THE EFFICIENCY ESTIMATION OF 900 MHZ RF ENERGY HARVESTER USING ARTIFICIAL NEURAL NETWORK

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ABSTRACT

In recent years, there is a significant increase in the number of devices with low power consumption. The energy requirements of these devices are provided by chemical batteries. The batteries must be charged at regular times, and cause some problems such as environmental pollution. RF energy harvesters are an alternative energy source for the batteries. In this study, the responses of 900 MHz RF energy harvester, which was previously tested, are estimated using an Artificial Neural Network (ANN) method in different states. For this aim, the output power values are determined by using the input power and the frequency of the signal and the load resistances connected to the energy harvester.

KEYWORDS

RF Energy Harvester, Artificial Neural Network, Efficiency

1. INTRODUCTION

The interest in energy harvesting systems (EHS), which generate a small amount of energy from the existing sources in the environment, is also increasing with the increase of micro autonomous electronic devices. The energy requirement of such devices is supplied with batteries. The batteries need to be replaced or recharged at regular times. These processes can be difficult or even impossible in hard-to-reach areas. In some cases, the lifetime of these devices may be limited by battery life [1]. EHS' are energy sources which are an alternative and/or a supporting to the batteries. Energy harvesting systems use the energy sources such as solar, wind, thermal gradient, vibration and radio frequency (RF). In recent years, it has become more efficient to obtain electrical energy using these signals due to the increase of RF signals in the environment. The electrical energy can be obtained from the signals have certain frequency and power level thanks to RF energy harvesters with proper circuit design.

In our previous work [2], a 900 MHz RF energy harvester has designed, implemented and analyzed. In the current work, it has been tried to determine how this harvester will behave in different frequency, power level and load resistance using the MATLAB Artificial Neural Networks (ANNs) toolbox. The experimental and estimated values are very closely each other.

DOI: 10.14810/elelij.2017.6303

2. ARTIFICIAL NEURAL NETWORKS (ANNS)

ANNs is software designed to simulate the way a simple biological nervous system works. It is tried to use the way of working of simple biological nervous system. The nerve cells contain neurons connect to each other in various ways to form the network. These networks have the capacity to learn, memory, and reveal the relationship between the data. In other words, ANNs produce solutions to problems that normally require an experiment. ANN systems use many elements which are highly interconnected with each other [3]. We can estimate the reactions of systems using ANNs without any experiments or observations. However, it is very important that the number of data which obtained previously is large for this process. One of the problems for the ANN applications is presence of irrelevant correlation between the input data variables. We can overcome this problem by providing more data [4]. If we have more data, the estimated results will be closer to reality.

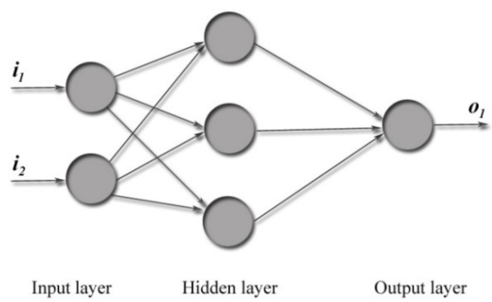


Figure 1. A simple model of ANN

Figure 1 shows a scheme of Artificial Neural Networks consist of input layer, hidden layer and output layer. The numbers of layers can be one or more. ANN systems can be realized a lot of commercial software. In this work, MATLAB software is used. ANN tool of MATLAB is very simple and flexible. In addition this tool gives good results.

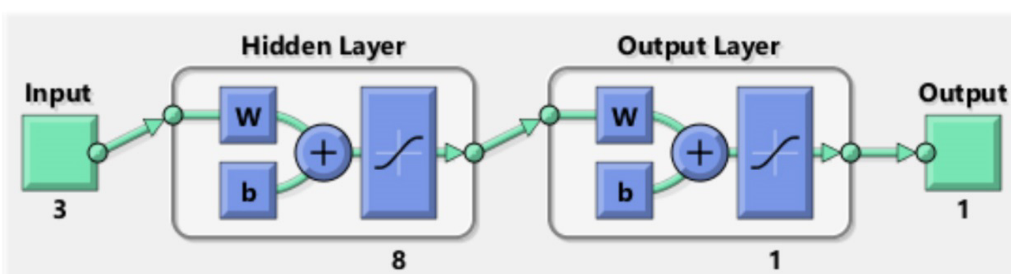


Figure 2. The ANN model used in this work

Figure 2 shows the Artificial Neural Network architecture of the current work. The model consists of 3 input and 1 output parameter, 8 hidden layer and 1 output layer. Input parameters are signal power value, the frequency of signal and load resistance. The output parameter is the system efficiency.

3. RF ENERGY HARVESTING SYSTEMS

RF energy harvesters use RF signals which are available in the environment for electricity generation. RF energy harvester systems mostly include four parts. The first of these is an antenna, which receives energy from free-space. It is important for an efficient system that the antenna should be efficient an appropriate. The second part is impedance matching circuit, which matches antenna impedance and the circuit impedance. This circuit contains inductors and capacitors. The third part is rectifier unit. The RF signals are high frequency alternative signals. So these signals must be rectified using this unit. Rectifier unit converts alternative voltage (AC) to direct voltage (DC). In generally, rectifier systems include diodes or mosfets and capacitors. To reduce the losses, HSMS 2852 diodes having low forward voltage and fast switching speed [5], and Dickson voltage multiplier having lower losses than most rectifiers [6] are used. The last part of the RF energy harvesters is the storage unit, which collects the obtained energy. A rechargeable battery or a super capacitor can be used for this unit.

In our previous work [2], we designed and implemented an RF energy harvester that could generate electrical energy using RF signals at a frequency of 900 MHz. The efficiency values of the RF energy harvester at different frequencies, loads values and input power levels were determined by experiments and simulations. The output power is calculated as in Eq.1 using the value of the load resistor and the rectified voltage on the load resistor.

$$P_{out} = \frac{V_{dc}^2}{R_l} \qquad (1)$$

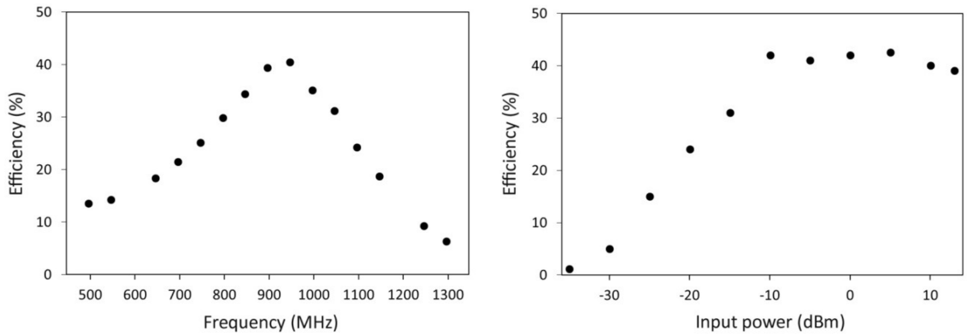
where, P_{out} is output power of the system (W), V_{dc} is rectified voltage (V) and R_l is load resistance. Since the input power applied to the system is known, the system efficiency can be found easily as shown in Eq. 2:

$$\%\eta = \frac{P_{out}}{P_{in}} x\, 100 \qquad (2)$$

where, η is system efficiency and P_{in} is input power (W). Since the input power is generally given in dBm for signal generators and communication systems, the input power must be converted to watt using Eq. 3.

$$P_{watt} = \frac{10^{\frac{P_{dBm}}{10}}}{1000} \qquad (3)$$

where, P_{watt} and P_{dBm} are power in watt and dBm, respectively. Although the system is designed to operate at 900 MHz, it can exhibited an efficiency of 20% or over in the all frequencies between 700 and 1200 MHz as shown in Figure 3(a).



(a) (b)

Figure 3. The experimental system efficiency (a) vs input frequency at 0 dBm. (b) vs input power at 900 MHz

As also shown in Figure 3(b), however the system is optimized for 0 dBm input power level, it has an efficiency of 20% or over at input power values above -20 dBm.

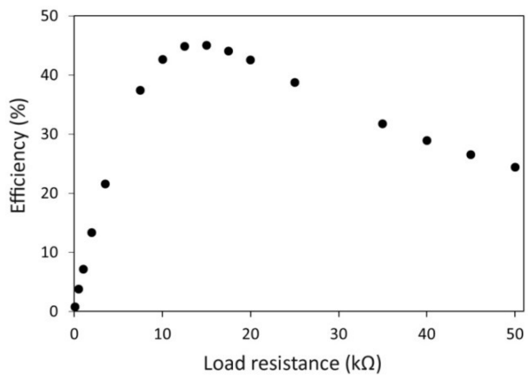


Figure 4. The experimental system efficiency vs load resistance at 0 dBm and 900 MHz

In the Figure 4, the efficiency graph is shown based on the load resistance for an input frequency of 900 MHz and an input power level of 0 dBm. As can be seen from the graph, the efficiency for the load resistance values between 10 and 20 kΩ is the highest level. However, for all resistance values between 4 and 50 kΩ, the efficiency is over 20%.

3. RF ENERGY HARVESTING SYSTEMS

The signals in the environment can be at various frequencies and power levels. Again, the circuits to be fed can have different resistance values. The designed systems to target specific values often provide the desired results. However, in some situations, such as changes in frequency and input power level, it is difficult to determine the obtained power from the system. For this purpose, some experiments and/or simulations may also be required. In these cases, using the Artificial Neural Network (ANN), the power values that can be obtained from the systems in different situations can be easily estimated. In this work, MATLAB ANN tool was used for artificial neural network works.

In this work, the efficiency values were determined in different situations for the 900 MHz RF energy harvester, which were previously made experiments and simulations [2]. Only three graphs (Fig 3(a), 3(b) and 4) that we have already obtained are used for this work. Of course, it is possible to make estimates with much higher accuracy by increasing experimental data. Figure 5 shows the efficiency values for six different random data sets. In the figure, first (blue) bars are experimental values, and second (red) bars are obtained values using Artificial Neural Network (ANN). As it can be seen from the graph, there are very few errors between experimental and ANN values.

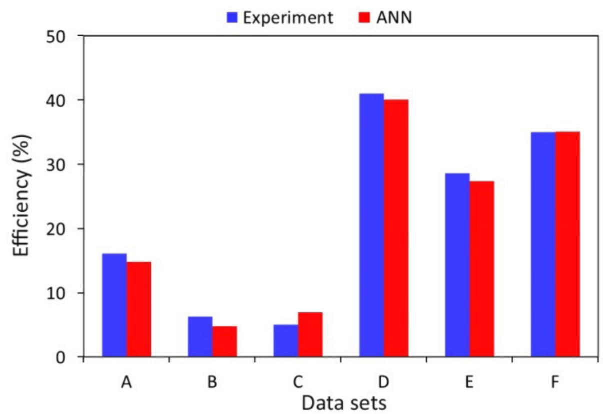


Figure 5. The comparison of experimental and ANN efficiencies in different situations

Table 1 shows values of the used data sets, the efficiency values between experiments and ANN, and errors. Data sets are selected within the range of values at which the experiments were made. In this work, it can roughly be said that the error rate drops below 8% when the system efficiency is 15% and higher. The error rate increases at the low efficiency values such as 5% (data set C). Because the efficiency is already very low, these error rates are not important. The usable efficiency rate is 20% or above for these systems. In addition, the used data was obtained from 900 MHz RF energy harvester. If a multiple frequency RF energy harvester will be used, the efficiency will increase and the error may decrease.

Table 1. The comparison of the efficiencies

Data set	Frequency (MHz)	Load Resistance (kΩ)	Input power (dBm)	Experimental efficiency	ANN efficiency	Error (%)
A	600	10	0	16.07	14.79	7.97
B	1300	10	0	6.26	4.76	23.96
C	900	10	-30	5.03	6.93	-37.77
D	900	10	-5	41.10	40.08	2.48
E	900	5	0	28.59	27.36	4,30
F	900	30	0	34.98	35.08	-0.29

Figure 6 shows the system efficiencies depends on the load resistance at the 850 MHz and 0 dBm input frequency and power, respectively. The circles (black) indicate the obtained values from Artificial Neural Network (ANN), and the squares (red) indicate the simulation results. The simulations are performed using Agilent Advanced Design Systems (ADS) software.

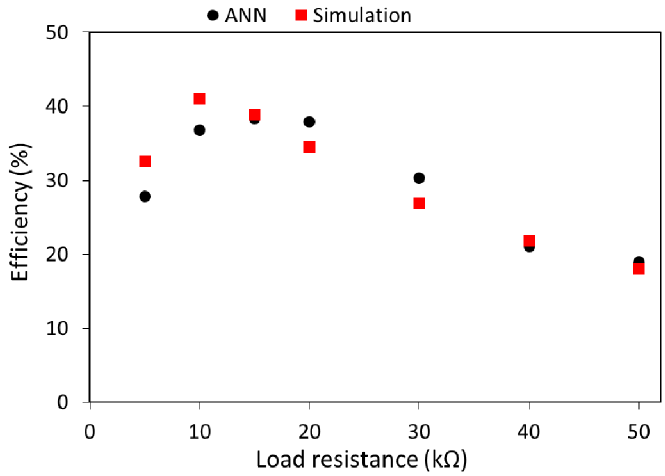


Figure 6. The efficiencies vs load resistance for ANN and simulation.

As it can be seen in Figure 6, the maximum error value is 14% and the average error value is about 8%. These values are acceptable for approximate estimates. In this work, we use only 3 experimental graphs consisting of 28 experimental data.

4. CONCLUSIONS

In this work, the efficiencies of the 900 MHz RF energy harvester, previously tested and simulated, were determined in the different input values. If the actual efficiency is 15% and above, the error rate decreases 8% and below. The ANN and simulations graphs are very close to each other based on load resistance at 850 MHz frequency. This error rate is enough for an estimate. When the efficiency is lower, the error rate increases. It is possible to further reduce the error rate by obtaining experimental results at different input values.

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