Design and Implementation of a Micro Scale Radio Frequency Energy Harvester

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Abstract—This paper discusses the design and implementation of a Radio Frequency (RF) energy harvester from ambient sources. Frequency of 1800 MHz was found to be suitable for harvesting as it contains the highest energy levels. A system design consisting of antenna, matching circuit and voltage multiplier is presented. An array antenna with 8 arrays is simulated for the targeted frequency. The voltage multiplier is simulated and it is concluded that 3 stages of multipliers is the optimum value for a 100 load with a voltage of 748 mV. A circuit was constructed with 3 voltage multiplier stages outputting a total ambient power of 3.60 ± 2.4 nW, and 24.01 ± 1.96 µW when fed with external RF source. The power levels, when fed, were enough to power a LED and a small digital clock.

Keywords—Radio frequency, harvester, energy, micro-power, antenna

1. Introduction
The environment contains many different forms of ambient energy including mechanical and electromagnetic. These can be harvested and utilized for conversion into electrical power for applications in devices which use them. [1] Benefits of such ambient energy harvesting comes with replacing the need for batteries which can be both economical and reduce waste created by disposing batteries. This project targets ambient energy in form of electromagnetic waves in the Radio Frequency range which is defined as frequencies in range of 3kHz to 300 GHz[2].

The benefits of targeting RF ambient energy are due to its advantages over other types of ambient energy sources such as solar cells and wind turbines. These include the fact that RF waves exist in virtually all populated areas, that they are present at all times of the day and year, and that they can be made in smaller sizes as the only required part are an antenna of a few cm long and a circuit. The major drawback however is that the energy acquired is very small and can only be used for low-powered applications [1].

2. Theory
Array antennas are used for capturing RF energy due to their benefit of being directional and beam-forming. The Array Factor for the array antenna is given by

$$AF = \frac{\sin(N\beta d \cdot \cos\phi + N\alpha / 2)}{\sin(\beta d \cdot \cos\phi + \alpha / 2)}$$

N is the number of arrays, β is 2pi/wavelength, and d is the distance between arrays, and α is the phase shift. [3][4].

3. Methodology
First stage of research involves finding out the sources of RF energy in an urban area and take into account their frequency ranges, power levels and reliability factors. Once the optimum frequency is decided a circuit is designed to simulate the antenna and other circuits associated with the circuit.

3.1 Sources of RF Energy
Table 1 shows the major sources of RF energy in a typical populated area. These are categorized based on their frequency ranges, typical power densities [5], and reliability which is how likely they are to transmit at all times of the day and year.

Table 1 shows the different sources of RF radiation and their characteristics

From the table it was concluded that the optimum frequency range was in the range of 900 MHz or 1800 MHz. The frequency of 1800 Mhz was selected as the target frequency as the majority of cellular providers were operating at that frequency in Malaysia and the world [2].

3.2 System Design
The system was designed to be able to convert RF energy of 1800 Mhz into a DC voltage large enough to power a small device. It consists of a receiving antenna which is designed to capture the target frequency, a matching circuit that increases the power acquired from the antenna, and voltage multiplier which also acts as a AC to DC rectifier [1][7]. The rectifier is needed to convert the sinusoidal waveform into steady direct current for use in a device. The voltage multiplier is needed because the devices cannot function without high enough potential difference. This is done at the expense of lowering the current [6]. Figure 2 shows the system overview.

![Fig. 2 shows the system overview of the RF Energy Harvester](image-url)
4. Results and Discussion

Simulations were conducted for antenna and voltage multiplier circuits.

4.1 Antenna

The antenna can be of different types such as a simple dipole antenna which is not directional and therefore receives equal amounts of energy from all angles. For a frequency of 1800 MHz the optimum antenna length was calculated to be 7.94 cm. A more efficient antenna is an array antenna which can be pointed at the source (in this case cellphone base tower) to harvest more power. Using a Java-based antenna simulator [8] array antennas with different array numbers were simulated showing greater gain with more arrays in Fig. 3.

Fig. 3 An antenna array directional intensity with 4 arrays (1), 8 arrays (2), phase shift of 30 deg (3), and phase shift of 60 deg (4)

As observed the gain of the antenna can be increased by increasing the number of arrays. Beam forming may be done by adjusting the phase shift. This way the antenna would only capture RF energy from one particular direction and would therefore be more efficient.

4.2 Voltage Multiplier

A voltage multiplier was simulated in Multisim to determine the optimum number of stages that would result in maximum voltage with minimum power loss.

The multiplier consists of schottky diodes which are chosen due to their low forward voltage for operation. This is important due to the very low power derived from the antenna. The circuit also uses ceramic capacitors. The value of capacitance controls the ripple voltage of the DC output. The relationship between ripple voltage and capacitance is that they are inversely proportional therefore to minimize ripple 100nF capacitors are chosen. Figure 4 shows the circuit design in Multisim.

Fig. 4 Design of the Voltage Multiplier in Multisim

Figure 5 shows the results of the voltage obtained versus number of stages. The simulation showed that the output voltage of the multiplier increased with increasing stages reaching a peak at 3 stages for 100 ohm load, and at stage 4 for 1k ohm and open circuit loads. After that as more stages were added the output results in a drop in voltage. The explanation for this is that more components create more energy loss in the system [6] and therefore the optimum number of stage is found to be 3. Since the power is fixed, the voltage drops with decreasing load resistance. A 1 k ohm load produced a maximum of 1.029 mV output voltage.

4.3 System Construction

A circuit was constructed with 3 voltage multiplier stages outputting a total ambient power of 3.60 ± 2.4nW, and 24.01 ± 1.96 uW when fed with external RF source through the dipole antenna with 2dB gain. The power levels, when fed, where enough to power a LED and a small digital clock. Figure 6 shows the circuit implementation.

Fig. 5 The maximum voltage obtained from the output of the voltage multiplier versus the number of the stages for different types of load resistance.

Fig. 6, RF Energy harvester construction

5. Conclusions

Overall it was found that the frequency to target which corresponds to mobile phone base tower frequency of 1800 MHz is the most suitable due to its power and reliability. The antenna is more suitable to be an array antenna instead of a dipole antenna due to its higher gain and directionality. The voltage multiplier would have the most efficient operation at 4 stages with a value of 1.029 mV at 1k ohm load.

Acknowledgment

I would like to thank my supervisor Dr Pirapaharan Kandasamy for his help and guidance.

References


