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Optimized Process Design of RF Energy Harvesting Circuit for Low Power Devices

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Abstract

The technology of energy harvesting system is becoming practical in many real life applications. Several studies on design optimization of RF energy harvesting circuit to energies low power devices have been done. In this paper, a design of five stage voltage multiplier with π type matching circuit for RF energy harvesting system with GSM-900 band as input power is presented. The design and simulation was done by ADS simulator and the output was measured for 180KΩ load resistance. The design is focused for specific input power range -30dBm to 30dBm for 915 MHz frequency. The output voltage 9.6V at 0 dBm and maximum 33.9V at 20 dBm is achieved at five stages. It also showed the comparison among previous works on different voltage multiplier stages of RF energy harvesting systems. Finally, it concludes that π type matching circuit is performed better than other matching circuits and the proposed design can be used to power low power devices ultimately in the replacement of batteries.

Keywords: RF energy harvesting, Impedance matching circuit, Voltage multiplier, Low power devices

INTRODUCTION

RF energy is more available among of all other ambient energy like solar, water, wind, thermal etc. It is easy and continually available to scavenge RF power from surrounds like cellular base stations, Wi-Fi access points, television and radio broadcast stations. The power transmits from these sources are very high in KW range, but just a little amount of power is received by the antenna of the receiver. So the wasted energy can be harvested to produce electricity which will energies the low power devices. The typical block diagram of RF energy harvesting circuit is shown in Fig. 1 [1]. It consists of a receiving antenna, impedance matching circuit, rectifying circuit followed by energy storage. Moreover, losses due to matching circuits and the nonlinearity properties of diode reduce the circuit performance. Also the antenna distance, line of direction and the presents of obstacles between the antennas is also a big challenge to scavenge the RF power. So to reduce the losses of RF energy many approaches has been taken. Many research works are now going on including antenna design, matching circuits and optimization of several stages of rectifying circuit with different types of voltage doubler like Cockcroft-Walton and Dickson voltage multiplier etc. From the theory of transmission it is proved that if the RF power is received in high amount and the power conversion efficiency is high then the output voltage automatically became high.

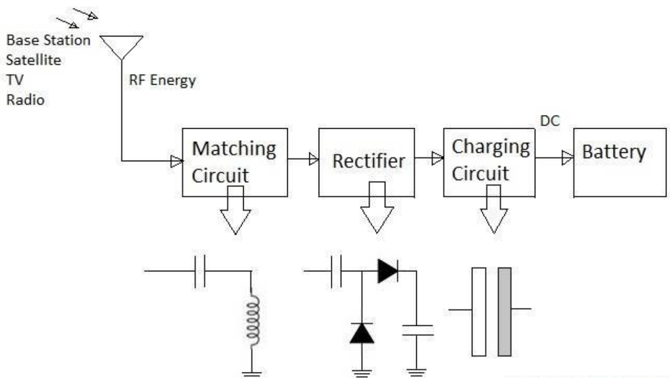


Figure 1: Typical block diagram of RF energy harvesting circuit

This paper focuses its design on impedance matching circuit and rectifying diodes that receives RF power from cellular tower in the range of frequency 900 band (Unlicensed ISM radio electric spectrum) as many wireless sensor node like mica2mote operated on this frequency range 868/916 MHz [2] and 915 MHz is the central frequency of this bandwidth. So the design and simulation is done for this frequency and the defined input range -30dBm to 30dBm. At first section of this paper, π type matching circuit is designed for a single stage voltage doubler and then observed the result on the basis of return loss and power conversion efficiency with respect to the variation of components values of LC resonant circuit. Then the circuit is designed for five stage voltage doubler with varying four types of HSMS-X series diode. Then comparatively better resultant circuit is proposed to design a RF energy harvesting circuit for low power devices.

LITERATURE REVIEW

There are many approaches have been employed to enhance the performance by scavenging the RF power from different frequency ranges with the multiple antenna design like [3]-[4] and [5]. But due to multi and wide band matching problem make this system more complex, massive and expensive. Another approaches is taken over this system is single band antennas with single band matching networks [6]-[7]. The system can operated on same or different frequency. Though, the increasing number of antennas and the rectifying diodes is not a final solution as it makes the circuit more complex and bulky. But there are also a lots of significance research has been done on diode's threshold voltage reduction method [8]-[9], passive booster [10], multistage voltage multiplier [3], DC to DC booster [11] and efficient low loss matching network have been proposed [12]. Recent RF energy harvesting research emphasized on matching circuit design like L type, π type and T type to achieve the maximum received power and optimization of voltage multiplier stages starting from 1 to 10 or 12. And in case of voltage doubler stages it was proved that higher voltage can be achieved by increasing number of stages and voltage gain decreases with increasing number of stages Fig. 2[13].

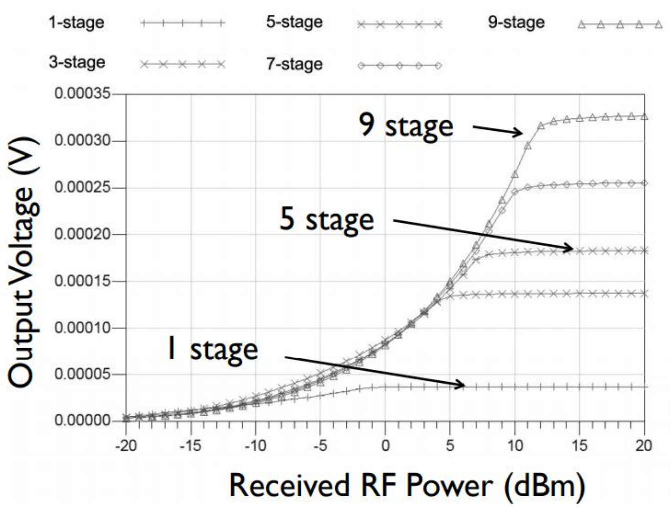


Figure 2: Effect of number of stages

The authors in [14] uses HSMS-2822 and HSMS-2850 schottky diode for 10-stage voltage multiplier. In that work, the DC output voltages obtained through simulated for 7 stage voltage multiplier 6.3V at 0 dBm and maximum 25.6 V and the voltage gain is comparatively better than in [13], where input frequency 900 MHz, at 0dBm, it achieved 5.0V through simulation and measurement.

RF ENERGY HARVESTING CIRCUIT: DESIGN AND METHODOLOGY

A. Single stage Voltage multiplier with π-matching circuit:

As the circuit achieves maximum power when the circuit impedance is matched with the antenna impedance and the impedance matching usually performed at the particular input power. Impedance matching network performs impedance transformation to assure maximum power delivery. In this paper, π type matching circuit is designed which operates on 915MHz and input impedance 50Ω and load resistance 180kΩ. As π type matching circuit attains wider bandwidth than L type matching circuit [15], so obtaining high output voltage with high voltage gain π type matching circuit is used for all of the design. The circuit design for π type for single stage voltage doubler is shown in Fig. 3.

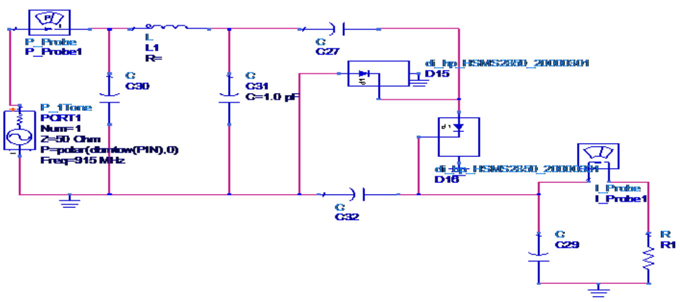
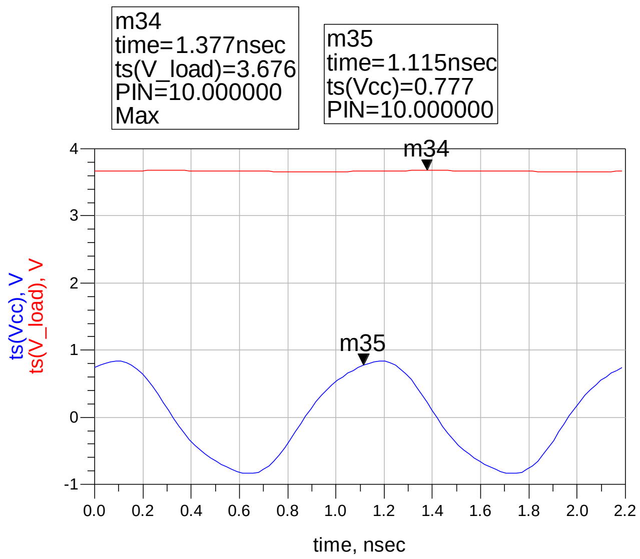
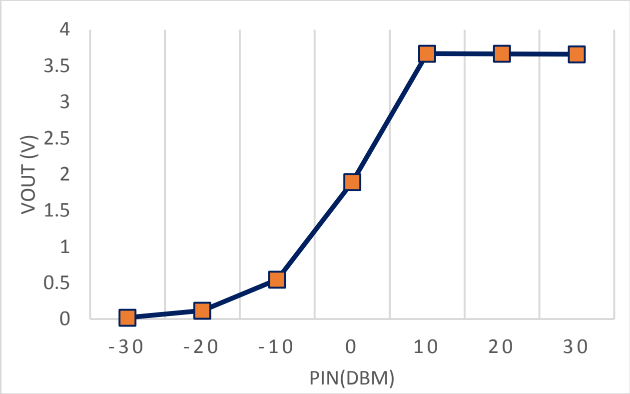


Figure 3: Single stage voltage doubler RF energy harvesting circuit with π type matching network



(a)



(b)

Figure 4: Output voltage for π type matching circuit for single stage (a) input-output voltage as function of time (b) Output voltage vs PIN(input power dBm)

In Fig. 4 simulated output shows that π type-matching circuit is performs better than previous works. For π type matching circuit the maximum output is found 3.68V at 20dBm.

Here the simulated graph Fig. 4(a) output voltage as a function of time in matching circuit. Which is higher than input voltage, achieved at the output (Agilent ADS). For this distinctive feature, increasing stages in the circuit can produce more voltage than the preceding stages. If another stage is connected on top of the single doubler circuit, the only waveform that the second stage receives is the noise of the previous stage. This noise is then doubled and added to the DC voltage of the first stage. Thus, adding more stages, theoretically, the more voltage will come from the system regardless of the input [16]. Each independent stage with its dedicated voltage multiplier circuit can be seen as a single battery with open circuit output voltage V_0, internal resistance R_0 with load resistance R_L, the output voltage V_{out}, is expressed as the following Eq. (1) using [16].

$$V_{out} = \frac{V_0}{R_0 + R_L} R_L \qquad \text{Eqn (1)}$$

When n number of these circuits are placed in series and connected to a load of R_L in Eq. (1) the output voltage V_{out} achieved is given by this variation in RC value will make the time constant longer which in turn retains the multiplication effect of two in this design of five stage voltage multiplier [16].

$$V_{out} = \frac{nv_0}{nR_0 + R_L} R_L = V_0 \frac{1}{\frac{R_0}{R_L} + \frac{1}{n}} \qquad \text{Eqn (2)}$$

The number of stages in the circuit has significant effect on the DC output voltage, as shown from Eq. (1) and (2). It can be said that the output voltage V_{out} is calculated by the summation of R_0 / R_L and 1/n, if V_0 is fixed. From this study it is observed that V_0, R_0 and R_L are all constants. If we assume V_0= 1 V, R_0 / R_L = 0.25, n = 2, 3, 4, 5, 6 and 7, the output voltage V_{out} = 1.33 V, 1.72 V, 2.0 V, 2.22 V, 2.43 V and 2.56V respectively when substituted methodically in the Eq. (2). With increasing the number of n, the output voltage will be almost double the input voltage up to several number of stages. But at some point the output voltage gained will be negligible with the increasing of stages [16]. Following this theorem, the design of RF harvesting circuit is confined to 5 stage voltage doubler and the simulation is performed with various diode of HSMS-X series to compare the output results among different schottky diodes.

B. RF Energy harvesting circuit using 5 stage voltage multiplier: Diode-HSMS-2822, HSMS-2850, HSMS-2852 and HSMS-2860

To design a 5 stage voltage multiplier, four types of schottky diode named HSMS-2850, HSMS-2822, HSMS-2852 & HSMS-2860 for RF energy harvesting circuit are selected. The components values are given in table 1. The circuit design in Fig. 5 (here the simulation design of HSMS_2850 diode is preferred, as all design are similar excepting the diode) uses a capacitor across the load to store and provide DC levelling of the output voltage and its value only affects the speed of the transient response. Without a capacitor, the output is not a good steady signal, but more of an offset AC signal. The capacitors are charged to the peak value of the input RF signal and discharge to the load resistance (R_L) of the diode. Therefore the output voltage through the capacitor of the first stage is almost double that of the input signal. As the signal shift from one stage to another, there is an additive resistance in the discharge path of the diode and increase of capacitance due to the stage capacitors [16]. Finally, the results will show that the output is multiplication of the input voltage.

Table 1: Component used in 5 stages voltage multiplier

Name of components	Level	Value
Stages capacitors	C_1-C_{10}	3.3nF
Stages diodes	D_1-D_{10}	HSMS-2822,HSMS-2850,HSMS-2852, HSMS-2860.
Filter capacitors	C_L	100pF
Load resistors	R_L	180kΩ
Frequency	P_1 Tone	915 MHz

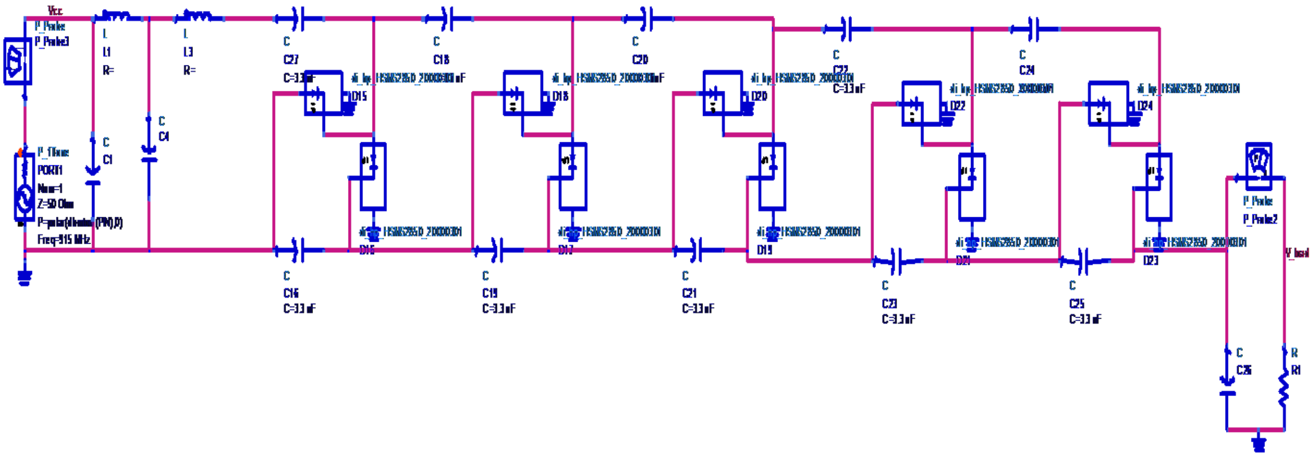
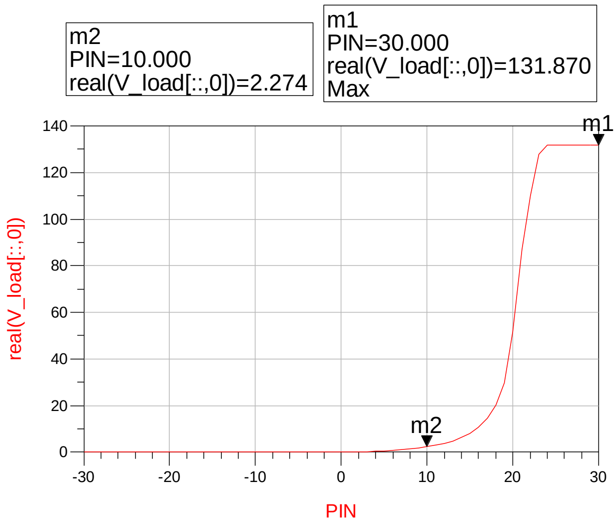


Figure 5: RF harvesting circuit design using 5 stage voltage multiplier with diode HSMS-2850 (Agilent ADS)



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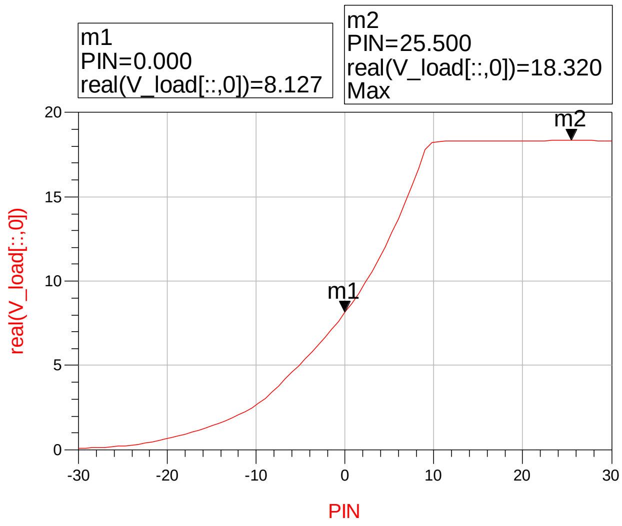

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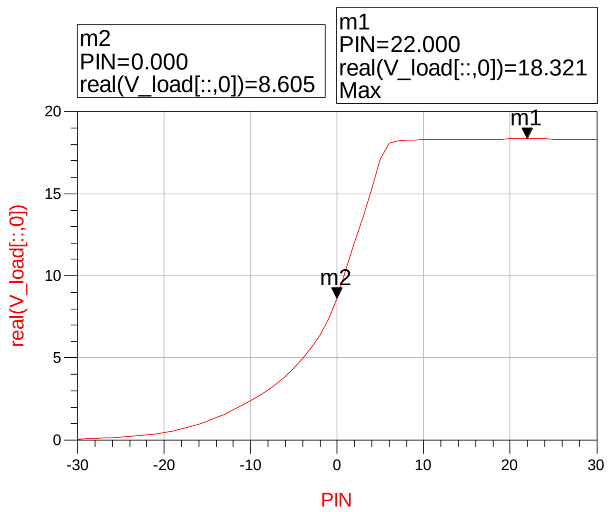

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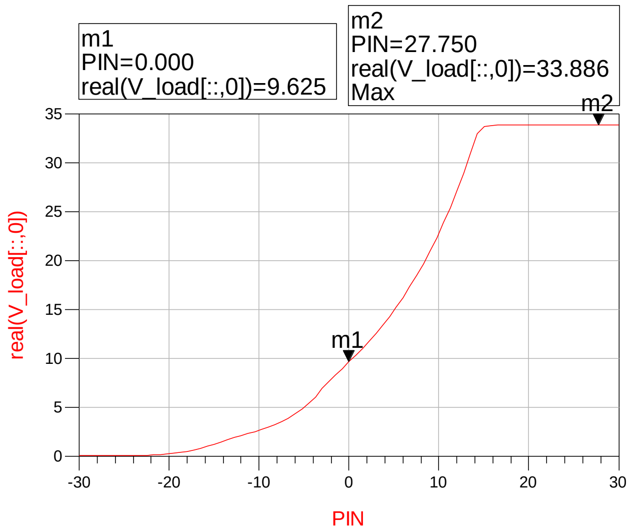

(d)

Figure 6: Output voltage of five stage RF harvesting circuit for different diodes(a) Diode-HSMS-2822 (b) HSMS-2850 (c) HSMS-2852 (d) HSMS-2860 (PIN = Input Power**)**

From above Fig. 6 (d) it is visible that the diode-HSMS-2860 gives the best output among other diodes. It exhibits the highest output 33.9 V with the maximum gain from -30dBm to 30dBm. For diode HSMS-2850 and HSMS-2852 exhibits approximately the same result and 5 stage RF energy harvesting circuit with HSMS-2822 was selected for high-power design (HPD) and after simulation, it was observed that it gave the maximum output 131.8V at 30dBm, but the gain was negligible. However, we conclude thus a 5 stage voltage multiplier circuit with HSMS-2860 diode, generates 9.6V at 0 dBm and the highest 33.9 V at 20dBm with maximum voltage gain.

RESULT AND DISCUSSION

The simulation results of RF energy harvesting circuit for 1,7,10 and 5 stage for HSMS-2850 and HSMS-2860 diode respectively (as HSMS-2860 performs better than others diodes in [Fig. 6]) and 5 stage for HSMS-2822, HSMS-2850, HSMS-2852 and HSMS-2860 are shown in Figs. 7 and 8 respectively. The simulation results of RF energy harvesting circuit for 1,7 and 10 stage can be found in [14]. From these results, the following graph of Fig.7 PIN (input power) of -30 dBm to 30 dBm versus output voltage can be drawn.

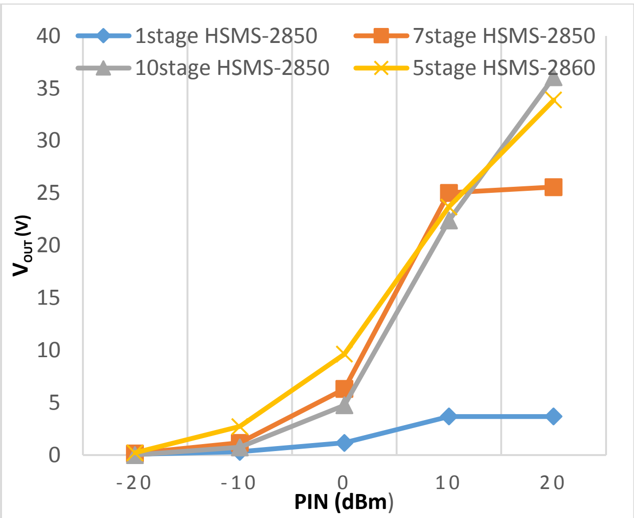

Figure 7: Output voltage of 1, 7, 10 and 5 stages RF harvesting circuit for diode HSMS-2850 and HSMS-2860 respectively

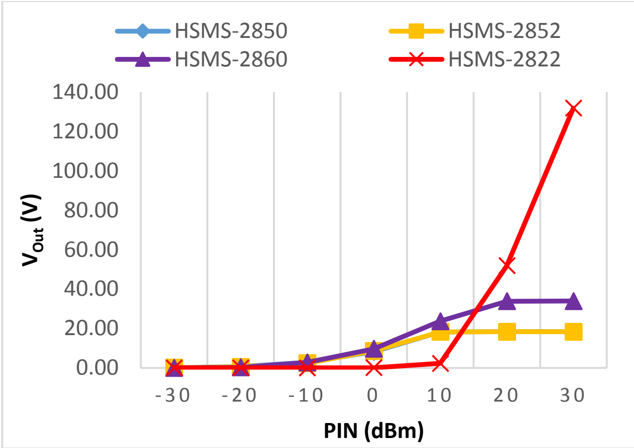

Figure 8: Output voltage of 5 stage RF harvesting circuit for diode HSMS-2822, HSMS-2850, HSMS-2852 and HSMS-2860

It is evident in the Figs. 7 and 8, the voltage increases when the number of stages increases with decreasing the voltage gain but in case of 5 stage voltage doubler with the diode HSMS-2860, the maximum voltage gain is achieved with output voltage 33.9V. In Fig. 8 the output voltage for HSMS-2822 diode is too high but voltage gain is very low. So it cannot be selected for low power design. As HSMS-2850 and HSMS-2852 diodes have been designed and optimized for use in small signal (Pin<-20dBm) applications [17]-[18], and the HSMS-286F family of biased detector diodes have been designed and optimized for use from 915MHz to 5.8GHz. They are also ideal for RF/ID and RF tag applications as well as large signal detection, modulation, RF to DC conversion or voltage doubling [19]. It is also proved in our simulation result that HSMS-2860 diode performs better than all other diodes. Finally, the decision can be made that 5 stage voltage doubler RF energy harvesting circuit with π type matching circuit and diode HSMS-2860 performs comparatively better than previous studies.

CONCLUSION

Energy-on-demand provided by RF energy harvesting has been actively studied as a sustainable solution to provide energy to low power devices but the minute amounts of energy that can be harvested from RF signals present an intimidating challenge. In this paper, the simulation was done for a 5 stage voltage multiplier with π type matching circuit and succeeded to achieve a large amount power with highest voltage gain, which can be used to energies low power devices instead of electric battery.

REFERENCES

[1] RF Wireless World: RF energy harvesting system basics-Radio Frequency harvesting, Retrieved from http://www.rfwireless-world.com/Articles/RF-energy-harvesting-system-basics.html

[2] Crossbow Technology Inc: Mica2 Datasheet, Retrieved from https://www.eol.ucar.edu/isf/facilities/isa/internal/CrossBow/DataSheets/mica2.pdf

[3] Hucheng Sun, Yong-Xin Guo, Miao He and Zheng Zhong,"A Dual-Band Rectenna Using Broadband Yagi Antenna Array for Ambient RF Power Harvesting", Antennas and Wireless Propagation Letters, IEEE, vol.12, no., pp.918-921,doi: 10.1109/LAWP.2013.2272873,2013

[4] D. Masotti, A. Costanzo, M. Del Prete, V. Rizzoli, "Genetic-based design of a tetra-band high-efficiency radio-frequency energy harvesting system", Microwaves, Antennas & Propagation, IET, vol.7, no.15, pp.1254-1263, 2013

[5] Hagerty, J.A., Helmbrecht, F.B., McCalpin, W.H., Zane, R., Popovic, Z.B., et al. "Recycling ambient microwave energy with broadband rectenna arrays", IEEE Trans. Microw. Theory Tech., MTT-52, (3), pp. 1014-1024, 2004

[6] P. Nintanavongsa, U. Muncuk, D. R. Lewis, and K. R. Chowdhury, " Design Optimization and Implementation for RF Energy Harvesting Circuits", IEEE Journal on Emerging and Selected Topics in Circuits and Systems, vol. 2, no. 1, pp. 24-33, 2012

[7] U. Olgun, C. C. Chen, J. L. Volakis, "Design of an efficient ambient WiFi energy harvesting system", Microwaves, Antennas & Propagation, IET, vol.6, no.11, pp.1200-1206, 2012

[8] T. Umeda, H. Yoshida, S. Sekine, Y. Fujita, T. Suzuki, and S. Otaka , "A 950 MHz rectifier circuit for sensor network tags with 10-m distance", IEEE J. Solid-State Circuits, vol. 41, no. 1, 2006

[9] T. Le, K. Mayaram, and T. Fiez, "Efficient far-field radio frequency energy harvesting for passively powered sensor networks", IEEE J. Solid-State Circuits, vol. 43, no. 5, pp. 2287-1302, 2008

[10] H. Kanaya, S. Tsukamaoto, T. Hirabaru, D. Kanemoto, R.K. Pokharel, K.Yoshida, "Energy Harvesting Circuit on a One-Sided Directional Flexible Antenna", Microwave and Wireless Components Letters, IEEE , vol.23, no.3,pp.164-166, doi : 10.1109/LMWC.2013.2246779, 2013

[11] Gaurav Singh, Rahul Ponnaganti, T.V. Prabhakar, K.J. Vinoy, "A tuned rectifier for RF energy harvesting from ambient radiations", AEU –International Journal of Electronics and Communications, vol.67, no.7, pp. 564-569, 2013

[12] Sachin Agrawal, Manoj S. Parihar, Parvin N. Kondekar , " Exact Performance Evaluation of RF Energy Harvesting with Different Circuit's Elements", IETE Technical review, pp.1-9, 2017

[13] Kaushik R. Chowdhury, "Energy harvesting wireless sensor networks: from device design to deployment", UPC –Barcelona, October 2011

[14] Nahida Akter, Bellal Hossain, Humayun Kabir, Amran Hossen Bhuiyan, et al., "Design and Performance Analysis of 10-Stage Voltage Doublers RF Energy Harvesting Circuit for Wireless Sensor Network", Journal of Communications Engineering and Networks' Bowen Publications, Vol. 2, no. 2, PP. 84-91, 2014

[15] Sachin Agrawal, Sunil Kumar Pandey, Jawar Singh, Manoj S. Parihar, " Realization of Efficient RF Energy Harvesting Circuits Employing Different Matching Technique", In: 15th Int'l Symposium on Quality Electronic Design, IEEE, Santa Clara, CA, USA, pp 754-761, 2014

[16] Kavuri Kasi, Annapurna Devi, Norashidah Din and Chandan Kumar Chakrabarty, "Optimization of the voltage doubler stages in RF-DC convertor module for energy harvesting" , Circuits and Systems, Scientific journal. vol.3, no.3, pp.216-222, 2012

[17] Avago Technologies: HSMS-2850, Retrieved from https://www.broadcom.com/products/wireless/diodes/schottky/hsms-2850

[18] Avago Technologies: HSMS-2852, Retrieved from https://www.broadcom.com/products/wireless/diodes/schottky/hsms-2852

[19] Avago Technologies: HSMS-2860, Retrieved from https://www.broadcom.com/products/wireless/diodes/schottky/hsms-2860