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Araştırma Makalesi / Research Article

Ekstra Alıcı Anten Olmadan Mikrodalga Enerji Toplama

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Öz

Bu makalede, farklı anten türlerinin verici anten olarak kullanıldığı, alıcı anten olarak ise voltaj doğrultucu devrede bulanan kapasitörün ucunun anten olarak kullanıldığı, farklı radyo frekansı hasadı durumlarını ele almaktadır. Girişte farklı antenler kullanılmış ve buna bağlı olarak iki farklı doğrultma devresi ile dönüşüm verimleri çalışılmıştır. Antensiz log periyodik anten kaynağı için uzak alanda %27.31 RF-DC güç dönüşüm verimi değeri elde edilmiştir. Yarım dalga boyu dipol anten kaynağı için yakın alanda %50.53 RF-DC güç dönüşüm verimliliği değeri elde edilmiştir. Sarmal anten kaynağı için 5 cm mesafeye kadar yaklaşık %14,78 RF-DC güç dönüşüm verimliliği gözlenmiştir. Kaynak olarak kullanılan Yagi-Uda anteni için herhangi bir alıcı anten olmadan uzaktan elde edilen RF-DC güç dönüşüm verimi %28,89 olmuştur.

Anahtar kelimeler
Radyo frekansı toplama; Log periyodik anten; Doğrultucu devreler; Dönüşüm verimliliği

Microwave Energy Harvesting With No Extra Receiving Antenna

Abstract

This paper addresses different cases of radio frequency harvesting using different antenna types as transmitting antenna but using just the lead of the capacitor as the wire antenna at the receiving end with a voltage rectifier circuit. Different antennas were used in the input and with two different rectification circuits the conversion efficiencies were studied accordingly. For a source of log periodic antenna, without any antenna, 27.31% RF-DC power conversion efficiency value was obtained at the far-field. For a source of half wavelength dipole antenna, at the near-field, 50.53% RF-DC power conversion efficiency value was obtained. For a source of helical antenna, up to 5 cm distance about 14.78% RF-DC power conversion efficiency was observed. For the Yagi-Uda antenna used as a source, RF-DC power conversion efficiency that was obtained at the far was 28.89% without any receiving antenna..

Keywords
Radio frequency harvesting; Log periodic antenna; Rectifier circuits; Conversion efficiency

1. INTRODUCTION

In a wireless power transmission system, the electrical power originated from some source gets transferred to the destination to be captured without the use of wires. The concept of power transmission first originated by Hertz and Tesla (Brown 1984). and the first experiments were done by a microwave-powered helicopter by Brown (1969). Although the initial applications of microwave power transmission focused on applications where directive, high-power transmission was required, the interest in autonomous sensors led to the concept of ambient electromagnetic energy harvesting where rectennas were used to provide DC power by converting the available radio frequency (RF) power (Boaventura *et al*. 2013).

The power harvesting techniques are classified as using methods to obtain energy including thermoelectric conversion and solar energy conversion. Nowadays there are many different energy harvesting technologies such as solar, thermal, wireless and piezoelectric. The design of energy efficient systems aim toward the operation of sensors and devices with self-sustained operation. Especially in low power electronics it is very important to have self-sustainable operation of instruments. There are still many different issues involving the design of wireless power transmission systems. Good review papers on radio frequency power harvesting was presented by Tran *et al*. (2017) and Divakaran and Krishna (2019). Scucchia and Limiti (2018) studied RF-DC conversion systems by establishing Greinacher voltage multiplier and harvesting RF energy from mobile phone base station signals. RF energy harvesting using millimeter-wave textile antenna between 26 GHz to 28 GHz was proposed by Wagih *et al*. (2019). Recently Fakharian (2021) proposed RF energy harvesting using high impedance asymmetric antenna array without impedance matching network.

Microwave energy harvesting has a wide variety of application domains to achieve energy efficient operation for a range of use cases. Energy sustainability can be considered as the major driving factor for different application domains such as Internet of Things (IoT), radio frequency identification (RFID), and smart buildings (Sherazi *et al*. 2022). Energy efficiency requirement for IoT applications in industrial automation applications can be at a lower level for example use of the technique in small sized sensors.

All the literature in wireless power transmission focusses on having receiving antenna. In this work, a simple demonstration of energy harvesting, without the use of any receiving antenna, except with the lead of a capacitor acting as a wire antenna, is demonstrated at around 660 MHz. This can really prove that without extra receiving antenna, we can obtain reasonable RF-DC power conversion efficiencies.

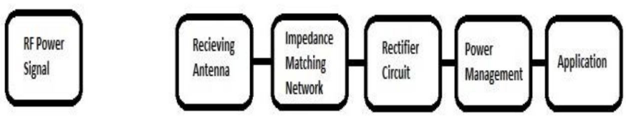


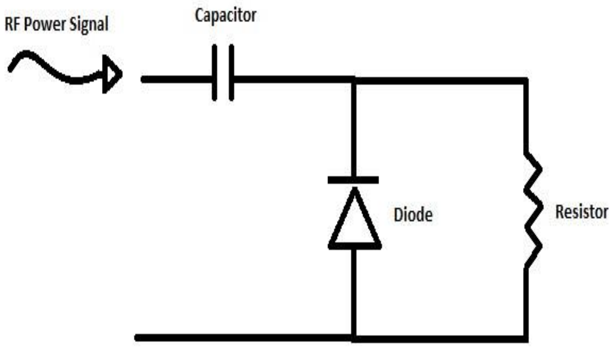
Figure 1. Conceptual block diagram of RF energy harvesting system.

2. Design and Methodology

Essentially the importance of receiving antenna and impedance matching network are crucial for highly efficient operation. We can see that the in real harvesting systems, an antenna is placed at the receiving end, which is followed by a matching network to match the impedance of the receiving antenna with the rectifier circuit to avoid any loss in power. After the rectifier circuit there should be components to store the rectified DC voltage. Also there have been different design methodologies for implementing different rectifier or voltage multiplier circuits to increase RF-DC power conversion efficiency. In our study our aim was to make some studies using no receiver antenna, except for the lead of a capacitor acting as a wire antenna, but just simple rectifier circuit and observe the conversion efficiencies accordingly. We can consider the conceptual block diagram for RF energy harvesting system as depicted in Figure 2.

Figure 2. Conceptual block diagram of RF energy harvesting system – simplified

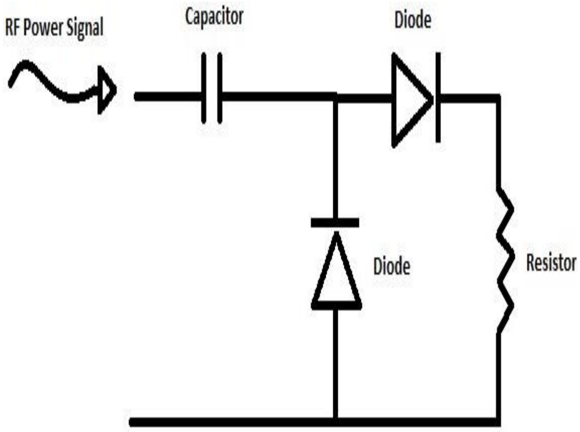
In Figure 2 we demonstrate our experiment with no extra receiving antenna, not having a matching network and using directly rectifying circuit to convert the RF power into DC voltage. Naturally the efficiencies were expected to be very low however the experiments using different transmitting antennas indicated that in fact it is possible to obtain about 50% in RF-DC power conversion efficiency. Two different circuit diagrams as well as their photographs for rectifier circuits are shown in Figure 3 and Figure 4. These circuits were used in the analysis.



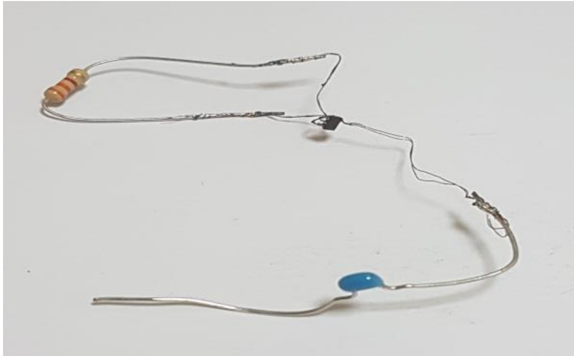
(a)

(b)

Figure 3. Single diode rectifier circuit a) diagram b) constructed circuit



(a)



(b)

Figure 4. Multiplier rectifier circuit a) diagram b) constructed circuit

In wireless power harvesting several evaluation metrics can be used, such as operation range, RF-DC power conversion efficiency, resonator Q-factor, sensitivity, and output power. In our work we used RF-DC power conversion efficiency as our evaluation metric. Namely:

$$Efficiency = P_{measured}/P_{available} \quad (1)$$

where $P_{measured}$ is calculated from the voltage value measured from the rectifier circuit and $P_{available}$ is measured using a receiver antenna placed at the same location as the receiving circuit.

3. Experiment and Discussion of Results

A simple experimental setup clearly showing the circuit is shown in Figure 5.

(a)

(b)

Figure 5. Experimental setup a) top view b) side view.

As for RF power source Antenna Trainer Scientech ST2261 was used (Scientech 2021). This equipment provides RF signal around 659-664 MHz. For measuring the available power to the circuit a spectrum analyzer GW INSTEK GSP-827 was used (Tequipment 2021), for measuring DC voltages BRYMEN BM807 true rms multimeter was used (Brymen 2021). As a load resistor 1.2 kΩ was used for the single diode configuration (Circuit 1, C1), a load resistor 3.3 kΩ was used for multiplier circuit configuration (Circuit 2, C2). For the rectification surface mount microwave Schottky diodes Avago HSMS-286B (Avago 2021) were used. Detection sensitivity of these diodes are 50 mV/microW at 915 MHz. A capacitor of 0.01 µF was used as a DC block. The operating frequency for our transmitting antennas were in the 500-750 MHz range. We observed the resonant frequency and used four different types of antennas as transmitter (Log periodic, half wavelength dipole, Helical and Yagi-Uda) and looked at the operation range, and RF-DC power conversion efficiency. Considering the dimensions of the transmitting antennas and the frequency of operation, we can consider the radiation in these examples to be in far-field for distances greater than 5 cm.

3.1 Log Periodic Antenna

A log periodic antenna which is a multi-element directional antenna with large bandwidth was used as the source for transmitting RF power. The results were obtained as shown in Table 1.

Table 1: log periodic antenna harvesting results

Source (dBm)	Distance (cm)	Received Power (mW)	Voltage C1 (mV)	Voltage C2 (mV)	C1 Efficiency (%)	C2 Efficiency (%)
14.0	1	0.457088	236	364	10.154	24.156
14.0	5	0.524807	45	253	0.322	10.164
14.0	10	0.346737	27	203	0.175	9.904
14.0	15	0.263027	15	229	0.071	16.615
14.8	1	0.575440	280	442	11.354	28.292
14.8	5	0.645654	60	307	0.465	12.164
14.8	10	0.489779	44	251	0.329	10.719
14.8	15	0.323594	24	289	0.148	21.509
15.9	1	0.676083	327	535	13.180	35.280
15.9	5	0.794328	80	356	0.671	13.296
15.9	10	0.575440	60	300	0.521	13.034
15.9	15	0.380190	36	353	0.284	27.313
17.4	1	1.023293	410	719	13.689	42.099
17.4	5	1.202264	110	465	0.839	14.987
17.4	10	0.912011	94	421	0.807	16.195
17.4	15	0.616595	55	441	0.409	26.284

Also we can observe the conversion efficiencies for these cases as well in Figure 6 for Circuit 1 and Figure 7 for Circuit 2.

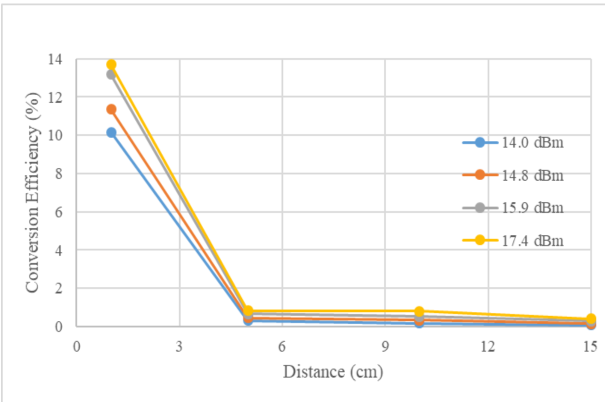


Figure 6. Efficiency values with increasing distance from source Log Periodic Antenna and Circuit 1

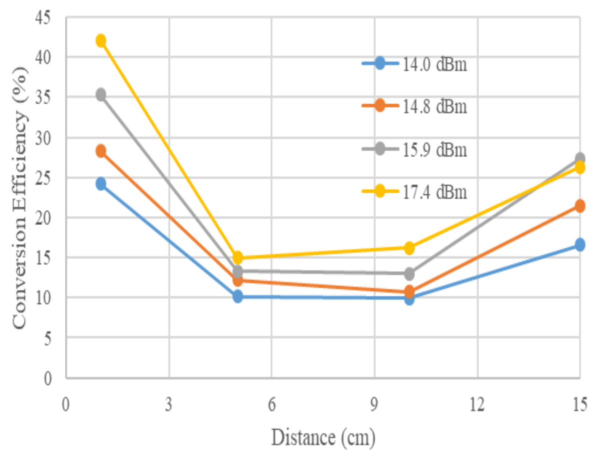


Figure 7. Efficiency values with increasing distance from source Log Periodic Antenna and Circuit 2.

It is very noticeable that single diode configuration (i.e. Circuit 1) was not very effective in converting the transmitted power into harvested power. Only at the near-field region (i.e. 1cm), some conversion efficiency values, around 10% to 13%, were observed. For the multiplier circuit configuration however, at the far-field good RF-DC power conversion values were observed. Even at 15 cm, efficiencies reaching to 27% were observed.

3.2 Half Wavelength Dipole Antenna

A half wavelength dipole antenna, which is an omnidirectional wire antenna with radiation is at maximum perpendicular to conductor and becoming zero at axial direction, was used as the source for transmitting RF power. The results were obtained as shown in Table 2.

Table 2: Half wavelength dipole antenna harvesting results

Source (dBm)	Distance (cm)	Received Power (mW)	Voltage C1 (mV)	Voltage C2 (mV)	C1 Efficiency (%)	C2 Efficiency (%)
14.0	1	0.93325 4	720	178	46.290	10.346
14.0	5	0.12882 5	52	50	1.749	0.711
14.0	10	0.10000 0	19	63	0.301	1.708
14.0	15	0.05011 9	24	110	0.958	6.866
14.8	1	1.07151 9	747	213	43.397	11.768
14.8	5	0.12882 5	68	61	2.991	0.860
14.8	10	0.10000 0	28	78	0.653	1.854
14.8	15	0.05495 4	26	124	1.025	7.092
15.9	1	0.14454 4	80	73	44.235	12.822
15.9	5	0.12589 3	40	110	3.690	1.001
15.9	10	0.06918 3	45	145	1.059	3.138
15.9	15	1.99526 2	1100	313	2.439	8.254
17.4	1	0.24547 1	128	98	50.536	14.289
17.4	5	0.12589 3	60	135	5.562	1.192
17.4	10	0.08912 5	77	212	2.383	2.983
17.4	15	0.93325 4	720	178	5.544	10.879

For this transmitting antenna again we can see Figure 8 and Figure 9 for comparison of two different configurations with different power levels.

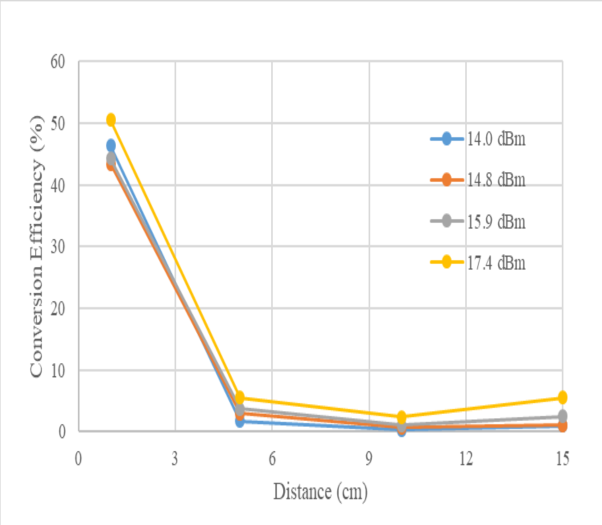


Figure 8. Efficiency values with increasing distance from source Half Wavelength Dipole antenna and Circuit 1

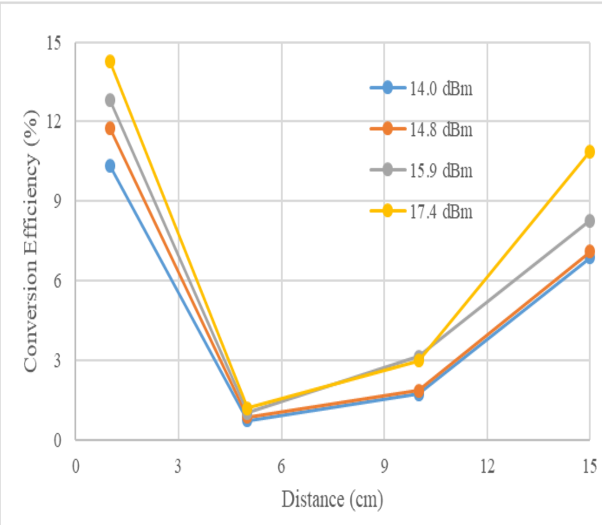


Figure 9. Efficiency values with increasing distance from source Half Wavelength Dipole antenna and Circuit 2

In this case, we obtained two different efficiency curves depending on single diode configuration and multiplier circuit configuration. In the near-field efficiencies in the 44-50% were obtained for the first circuit configuration, however negligible power was received in far-field. For the multiplier circuit configuration at the far-field conversion efficiencies around 10% were obtained.

3.3 Helical Antenna

A helical antenna, which is a travelling wave antenna in the shape of a corkscrew was used as the source for transmitting RF power. This type of antenna has a wide bandwidth and can produce circularly polarized fields. The experimental results were obtained as shown in Table 3.

Table 3: Helical antenna harvesting results

Source (dBm)	Distance (cm)	Received Power (mW)	Voltage C1 (mV)	Voltage C2 (mV)	C1 Efficiency (%)	C2 Efficiency (%)
14.0	1	1.995262	410	513	7.021	10.991
14.0	5	0.407380	208	220	8.850	9.901
14.0	10	0.177828	12	52	0.067	1.267
14.0	15	0.144544	1	56	0.001	1.808
14.8	1	2.398833	486	600	8.205	12.506
14.8	5	0.588844	268	273	10.165	10.547
14.8	10	0.251189	36	61	0.430	1.234
14.8	15	0.199526	1	65	0.000	1.765
15.9	1	3.019952	600	719	9.934	14.265
15.9	5	0.741310	319	318	11.439	11.368
15.9	10	0.281838	58	82	0.995	1.988
15.9	15	0.257040	2	73	0.001	1.728
17.4	1	3.890451	847	908	15.367	17.660
17.4	5	1.023293	454	426	16.785	14.779
17.4	10	0.457088	122	127	2.714	2.941
17.4	15	0.446684	7	90	0.009	1.511

For the helical antenna observed conversion efficiency percentage values were also plotted as Figure 10 and Figure 11 for both of the configurations.

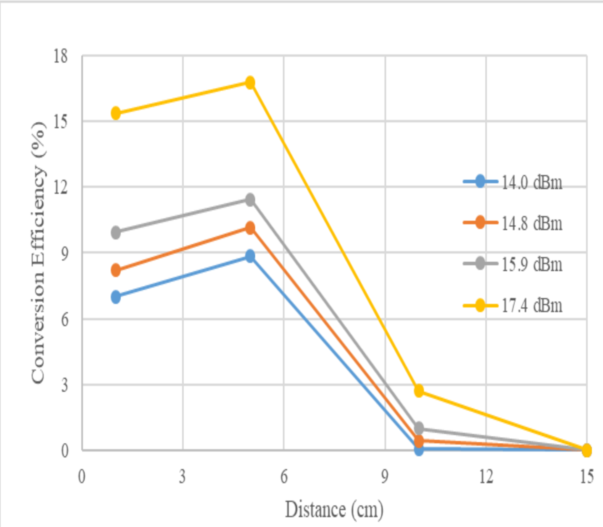


Figure 10. Efficiency values with increasing distance from source Helical antenna and Circuit 1

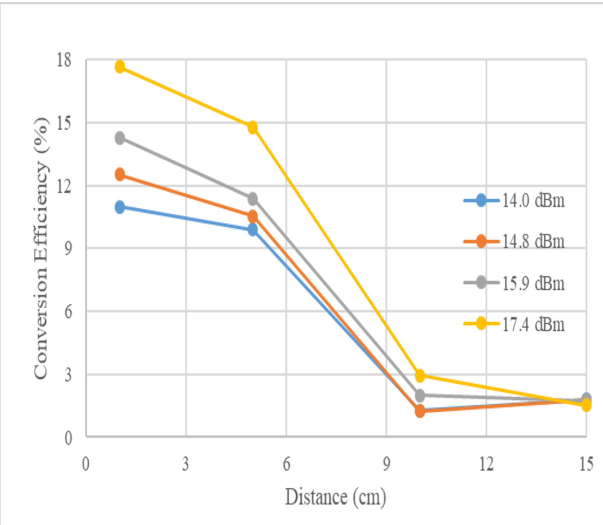


Figure 11. Efficiency values with increasing distance from source Helical antenna and Circuit 2

When helical antenna was used as the transmitter, conversion efficiency values were around 8-16% at the beginning of the far-field region (i.e. around 5 cm) and then dropped drastically. It was also noticeable that unlike the other antenna types, in this case both the single diode rectification circuit and multiplier circuit configuration RF-DC power conversion efficiencies were similar.

3.4 Yagi-Uda Antenna

The Yagi-Uda antenna, which is a travelling wave antenna but relatively smaller bandwidth, was used as the source for transmitting RF power. The results were obtained as follows in Table 4.

Table 4: Yagi-uda antenna harvesting results

Source (dBm)	Distance (cm)	Recived Power (mW)	Voltage C1 (mV)	Voltage C2 (mV)	C1 Efficiency (%)	C2 Efficiency (%)
14.0	1	0.015849	17	50	1.520	13.145
14.0	5	0.010000	6	21	0.300	3.675
14.0	10	0.006310	5	37	0.267	18.081
14.0	15	0.012589	1	24	0.007	3.813
14.8	1	0.019953	30	63	3.759	16.577
14.8	5	0.010000	10	30	0.833	7.500
14.8	10	0.007943	8	48	0.671	24.171
14.8	15	0.015849	2	30	0.021	4.732
15.9	1	0.025119	70	76	16.256	19.162
15.9	5	0.012589	16	41	1.695	11.127
15.9	10	0.010000	21	58	3.675	28.033
15.9	15	0.019953	4	36	0.067	5.413
17.4	1	0.039811	115	114	27.683	27.204
17.4	5	0.019953	41	65	7.021	17.646

17.4	10	0.015849	22	74	2.545	28.793
17.4	15	0.031623	11	50	0.319	6.588

For this harvesting configuration as well, we can see the responses in Figure 12 and Figure 13.

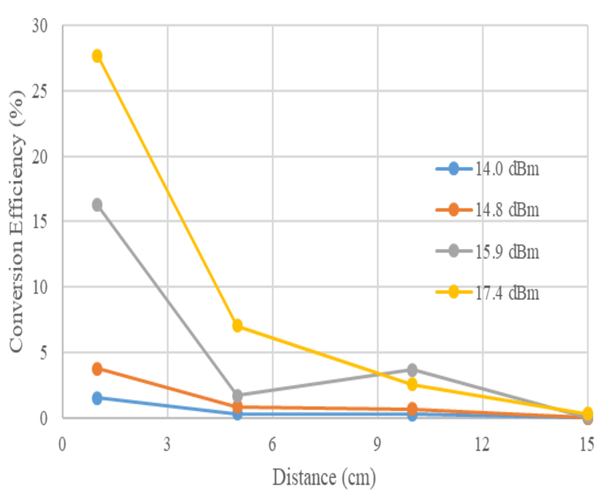


Figure 12. Efficiency values with increasing distance from source Yagi-Uda antenna and Circuit 1

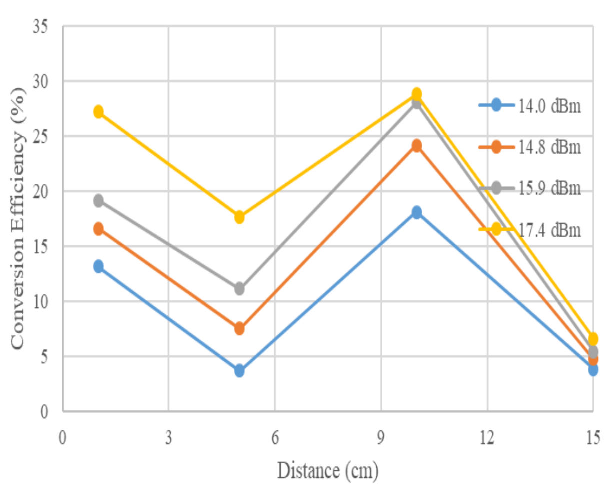


Figure 13. Efficiency values with increasing distance from source Yagi-Uda antenna and Circuit 2

In these configurations, decent RF-DC power conversion efficiencies were obtained for single diode configuration in near-field and for multiplier circuit configuration in the far-field. In the near field about 27% RF-DC power conversion efficiencies were obtained as maximum for single diode rectifier circuit. For the far-field, using multiplier circuit configuration, RF-DC power conversion efficiencies close to 28% were obtained.

4. Conclusion

This paper presents work conducted using RF energy harvesting without the use of extra receiving antenna. Different antennas were used for transmitting the power and two different circuit configurations were used to study the received power in terms of RF-DC power conversion efficiencies. It was observed that, for log periodic antenna, with single diode configuration only in the near-field some RF-DC power conversion efficiency (around 10%) was obtained. For the multiplier circuit however in the far-field as well some RF-DC power conversion efficiencies reaching to 25% were obtained.

When the half wavelength dipole was used as a power source, single diode configuration at the near-field produced good RF-DC power conversion efficiencies reaching to 50.5%. At the far-field, similar to log periodic antenna only multiplier circuit configuration produced reasonable RF-DC power conversion efficiencies, reaching about 6-8%.

When the helical antenna was used as a power source, only up to 5 cm distances RF-DC power conversion efficiencies with reasonable values were obtained. In this case for both of the configurations RF-DC power conversion efficiency values were similar being around 10%-15%. Also there were no noticeable received power for distances greater than 5 cm.

As a power source, when Yagi-Uda antenna was used, for the single diode configuration only at the near-field RF-DC power conversion efficiencies especially at high input powers were observed. For the multiplier circuit the best results were obtained at the distances of 10 cm and the highest RF-DC power conversion efficiency value was 28.8%.

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