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Design of RF Energy Harvesting Circuit for Low Power Devices

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Abstract- Radio frequency (RF) energy transfer and harvesting techniques have recently become alternative methods to power the next generation wireless networks. The RF energy harvesting system was designed to convert the RF energy available in the atmosphere into useful electrical energy which can be used to charge a battery of capacity 50 uAh. This battery requires a voltage in the range of 4- 4.2V to get itself charged. In this paper we have designed and simulated a Radio Frequency (RF) energy harvesting circuit which utilized available RF energy with the voltage boosting circuit. Simulation results represents that by using matching network of high-Q, output voltage of harvesting circuit increases and it becomes more sensitive with respect to input signal frequency and value of elements used.

Keywords- *Radio frequency energy harvesting, matching network, RF to DC power conversion.*

1. INTRODUCTION

It seems these days that everyone has a cellular phone. Whether yours is for business purposes or personal use, you need an efficient way of charging the battery in the phone. But, like most people, you probably don't like being tethered to the wall. Imagine a system where your cellular phone battery is always charged. No more worrying about forgetting to charge the battery. Sound Impossible?

It is the focus of this paper to discuss the first step toward realizing this goal. A system will be presented to charge a cellular phone battery without wires. Energy harvesting is a process of utilizing the energy available in the atmosphere into usable electrical energy. There are various forms of energy available in the atmosphere like solar energy, RF energy, wind energy, piezoelectric energy, light energy and heat energy. This technology has been around for many years in the form of developing wind turbines, hydro-electric generators and solar panels. This technology has its importance because of mainly two reasons. This energy is inexhaustible and this is the main advantage behind energy harvesting from the atmosphere and the other advantage being this process never does any harm to the atmosphere. The cost for maintenance of such a system is also very low. Energy harvesting from pressure variations and RF energy come under the ultra-low power solutions.

Since huge amount of ambient RF energy is available, spread over several frequency bands according to their application areas. Hence it is possible to receive them in combined form and converted into equivalent electrical energy by employing appropriate circuit. The development on RF energy harvesting techniques provides reasonable solution of overcoming these problems. For charging of battery it is required that received RF signal is converted in to DC power through rectification. The process of rectification of microwave signals to DC power has been proposed and researched in the case of high power signal. It has been proposed for helicopter powering [3], solar power satellite [2], the SHARP System [5]. The DC power depends on the available RF power, the choice of antenna and frequency band. Maximum theoretical power available for RF energy harvesting is 7.0 μW for 2.4 GHz and 1.0 μW for 900 MHz band, for a free space distance of 40 m [4]. A great motivation behind the energy harvesting research and development is ultra-low-power applications.

2. CIRCUIT DESIGN

This research project is primarily empirical. There are many variables in the system that can change the voltage that is developed. The stage capacitors need to be optimized. The number of stages needs to be determined that, combined with the capacitor values for each stage, will result in a sufficiently high voltage level to turn on the phone and charge the phone's battery. Also, a capacitor can be used across the output as a filter to provide a flat DC signal and store charge. The value of that capacitance also needs to be determined. There really are no fixed parameters for any of these values. The only specified value for any element in this research is the frequency that is being transmitted to the station. The number of stages in the system has the greatest effect on the output voltage. The capacitance, both in the stages and at the end of the circuit, affects the speed of the transient response and the stability of the output signal. The

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number of stages is essentially directly proportional to the amount of voltage obtained at the output of the system. Generally, the voltage of the output increases as the number of stages increases. ADS software was used for the designing of circuit and simulation purpose.

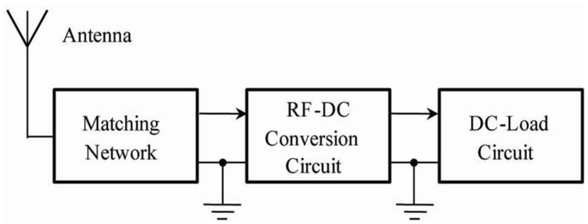

Fig. 1: Proposed design structure presented in [1]

A. Antenna

Antenna receives RF energy of different frequency band from ambient [6], [7], [8], [9] and converts it in to equivalent electrical signal through electromagnetic induction. It may be single band [10], [5], dual bands [11] and triple bands [12] – [14]. A broadband antenna [15] receives RF power over wide frequency band with maximum 20% efficiency.

B. Matching Network

To deliver maximum received power from antenna to rectifier stage, it is necessary that antenna impedance must be matched to input impedance of diode used in rectifier stage, called impedance matching. It reduces transmission loss. For this purpose matching network [16],[17] is connected between antenna and rectifier stage which consist of inductive and capacitive element or LC network in 'L', 'T' or 'π' shape, according to which these are called 'L', 'T' or 'π' matching network.

C. RF to DC converter or Rectifier

To charge the battery of wireless devices or sensors, RF electrical signal supplied from matching network have to convert in DC power through rectifier circuit. Since signal strength depends upon distance between transmitter and receiver, power of RF sources, size / gain of receiving antenna and transmission frequency as given by Friis transmission equation [17], this arises a problem of low conversion efficiency, gives low output DC voltage. Hence to boost up the DC voltage we may use voltage multiplier circuit [18]. The Schottky barrier diode [19] is most commonly used device for this purpose due to lower built in voltage capable of providing high conversion efficiency at lower input power level.

D. Energy storage

To ensure smooth power delivery from RF to DC power converter stage to the load, the energy storage device is connected at output, which works as a reserve for durations when external energy is unavailable or insufficient.

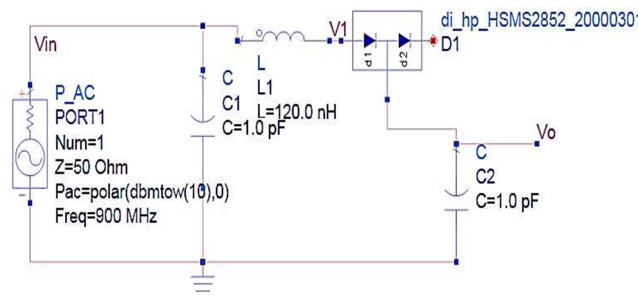

Fig. 2: Designed circuit on ADS software with indicated parameters

3. EFFECT OF MATCHING NETWORK

The output DC voltage and conversion efficiency of RF energy harvester badly affected due to diode's nonlinear behavior and value of matching network's element. Hence efficient design of matching network is essential to get optimum performance. The impedance of rectifier circuit varies with input signal frequency and load impedance due to nonlinear characteristics of rectifier diode, which limits the circuit efficiency. The matching network may effectively solve this problem can be realized either by using lumped element like resistor, inductor and capacitor or by using distributed elements such as microstrip lines. For L matching network consisting of series inductor and shunt capacitor, the element value may be determined by using design equations [1]:

$$B_L = \pm\sqrt{R_L(Z_o - R_L)} - X_L \qquad (1)$$

$$B_C = \pm\frac{\sqrt{(Z_o - R_L)}/R_L}{Z_o} \qquad (2)$$

Where RL and XL represents real and imaginary part of the load impedance ZL. Z0 is the antenna impedance which is 50 Ω. The rectifier circuit consist of diode HSMS-2852 with impedance value ZL = (46.25 – J 563.08) Ω at 0.9 GHz. In order to match the antenna impedance with diode, the value of series inductor and shunt capacitor are 120 nH and 1 pF respectively calculated from eqn. 1 and 2 and implemented in the designed circuit shown in figure 2. This designed circuit yields some good results which is close to the desired output of 4 to 4.5 volts to charge the battery of any available mobile handset whether it's any smartphone or any ordinary available handset.

4. RESULTS

Simulated results of the design in figure 2 are shown in figure 3 and 4, where fig 3 represents its graphical results and figure 4 represent the tabular form of graphical representation so it can specifically separate the output voltage at different input frequencies. As our available RF frequency is 895 MHz to 915 MHz so we can check whether the results are compatible or not with our desired results.

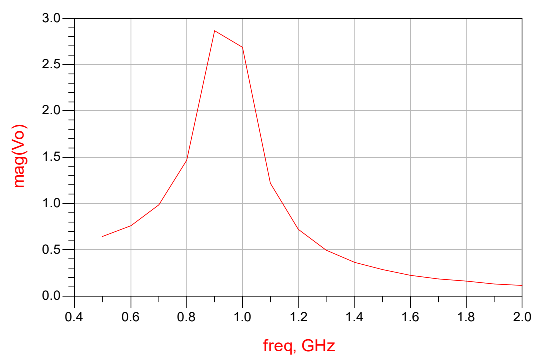

Fig. 3: Simulated result in graphical form which shows the maximum output of 2.8 Volts at the frequency of 900MHz.

freq	mag(Vo)
500.0 MHz	0.643
600.0 MHz	0.763
700.0 MHz	0.983
800.0 MHz	1.465
900.0 MHz	2.861
1.000 GHz	2.690
1.100 GHz	1.216
1.200 GHz	0.720
1.300 GHz	0.492
1.400 GHz	0.364
1.500 GHz	0.283
1.600 GHz	0.228
1.700 GHz	0.188
1.800 GHz	0.157
1.900 GHz	0.134
2.000 GHz	0.116

Fig. 4: Simulated result in tabular form which shows the maximum output of 2.861 Volts at the frequency of 900MHz.

5. CONCLUSION

In this paper the effect of diode's nonlinear characteristics and value of matching network elements on output voltage is presented. It has been observed that RF energy harvesting circuit achieves higher output voltage with High-Q matching network. It provides maximum power transfer from receiving antenna to rectifier circuit so that conversion efficiency of the circuit may increase, because this circuit has to work with very low input RF power level.

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