A Highly Efficient Power Management System for Charging Mobile Phones using RF Energy Harvesting

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Abstract

RF energy harvesting holds a promise able future for generating a small amount of electrical power to drive partial circuits in wirelessly communicating electronics devices. RF power harvesting is one of the diverse fields where still research continues. The energy of RF waves used by devices can be harvested and used to operate in more effective and efficient way. This paper highlights the performance of energy harvesting in an efficient way by using a simple voltage doubler. With slight modifications we attained high output voltage from harvested RF energy. The modified form of existing schottky diode based voltage doubler circuit is presented to achieve high output power for an average input RF power of 20 dBm. The performance of the circuit is studied with simulation results in ADS tools. Also in this paper we are proposing an application where this circuit that can receive the transmitted RF signals from the Bluetooth of any other device and extract power efficiently from the received signal.

Keywords:

RF power scavengers, voltage doubler, Impedance matching, resonant circuits, Class 1 Bluetooth.

1. INTRODUCTION TO RF ENERGY HARVESTING

Finite electrical battery life is encouraging the companies and researchers to come up with new ideas and technologies to drive wireless mobile devices for an infinite or enhance period of time. Common resource constrained wireless devices when they run out of battery they should be recharged. For that purpose we need main supply & charger to charge drained mobile phone batteries or any portable devices. Practically it is not possible to carry charger wherever we go and also to expect availability of power supply everywhere. To avoid such disadvantages some sort of solution should be given and that can be wireless charging of mobile phones. If the mobile can receive RF power signals from the mobile towers, why can't we extract the power from the received signals? This can be done by the method or technology called RF energy harvesting.

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2. Energy harvesting

Capturing the available energy from the external ambient sources is a technology known as *Energy Harvesting* .Other names for this technology are – Power harvesting, energy scavenging and Free energy derived from Renewable Energy. Energy harvesters take the necessary fuel from the ambient external sources and obviously available freely for the user, cutting down the cost factor of charging batteries. The external ambient energy sources which are most considered and used for energy harvesting are Wind, Solar, Vibration, Thermoelectric, Temperature Gradient, Radio Frequency (RF), Acoustic etc. Notable advancements in the low power consuming wireless electronic devices are also a driving factor for thirst in such RF power scavenging technologies.

3. ENERGY HARVESTING THROUGH RF

Radio waves are present everywhere since it is used for signal transmissions of TV, Radio, Mobile phones etc. Omni directional antennas are the major components used in communication systems to broadcast RF power in KW range. In practice for mobile communication, very few milli-watts of RF power can be scavenged from the atmosphere as the receiver sensitivity of the mobile phone antennas is very high. The major factor for such a tremendous reduction in the transmitted power is absorption by the objects (i.e. obstacles) present in the path of the RF waves and also loss of power in the form of heat in materials where it gets absorbed. Most of the wireless devices like mobile phones consume only microwatts to milliwatts range of power for their operation in sleep & active modes respectively. So we can readily tap the RF power available in the external environment using scavenging circuit and use it to operate our mobile phones. Now, we can see our proposed circuit for achieving such functionality. The figure [1] shown represents the block diagram of various ingredients to design our proposed circuit.

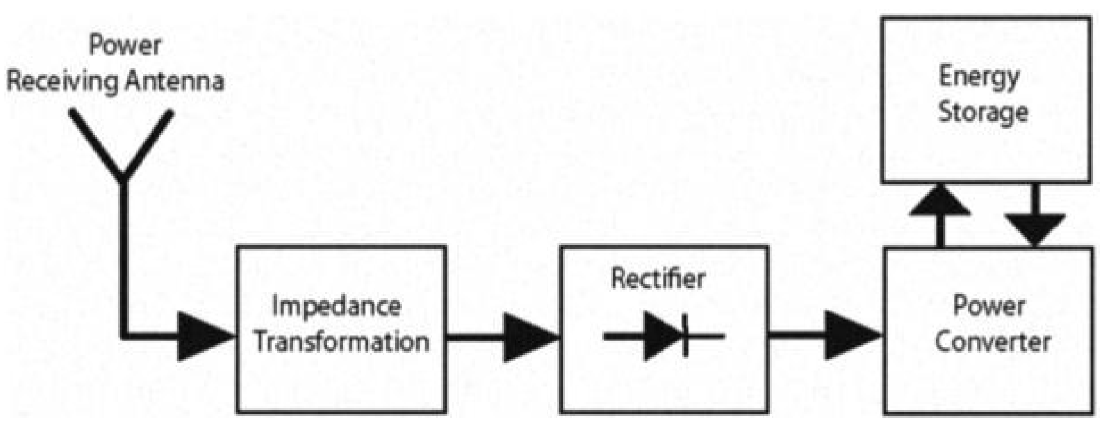

Figure 1: Block diagram

4. SYSTEM OVERVIEW

The received RF power by an antenna is streamed through a rectifier circuit and then through a power converter circuit which increases the rectified voltage i.e. doubles /triples/quadruples. Finally the converted output DC power can be used for driving the device or it can also be used to recharge batteries. The significance of the Impedance Matching circuit is to match the impedance of antenna with that of rectifier circuit. This achieves higher efficiency in attaining the output power. The input power received by the antenna is transferred to the rectifier circuit only at the resonant frequency. By using impedance transformation circuit, operation of the circuit is restricted to a specific frequency range of 0.9GHz – 1.8GHz which is the operating band for mobile communication.

5. OUR PROPOSED DESIGN

Figure [2] shown is our proposed circuit. In our design, in the front end of our circuit, we use ideal power source offering impedance of 50Ω to deliver power ranging from -5dBm to 40dBm. This power range is chosen because the RF signals are transmitted from the mobile towers at a power range of -5dBm to 40dBm. Following the source, we include a resonant circuit to resonate in the frequency range of 0.9GHz to 1.8GHz. This is the frequency range at which the mobile service providers in India are allowed to communicate and hence this frequency range is chosen.

$$f = \frac{1}{2\pi\sqrt{LC}}$$

We attained the resonant circuit by adding inductor to the circuit. In order to achieve a wide band, the quality factor of inductor is reduced by adding resistance to the inductor. This helps us to boost the output power for a range of frequencies. The frequency range can be changed by tuning the impedance matching circuit which also acts a resonant circuit.

Following, we have voltage doubler circuit in our design. During the positive half cycle, diode D1 gets forward biased and charges the capacitor C1. During negative half cycle, diode D2 gets forward biased and charges the capacitor C2. The output is taken across the load resistance RL. This circuit was designed implemented and simulated in ADS tool. The performances of our proposed circuit are described in the following section.

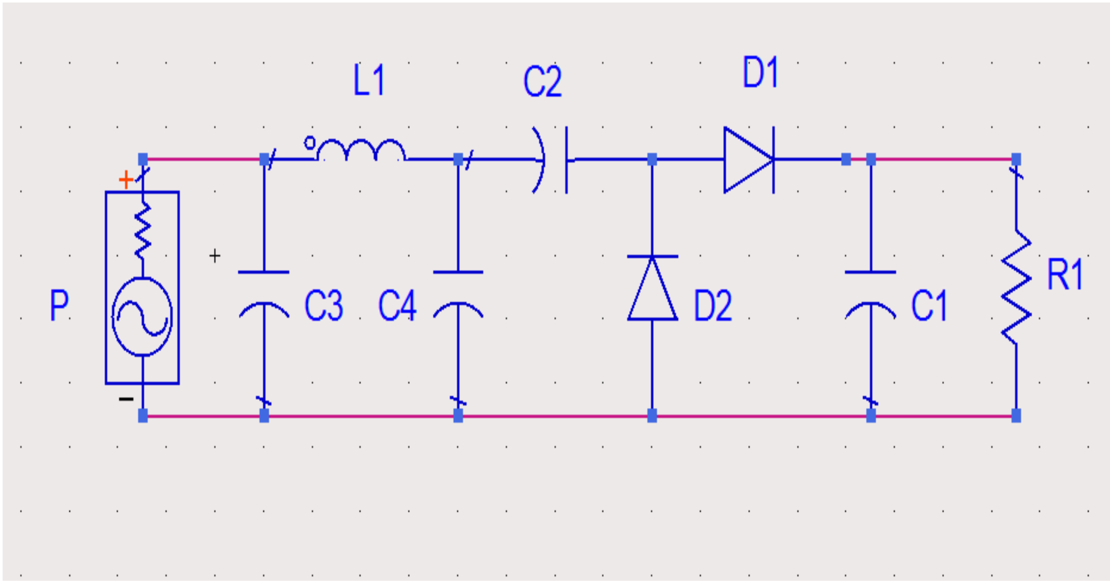

Figure 2: Circuit for RF energy harvesting

6. MATHEMATICAL MODEL

Our proposed circuit is mathematically modeled and the expressions are as follows-

Let X_{L1}, X_{C1}, X_{C2}, X_{C3}, X_{C4}, D_1 & D_2 are the resistance and reactance values of the respective Inductor, Capacitors & Diodes.

If Z_1 is the output impedance of the matching network and Z_2 is the input impedance to the voltage multiplier stage, then

$$Z_1 = (X_{L1} || X_{C3}) + X_{c4}$$

$$Z_2 = X_{c2} + [((X_{c4} || R_1) + D_1) || D_2]$$

Taking $X_{C1} = X_{C2} = X_{C3} = X_{C4} = X_c$ and $D_1 = D_2 =$ D , the final expression of Z_1& Z_1 are as follows-

$$Z_1 = \{1 + [\omega^2 LC/(\omega^2 LC - 1)]\} / j\omega C$$

$$Z_2 = \left\{ [2R_1^2D^3] + [D(R_1 + D)(R_1 + 2D)/\omega^2Xc^2] \Big/ [4R_1^2D^2] + [((R_1 + 2D)/\omega Xc)^2] \right\} + j\left\{ [(R_1 + 2D)(\omega^2Xc^2R_1D^2 - R_1 - 2D)/\omega^3Xc^3] - [2R_1D(R_1D - D^2)/\omega Xc] \Big/ [4R_1^2D^2] + [((R_1 + 2D)/\omega Xc)^2] \right\}$$

$\omega = 2\pi f$. Where f is the frequency of the input RF power signal.

On substituting the values for the above expressions, we find them to be equal, thus satisfying the property of the matching network in the circuit.

7. SIMULATION RESULTS

Usually mobile phones receives a power ranging from -5dBm to 40dBm. If the device is close to the transmitter, maximum power can be received. Assuming the device can receive an average power of about 20dBm, performance of the circuit is measured. Figure [3] and figure [4] are graphs plotted for the input signal of 20dBm.

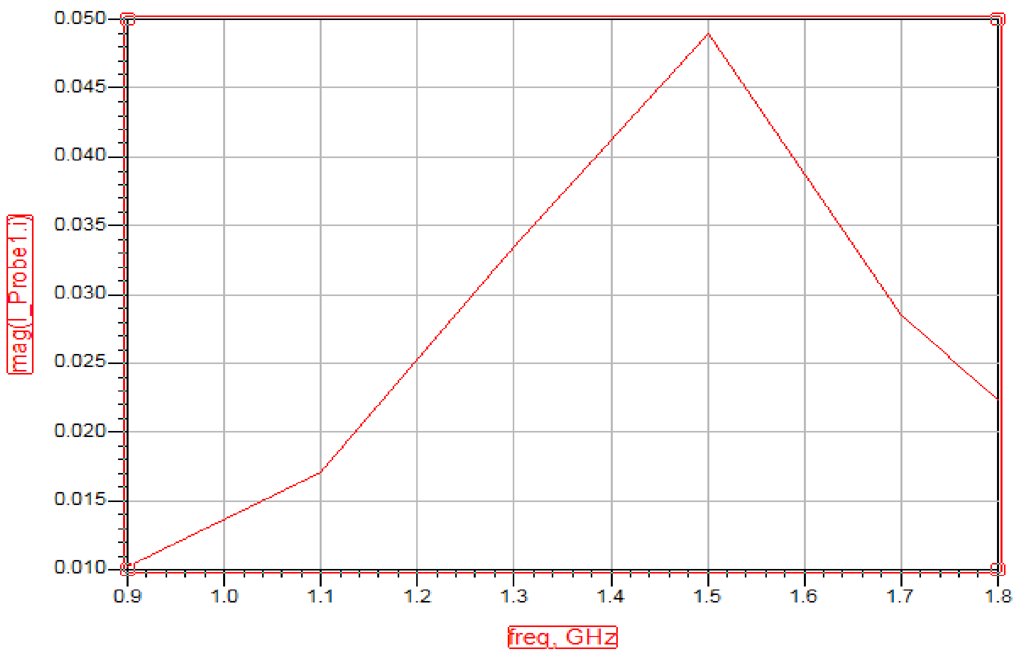

Figure 3: Graph plotted Current I Vs Frequency

If the graphs are plotted with 40dbm as input, then the output will be more, which is more than sufficient for the mobile phone to operate.

From Figure [3] and [4] it is obvious that we may get a more efficient and rectified output voltage as well as current for the mobile to work at active state or while talking over phone for the desired operating frequency range of 0.9GHz to 1.9GHz.

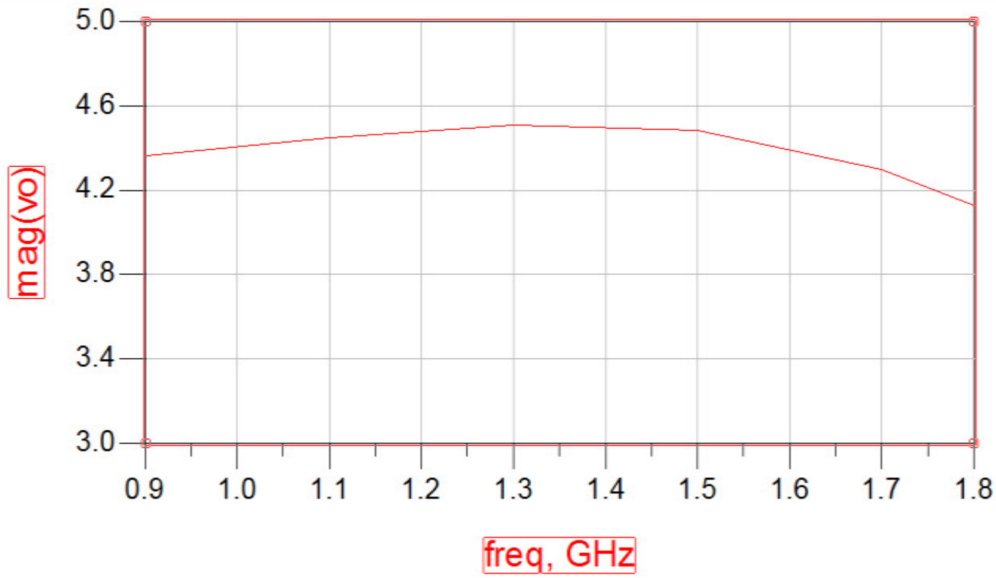

Figure 4: Graph plotted Output voltage Vo Vs Frequency

8. Charging mobile phones via Bluetooth

Bluetooth is a standard for short range, low power, and low cost wireless communication that uses radio technology. Over 2100 companies around the world already support Bluetooth technology. Bluetooth technology is a wireless communications system intended to replace the cables connecting many different types of devices, from mobile phones and headsets to heart monitors and medical equipment. Bluetooth is a low power device that is used in almost all portable devices like mobile phones, I-pods, mp3 player, etc.

Class	Maximum Power	Range
Class 1	100mW (20dBm)	~100 meters
Class 2	2.5mW (4dBm)	~10 meters
Class 3	1mW (0dBm)	~1 meter

Figure 5: Bluetooth power class

Figure [5] represents the three classes in Bluetooth based on the maximum power it can transmit. Class 1 & Class 2 types of the Bluetooth power classes are commonly employed and class three is uncommon because of its low power transmission and its low range of 1m. Bluetooth acts as both a transmitter as well as a receiver.

Bluetooth can transmit Radio Frequency (RF) signals of varying power and range. Commonly used are Class 1 & Class 2 and we considering Class 1 Bluetooth device for wireless power transmission i.e. Wirelessly charging the mobile phones. The basic idea behind this process is absorbing the transmitted RF signals using a receiver which is another Bluetooth device and from the received RF signal, maximum energy is extracted using the circuit that is shown in figure [2]. By using impedance transformation circuit, operation of the circuit is restricted to a specific frequency range around 2.4GHz which is the operating frequency range for Bluetooth.

9. PERFORMANCE

Class 1 Bluetooth device used in mobile phones can transmit a power ranging about 20dBm for a range of 100m. And if the receiver is near to the transmitter for less than 10m distance then maximum power can be received. When the mobile is paired with the other via Bluetooth, it receives an average power of about 20dBm. Figure [6] and figure [7] are graphs plotted for the input signal of 20dbm which is received by the Bluetooth device when the mobile is paired with the transmitter.

From the graphs shown, it is obvious that we may get a more efficient and rectified output voltage as well as current for the mobile battery to get charged when it is paired with the transmitter via Bluetooth for the desired frequency range around 2.4GHz.

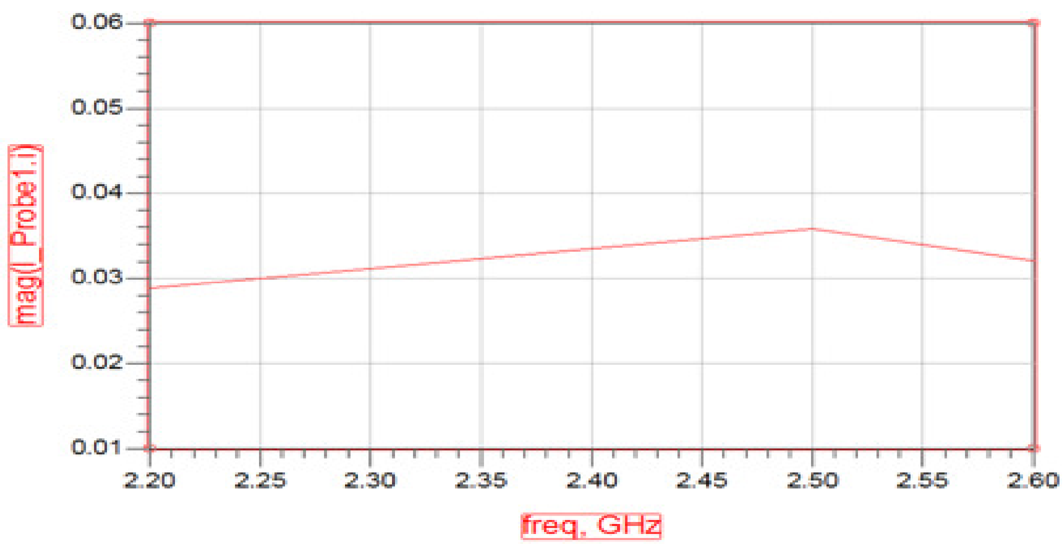

Figure 6: Graph plotted Current I Vs Frequency

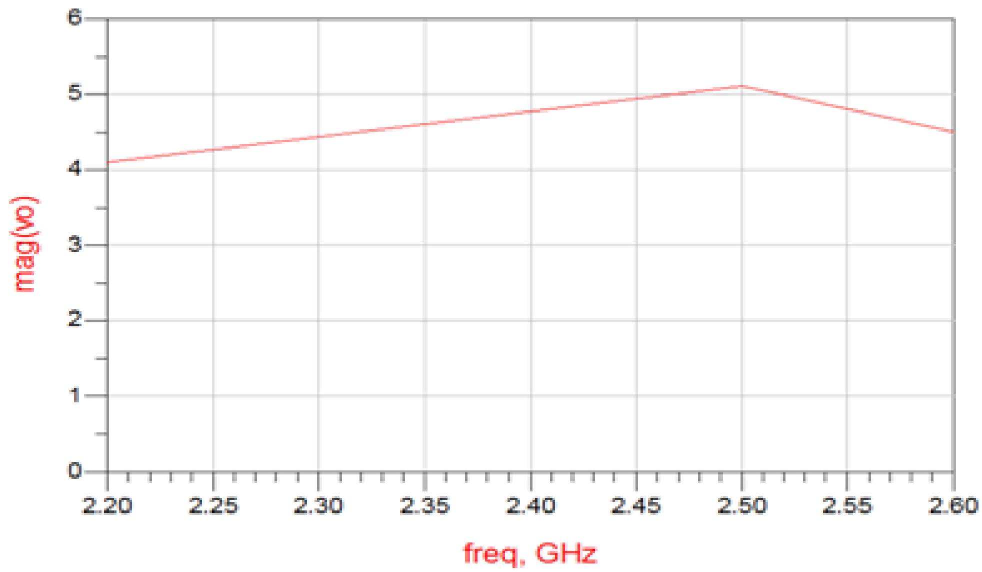

Figure 7: Graph plotted Output voltage Vo Vs Frequency

10. ADVANTAGES

Schottky diode offer low forward voltage and high switching speed, and consider as an ideal component for RF energy harvesting. All schottky diodes used in our circuit are of low series resistance which are the best diodes used for operations in RF region. And the switching property of the schottky diodes is superior. The capacitors used are of values that are easily available. The inductor used in the circuit has low inductance value which is smaller in size also easily available. Almost all portable devices have Bluetooth which have become essential nowadays and hence this system can be easily implemented. This proposed circuit can be readily and easily manufactured without the need to order for fabrication thereby proving to be a cost effective one.

11. CONCLUSION

Our proposed circuit for harvesting energy from the received RF signal generates a minimum rectified output voltage and current. This output can still be increased by reducing the capacitance values to the range of very low values and increasing the voltage multiplier stages. However this proposed circuit can conveniently capture the RF energy from the transmitted by the mobile phone towers or even the Bluetooth device of some paired portable device and convert it to a useful power which can be used to run the mobile phones or to charge the drained batteries of the mobile phones. Because of the minimum size of the above circuit, it can easily be implemented inside the mobile phones without any space constraints. As on whole this system can conveniently charge a drained battery of the mobile phones without the need for main supply or charger and the application of this circuit i.e. charging the mobile phones using Bluetooth can help charging the devices during a situation of emergency.

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