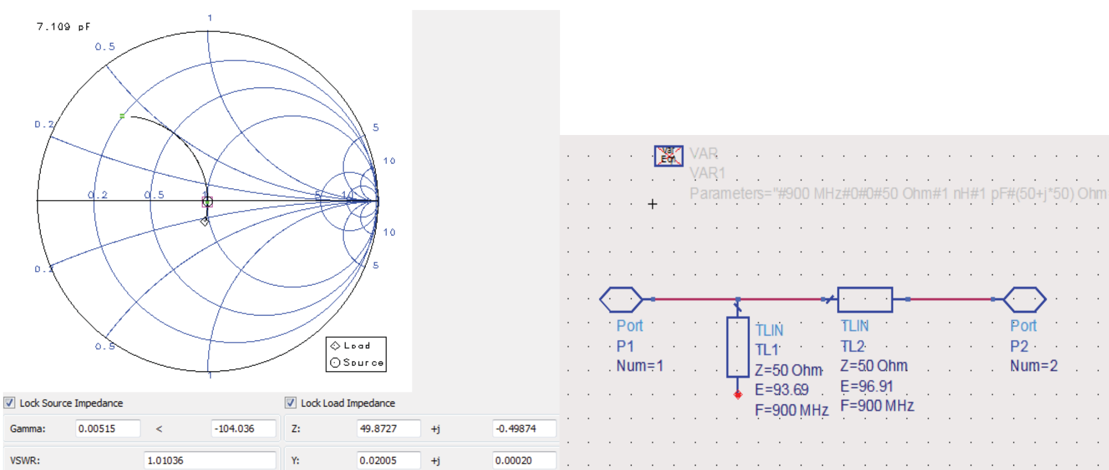

Figure 9.Smith Chart Matching Circuit

Hence the matching circuit is designed and the output is also obtained.

V. CONCLUSION

Arectenna is designed and simulated for RF energy harvesting using Advanced Design System Software. Here the Energy harvesting circuit is designed for the dominant RF Signal of GSM 900 MHz. An E-Shape microstrip antenna is designed at 900 MHz frequency. The minimum return loss of -9.5 dB is obtained near 8 to 9 GHz. By using the S Parameter the input impedance of the rectifier is matched with the rectifier feed impedance. A five stage voltage multiplier circuit is designed and simulated using ADS Software. From the rectifier circuit the output power of 31µW. The output voltage of 2.5 volts is obtained for the input voltage of 180 mV. Also the output current of 25µA is. A TL matching circuit for matching the antenna impedance with the rectifier impedance is studied by using smith chart in the ADS Software.

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