Design of RF Energy Harvesting Using Microstrip Antenna

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Abstract - *In this paper, an experimental RF energy harvesting system is designed to harvest energy from cell towers operating at 900MHz frequency band. Design procedure and characteristics of RF energy harvesting system using Microstrip patch antenna have been discuss and analyzed. The main function of RF energy harvesting system is to convert the RF signal into DC signal. This system is designed is such a way that it will capable to recycle RF energy at 900MHz, by connecting an antenna that is operating at 900MHz it is possible to form a complete rectenna device. A single stage as well as seven stage voltage doubler circuit designed and fabricated for DC voltage generation using Schottky diode. The designed is based on Villard voltage doubler circuit method.*

Key Words: RF Energy harvesting, Microstrip patch antenna, Schottky diode, voltage doubler circuit, Villard.

1. INTRODUCTION

For the past decades, with the widespread diffusion of services and devices using wireless communication, the finite life of battery is asking for new ideas to increase the lifetime of mobile devices. Nowadays, with the improvement in the design of microelectronic, wireless technology and semiconductor the wireless electronic devices are become more compact, wireless, low power consumption and highly autonomous. In general, almost all electronic devices are powered by batteries, due to this some problems are required to face that is size become large and weight of device is also increase, regular maintenance is necessary due to limited battery lifetime, it can become more difficult and more expensive when the device operates in severe or even difficult to access environment. So, the ambient energy harvesting techniques are proposed as a solution

Several feasible studies and prototypes about RF energy harvesting have been discussed by many researchers. "RF Energy Harvesting System from Cell Towers in 900MHz Band" is based on an experimental RF energy harvesting system to harvest energy from cell towers. For deployment in the presented device an electromagnetically-coupled square Microstrip antenna is designed and fabricated. Antenna gain of 9.1dB and bandwidth from 877 MHz to 998 MHz is achieved.[3] "Optimization of the Voltage Doubler Stages in an RF-DC Convertor Module for Energy Harvesting" presents use of voltage doubler circuit in an energy conversion module for Radio Frequency (RF) energy harvesting system at 900 MHz band.[4]

Therefore, with the goal of designing an ambient RF energy harvesting system with high energy utility, this paper first deal with selection of 900MHz frequency band for antenna , software simulation of antenna & voltage doubler circuit . A practical rectenna design and measurements are presented in Section 2. A final conclusion is drawn in section 4.

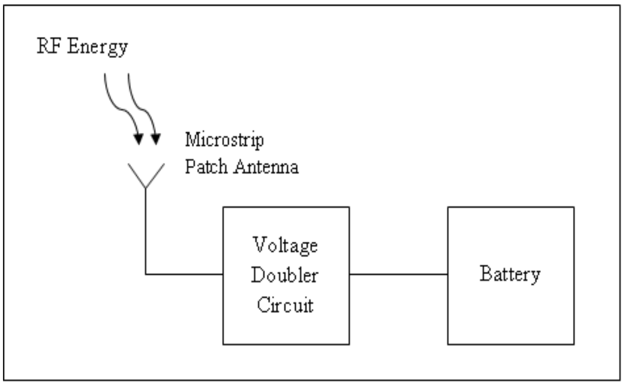

Fig -1: Block Diagram of RF Energy Harvesting System

2. METHODOLOGY

2.1 Antenna

In this RF harvesting system radio frequency is extracted from 900 MHz GSM band. The energy is extracted using antenna; this antenna is designed for particular frequency that is 900 MHz frequency. There are limitations to use the particular band of frequency. You cannot use the licensed frequency band. Therefore we select unlicensed frequency band for RF harvesting system. Unlicensed frequency band means that the operator of radios does not need directly to deal with the FCC to operate radio. The available unlicensed frequency bands are 900MHz, 2.4GHz and 5.8GHz. There are three unlicensed frequency bands out of these three bands we select 900MHz band. There are lots of reasons behind selecting this particular frequency band.

According to laws of physics it will states that as we go to the higher frequency band, the wavelength of the signal will decreased. The 900MHZ band will provide better coverage area and it will provide best range as compared to other frequency bands. Because of this reason 900MHz frequency band is mostly used for mobile communication from last 20 years. Other than laws of physics, the devices and network equipment that can be required for antenna design are available at cheap price. As we know higher frequency signal will travel lesser distance than signal sent on a lower frequency band.

The most significant part of antenna design is selection of substrate. There different types of substrate that can be used for antenna design these are foam, Duroid, benzocyclobutance, roger 4350, epoxy FR - 4, Duroid 6010 and so on. There are different criterion for selection of correct substrate these are its price, efficiency and size. The choice of substrate also depends on thickness and permittivity of its. These factors effects on bandwidth of signal. Foam substrate will provide small size but its cost is high and losses are more in it even it will give less efficiency than others. Maximum efficiency is achieved in roger 4350 but it also have limitations related to size and price. By studying advantages and disadvantages of all these substrates we reach to optimum solution is that FR – 4 substrate.

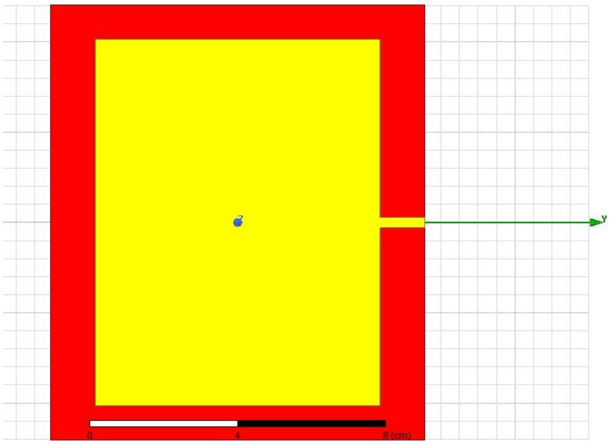

Fig -2: Antenna Design in HFSS software

The most commonly used dielectric substrate is Flame Retardant 4 (FR – 4) substrate. There are lots of reasons behind selecting this substrate. FR – 4 is cheaper, also it is easily available in market as per our requirements. Moreover, it is used for lower frequencies. FR – 4 is widely used for frequencies that are less than 1GHz. The reason behind is that the permittivity of this material is almost constant for frequencies less than 1GHz. The FR – 4 substrate is also available in different thickness values than other materials which provide you more design flexibility. It is mostly used for designing patch antenna because of its lower price and easily availability. This material will retain high mechanical values and electrical insulating qualities in both dry and humid conditions. So FR – 4 substrate combines good electrical features, price and availability. The FR – 4 substrate has dielectric constant of 4.4 and thickness of substrate is 1.6 mm.

The feeding is used in antenna for transmission of power from the feeding to the patch. The antenna feed acts as a matching system at the attachment point. It will convert the feed line impedance to antenna's intrinsic impedance and makes any balanced – to – unbalanced conversion.

In this paper, Microstrip antenna is used for the proposed RF energy harvesting system. Antenna is designed for GSM 900MHz band. Antenna is design in HFFS software. The antenna consists of ground plane of 120.63mm × 101.438mm. On the ground plane square patch of length 101.43 mm and 77 mm respectively. The total height of the antenna is 1.6 mm.

2.2 Voltage doubler circuit

The efficiency of an antenna particularly relies upon on its impedance and an impedance of the energy converting circuit. If the impedance of an antenna and impedance of energy converting circuit is not matched then it is not able to hold all the available power in free space for designed frequency band. Matching of the impedance manner that the impedance of the antenna is the complex conjugate of the impedance of the voltage doubler circuit.

The function of the electricity conversion module is to convert the RF signals into DC voltage at the given frequency band to power the low power devices. A seven-stage Schottky diode voltage doubler circuit is designed, simulated, fabricated and examined in our work. There are various voltage doubler circuit designing methods. The design used in this module is obtained from the function of peak detector or a half wave peak rectifier. In this paper voltage doubler circuit is designed using Villard voltage multiplier designed technique. The reason behind is that it can double the input voltage towards the ground in single output and may be cascaded to form a voltage doubler with an arbitrary output voltage and its layout simplicity.

2.2.1 Diode modeling

Table -1: Specification of Schottky diode

Parameter	Symbol	Minimum	Maximum	Units
Reverse voltage	VR		Rated VB	V
Forward current, steady state	IF		50	mA
Power dissipation	PD		75	mW
Storage temperature	TSTG	-65	+150	C
Operating temperature	TA	-65	+150	C
Junction temperature	TJ		+150	C

The voltage doubler circuit in this design uses zero bias Schottky diode SMS7630-005LF. RF and microwave mixers and detectors are designed using surface-mountable, plastic-packaged silicon mixer Schottky diodes.

They include low-barrier diodes and zero-bias detectors that combine advanced semiconductor technology with low-cost packaging techniques. They can be used at frequencies up to 24 GHz. Skyworks gives modeling parameters of these diodes in their data sheets. Those parameters are utilized in Multisim for its very own modeling purposes. The modeling is carried done it means that remodeling the diode into an equivalent circuit by the usage of passive components

2.2.2 Single stage voltage doubler

Single stage voltage doubler circuit is also known as a voltage doubler because in concept, the voltage that arrives at the output is about two times of that at the input. The circuit consists of 2 sections; each incorporates a diode and a capacitor for rectification. In the positive half cycle of input signal RF input signal is rectified, accompanied by the negative half of the input cycle. But, the voltage stored on the input capacitor during one half cycles is transferred to the output capacitor during immediately next half cycle of the input signal. For that reason, the voltage on output capacitor is more or less two times the peak voltage of the RF supply eliminated the flip-on voltage of the diode.

2.2.3 Seven stage voltage doubler

The seven stage voltage doubler circuit design carried out in this paper. Starting on the left aspect, there's a RF signal supply for the circuit accompanied by means of the primary stage of the voltage doubler circuit. Each level is stacked onto the previous stage. Stacking is achieved from left to right for simplicity in preference to traditional stacking from bottom to top. The circuit uses 8 zero bias Schottky surface-mount Skyworks SMS76xx collection, SMS7630-005LF diodes. The special features of these diode is that, it gives a low forward voltage, low substrate leakage and uses the non- symmetric residences of a diode that permits unidirectional flow of current below the ideal situation. The diodes are constant and are not concern of optimization or tuning. DC voltage produced by this circuit depends upon the incident RF energy signal. Input to the circuit is a predefined RF source. If the input voltage is higher than the Schottky forward voltage then voltage conversion can give better result.

The other additives related to the circuit are the stage capacitors. The chosen capacitors for this circuit are of via-hole kind, which make it less difficult to regulate for optimization, in which in the optimization turned into executed on the enter impedance of the CMOS chip for a 3 stage voltage doubler. The circuit design in this paper uses a capacitor throughout the load to store and offer DC leveling of the output voltage and its value handiest affects the speed of the transient response. Without a capacitor across the load, the output is a bad DC signal, but more of an offset AC sign.

In addition to the above, an equivalent load resistor is connected up on the very last node. During negative half cycle of the AC input signal output voltage across the load decreases. This decrease in output voltage is inversely proportional to the product of resistance and capacitance across the load. Without the load resistor on the circuit, the voltage would be kept indefinitely on the capacitor and appear to be a DC signal, assuming ideal components

Fig -3: Actual implementation of seven-stage voltage doubler circuit

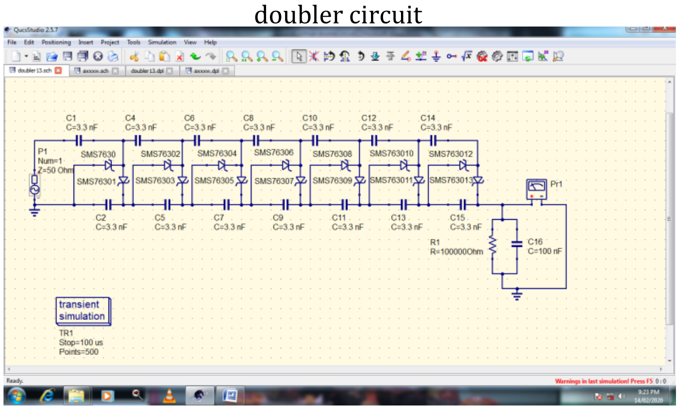

Fig -4: Schematic diagram of seven-stage voltage doubler circuit

3. RESULT AND SIMULATION

The Microstrip patch antenna and voltage doubler circuit are designed and simulated respectively with HFSS and Qucs Studio to check result of both circuit before fabrication.

3.1 Antenna

The antenna is designed for 900 MHz GSM frequency band. The reflection coefficient obtained is -15.83dB at 900MHz frequency by simulation. From reflection coefficient we predict that return loss is low at the designed frequency. Bandwidth measured is 1.11%. This fulfilled requirements of wireless communication standards. Fig. 6 shows return loss of the antenna.

Fig -5: Actual implementation of antenna

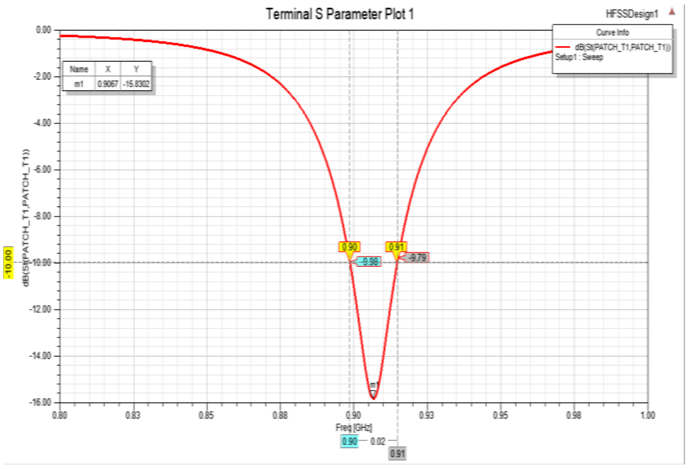

Fig -6: Return loss of the antenna

Fig. 5. Shows radiation pattern at Phi = 0^0. Phi can be vary from 0^0 to 180^0 and theta can vary from 0^0 to 360^0. The maximum gain is obtained at frequency of 900MHz. 0.9dB gain can be obtained is the direction of maximum radiation. The direction of radiation pattern is at 0^0.

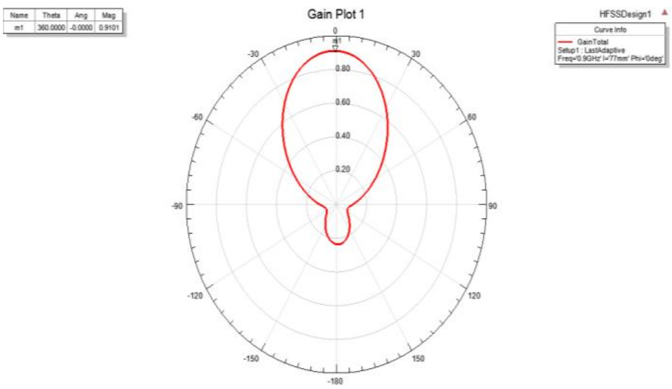

Fig -7: Radiation pattern at 0^0

Fig. 6 shows Radiation pattern at Phi = 90^0. It also obtained in the direction of 0^0. The radiation pattern at Phi = 90^0 is similar to Phi = 0^0. In this also maximum gain obtained is 0.9dB. The radiation pattern is directional. Is concentrated in only one direction.

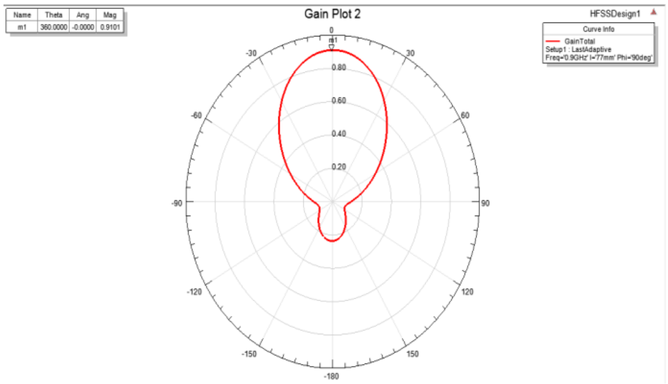

Fig -8: Radiation pattern at 90^0

Table -2: Antenna Parameters

Quantity	Value
Peak Directivity	4.0561
Peak Gain	0.75497
Peak Realized Gain	0.098596
Peak System Gain	0.098596
Radiated Power	1.2045mW
Accepted Power	6.4711mW
Incident Power	49.55mW
System Power	49.55mW
Radiation Efficiency	0.18613
Front to Back Ratio	4.5092
Decay Factor	0

3.2 Voltage doubler circuit

Qucs (Quick Universal Circuit Simulator) software was chosen for modeling and simulation which is a circuit simulation tool by GPL. The simulation and practical implementation were carried out with fixed RF at 900 MHz the simulations were also carried out using same stage capacitance value (3.3nF).

The simulated and measured results at the output voltage of voltage doubler circuit are shown graphically in Fig.7. In this work, the DC output voltages obtained through simulation and measurement at 0dBm are 2.12 V and 5.0 V respectively. These results are comparatively much better than in ref. [9], where in at 0dBm, 900 MHz they achieved 0.5 V and 0.8 V through simulation and measurement respectively.

Table -3: Voltages at different stages of voltage doubler circuit

Stages	1st	2nd	3rd	4th	5th	6th	7th
Voltage(v)	1.9	3.8	5.7	7.6	9.5	11.4	13.3

From the analysis of these two simulations, it can be observed that the resulting output voltages are equal.

The results from Fig.9, shows that the output voltage reaches to 2.0 V within 20µS and then uniformly increasing to 3.9 V, 6.8 V, 7.7 V, 9.5 V, 11.2 V and 13.1 V for 2, 3, 4, 5, 6 and 7 stages respectively compared to 2mS shows that the conversion ratio of 22 is achieved at 0dBm input power and drops to 2.5 at –40dBm. The highest value at 0dBm is due to the innate characteristics of the zero bias Schottky diodes which conduct fairly well at higher input voltages.

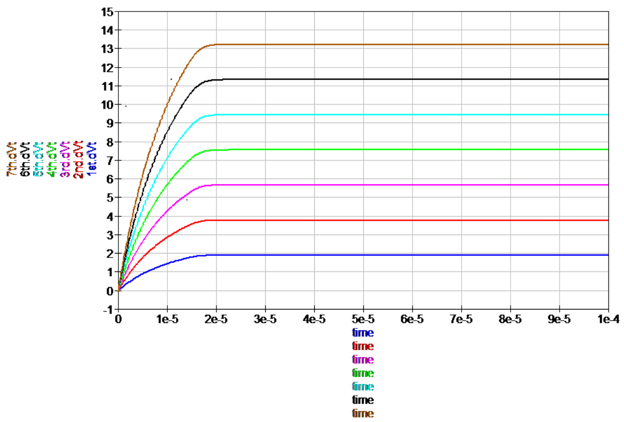

Fig -9: Output of seven stages voltage doubler circuit

4. CONCLUSIONS

In this paper, a RF energy harvesting system from RF source is presented. The antenna is designed for 900MHz band. The maximum gain obtained for this frequency is 0.9dB. A high gain Microstrip antenna is developed. A silicon mixture based Schottky diode single stage and 7 stage rectifiers are also designed. A voltage of 6.78V is measured at 4th stage of voltage doubler circuit. Due to the increase in the population density, many people live near to the cell tower. RF energy harvesting will help to minimize the effect caused due to radiation and provide an alternative source of energy.

REFERENCES

[1] M. Arrawatia, M. S. Baghini, and G. Kumar, "RF energy Harvesting system from cell towers in 900MHz band," in 2011 NationalConference on Communicstions (NCC). Harvesting system from cell towers in 900mhz band," in 2011 National Conference on Communications (NCC). IEEE, 2011, pp. 1-5.

[2] Q. Zhao, J. Xu, H. Yin, Z. Lu, L. Yue, Y. Gong, Y. Wei, and W. Wang, "Dualband antenna and high efficiency rectifier for rf energy harvesting system," in 2015 IEEE 6th International Symposium on Microwave, Antenna, Propagation, and EMC Technologies (MAPE). IEEE, 2015, pp. 682-685.

[3] D.-K. Ho, I. Kharrat, V.-D. Ngo, T.-P. Vuong, Q.-C. Nguyen, and M.-T. Le, "Dualband rectenna for ambient rf energy harvesting at gsm 900 mhz and 1800 mhz," in 2016 IEEE International Conference on Sustainable Energy Technologies (ICSET). IEEE, 2016, pp. 306–310.

[4] S. S. Sarma and M. J. Akhtar, "A dual band meandered printed dipole antenna for rf energy harvesting applications," in 2016 IEEE 5th Asia-Pacific Conference on Antennas and Propagation (APCAP). IEEE, 2016, pp. 93