

Analyzing Simulation and Measurement Results for Single Layer Dickson Rectifier Topology

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Abstract: - Energy harvesting has emerged as a promising alternative power solution by enabling the conversion of ambient electromagnetic energy into usable electrical power. This capability is particularly valuable for low-power electronic devices, where reducing or eliminating dependence on conventional batteries can significantly enhance operational lifetime and reliability. In typical RF energy-harvesting systems, a microstrip antenna collects radio-frequency signals from the surrounding environment, and the received energy is transferred to a rectifier circuit that converts it into DC power. In this study, an RF energy-harvesting module based on the Dickson charge-pump topology is designed and analyzed for efficient operation at 900 MHz. The entire structure is implemented on an FR-4 substrate, which offers a cost-effective and widely accessible platform despite its moderate dielectric losses at microwave frequencies. The rectifier circuit employs the HSMS-285C Schottky diode, chosen for its low threshold voltage and high sensitivity, enabling efficient rectification even at low input power levels. To ensure maximum power transfer from the antenna to the rectifier, the matching network integrates both discrete L–C components and microstrip stubs, enabling fine-tuning of impedance characteristics across the operating band. Comprehensive simulations of the antenna, matching network, and rectifier stages are carried out using Keysight ADS, allowing accurate prediction of RF-to-DC conversion performance under various input power conditions. The resulting DC output from the rectifier is suitable for powering ultra-low-power electronic devices—including calculators, wristwatches, wireless sensor nodes, Bluetooth headsets, and similar portable systems—or for recharging small batteries and supercapacitors to extend their operational lifetime. The simulation results demonstrate that the proposed design efficiently converts ambient RF energy into usable DC power, highlighting its strong potential for practical integration into next-generation low-power and energy-autonomous electronic applications.

Key-Words: - Dickson Rectifier; Energy Conversion; Radio Frequency (RF); Schottky Diode; ADC; Energy Harvesting.

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1 Introduction

Collecting the energy carried by radio-frequency signals that naturally exist in the surrounding environment through properly designed antennas, and subsequently delivering this captured energy to a load in the form of DC voltage by means of amplifier and rectifier circuits, is broadly defined as RF energy harvesting. This method has gained considerable importance in recent years, primarily because it offers a practical and efficient power alternative for modern electronic devices that operate with extremely low energy requirements.

RF energy harvesting encompasses the entire procedure of detecting, capturing, and converting electromagnetic waves in the radio-frequency spectrum into a stable and usable direct-current

output. To accomplish this, suitable antennas are employed to intercept RF signals, after which amplifier and rectifier stages process these signals and transform them into DC power. Owing to its capability to supply small but continuous amounts of energy, this technique has become a highly appealing approach for low-power electronic systems. The main purpose of incorporating RF harvesting into such systems is to significantly extend the lifetime of batteries, especially in devices that rely on low-power wireless communication technologies. Within a typical RF harvesting configuration, the antenna receives ambient electromagnetic radiation, while the rectifier stage converts the alternating nature of the signal into a direct voltage suitable for powering electronic loads. A conceptual illustration of this

general energy harvesting mechanism is provided in Figure 1, [1].

In contemporary applications, compact and efficient energy harvesting modules have found widespread use in numerous portable and wearable devices. Examples include pocket calculators, digital watches, Bluetooth audio accessories, fitness trackers, and a wide range of wireless sensor nodes. These systems are capable of capturing electromagnetic energy emitted by various wireless communication infrastructures such as GSM base stations, radio broadcast antennas, and television transmitters. The harvested energy can also play a supplementary role in increasing the battery life of mobile phones by contributing additional charge when RF energy is available.

Whether obtained from naturally occurring ambient RF fields or from signals deliberately radiated by dedicated transmitters, RF energy harvesting allows low-power electronic devices to be recharged continuously. This ongoing replenishment minimizes, and in some cases completely removes, the need for frequent battery replacement or wired charging, thereby enhancing device longevity and operational reliability, [2].

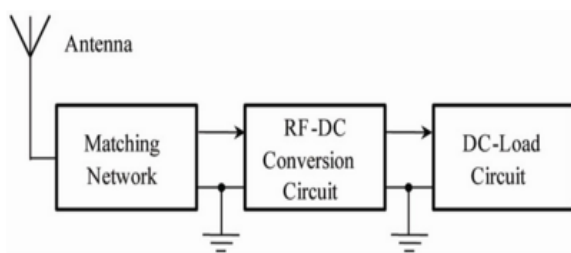


Fig. 1: Schematic view of a RF energy harvesting system
 Source: [1]

2 Literature Review

A number of studies have proposed advanced system configurations and circuit architectures aimed at improving RF energy harvesting efficiency, sensitivity, and overall output performance. One such study introduces an integrated architecture that combines a resonant voltage booster with a rectifier stage. In this configuration, the resonant booster amplifies small RF input signals into higher-amplitude oscillations through resonance enhancement, thereby increasing the effective voltage delivered to the subsequent rectification block. The rectifier then converts the boosted AC signal into DC energy, which is stored in output capacitors. Simulation results demonstrate that this hybrid structure is capable of maintaining stable DC

output even under extremely weak RF excitation, making it highly suitable for long-distance and self-powered wireless sensing applications, [3].

Another work proposes an RF energy-harvesting circuit featuring a six-stage Dickson charge pump topology. In this design, ambient RF energy is captured by a loop antenna tuned to 954 kHz, corresponding to a 100 kW AM radio broadcast source. The multi-stage Dickson multiplier successively elevates the input voltage, enabling the output capacitor to reach approximately 520 mV under experimental conditions. This study highlights the potential of low-frequency, high-power broadcast signals as reliable energy sources for low-power electronics, [4].

A further contribution in the literature reports a reconfigurable differential RF–DC CMOS converter capable of dynamically switching between different rectification modes depending on the input power level. This reconfigurability enhances both the conversion efficiency and the sensitivity of the system. Fabricated using 130 nm CMOS technology, the converter prototype demonstrated an output voltage of about 2 V, a minimum sensitivity of -21 dBm at 868 MHz, and a peak conversion efficiency of 60%. Notably, the efficiency remained above 40% across an 18 dB range of input power, underscoring its robustness for practical deployment in IoT and low-power wireless systems, [5].

In another study, a seven-stage Dickson rectifier composed of Schottky diodes and capacitors was developed and analyzed. The design exhibited strong rectification performance within the targeted frequency band, benefiting from the low forward-voltage characteristics of the Schottky diodes and the voltage-multiplying capability of the multi-stage structure. The results confirm that increasing the number of stages in Dickson-based topologies can enhance output voltage, provided that diode and parasitic losses are well managed, [6].

Multiband energy harvesting has also been explored in the literature. A notable example is a multiband rectifier employing several resonator networks tuned to 1.3, 1.7, 2.4, and 3.6 GHz. This architecture enables simultaneous energy harvesting across multiple frequency bands commonly used in cellular, Wi-Fi, and wireless communication systems. A fabricated prototype demonstrated an output voltage of 1 V with an input power of -11 dBm for each band when connected to a 3 k Ω load, highlighting its effectiveness for heterogeneous RF environments, [7].

Additionally, wideband and polarization-diverse rectenna systems have been proposed to improve harvesting stability under varying signal orientations

and channel conditions. One such dual-polarized rectenna integrates a novel RF rectifier–boost regulator capable of simultaneously rectifying and stepping up the captured RF energy. Experimental results show voltage conversion efficiencies as high as 85% and a boosted output of 1 V at a distance of 50 cm from a 20 dBm Wi-Fi transmitter, demonstrating its practicality for WLAN-based wireless-power transfer applications, [8].

3 Rectification Topologies

Long-distance RF energy harvesting requires the use of circuit topologies capable of delivering higher power gain, often supplied by large infrastructure such as broadcast towers and cellular base stations. Among various rectification architectures, multi-stage configurations—such as Dickson, Greinacher, Villard, and Cockcroft–Walton rectifiers—are widely adopted due to their ability to accumulate voltage across multiple stages.

3.1 Dickson Rectifier Circuit

The Dickson rectifier consists of two subcircuits: a clamping network (Dc and Cc) and a rectifying network (Dr and Cr), each composed of a diode–capacitor pair, as shown in Figure 2. Here, Vdc represents the DC bias input, Vi denotes the sinusoidal RF input, and Vo indicates the output DC voltage. The DC input of each stage is obtained from the previous stage; for instance, the second stage receives its Vdc from the output (VC2) of the first stage, [9].

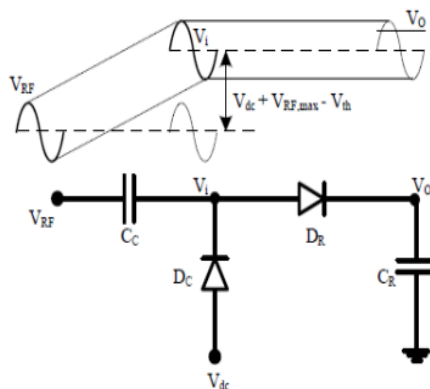


Fig. 2: Dickson voltage rectifier
 Source: [9]

For analytical simplicity, diode resistance is assumed negligible, resulting in immediate capacitor charging and steady-state conditions. The load is also treated as an open circuit during analysis. When the input voltage becomes negative but its magnitude exceeds the diode threshold, the diode switches off

and the capacitor Cc charges up to the threshold voltage.

In this case, the voltage across the capacitor Cc is expressed as follows:

$$V_{C_c} = -V_{RF_{min}} + V_{dc} - V_{th} \quad (1)$$

During the positive half-cycle, the voltage across Cc adds to the input voltage, thereby increasing the effective driving voltage of the rectifying section. The capacitor Cr then stores the accumulated charge and filters the ripple components to produce a nearly constant DC output. For an n-stage Dickson rectifier, the ideal output voltage is expressed as:

$$V_i = -V_{C_c} + V_{RF_{max}} \quad (2)$$

$$V_i = 2V_{RF_{max}} + V_{dc} - V_{th} \quad (3)$$

In the rectification stage, the applied input voltage Vi consists of a sinusoidal waveform superimposed with a DC component. The capacitor Cr functions as an energy storage element, accumulating charge while simultaneously smoothing out the AC ripple. As a result, the rectifier produces a predominantly DC output voltage Vo, expressed in Equation 4

$$V_o = 2V_{RF_{max}} + V_{dc} - 2V_{th} \quad (4)$$

At the first stage of the structure, the DC input level is zero because the VDC node is directly tied to ground. For an n-stage Dickson rectifier, the ideal output voltage can be expressed by the following relationship:

$$V_o = 2n(V_{RF_{max}} - V_{th}) \quad (5)$$

In practice, leakage current and diode non-idealities cause the output to be slightly lower than the theoretical value, [10].

4 System Design For Dickson Rectification Topology

The frequency ranges of generator sources for harvesting RF energy are given in Table 1, [11].

The RF energy harvester circuit in this study is aimed to operate in the 0.9 GHz frequency range. In addition, a 0-100 kohm variable potentiometer load resistance was used for the design. Output voltages at 7 dBm and -50 dBm input power were examined. Advanced Design System (ADS) was used as the simulation program. FR4 material was used as the substrate. HSMS-285C was used as the Schottky diode. The properties of the FR4 dielectric material are presented in Table 2.

Table 1. Energy harvesting frequency range

FM	87.5 MHz – 108 MHz
Radio	370 MHz – 450 MHz
VHF	174 MHz – 230 MHz
UHF	470 MHz – 854 MHz
GSM 900	935 MHz – 960 MHz
GSM 1800	1805 MHz – 1880 MHz
Wi-Fi	2400 MHz – 2483.5 MHz
3G	2110 MHz – 2200 MHz
Wi-MAX	2500 MHz – 2690 MHz and 3400 MHz – 3600 MHz

Source: [11]

Table 2. Properties of FR4 dielectric material

H=1.584 mm
$\epsilon_r = 4.2$
T=0.035 mm
$\tan \delta = 0.002$

Source: [2]

The printed view of the circuit designed in the ADS program is given in Figure 3.

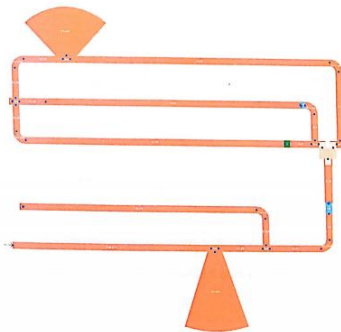


Fig. 3: Printed view of the circuit designed in the ADS program

Source: Drawn by the authors

The s parameters of this drawn circuit are also given in Figure 4.

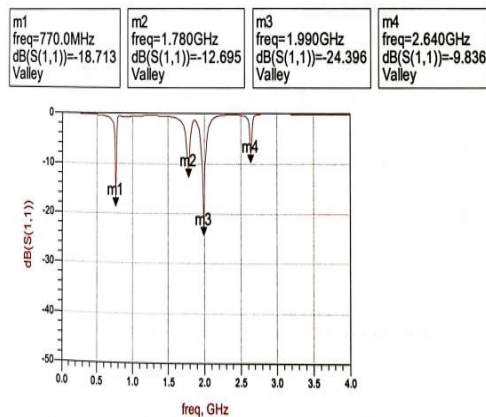


Fig. 4: s parameter of the circuit designed with FR4 material

Source: Measured by the authors

5 Results

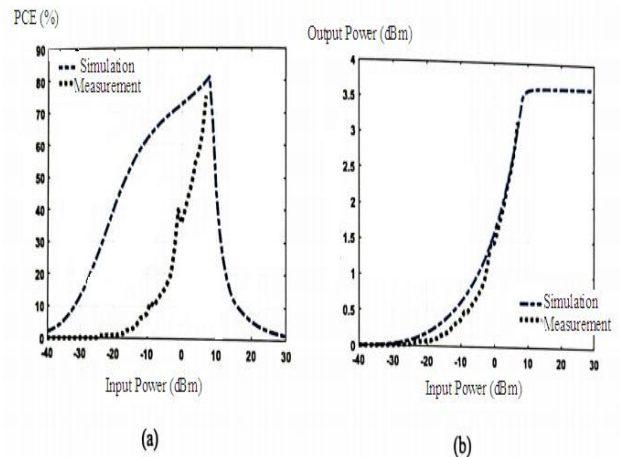


Fig. 5: a) Efficiency comparison of the designed circuit, b) Voltage comparison of the designed circuit
 Source: Measured by the authors

The simulation and measurement results of the Dickson rectifier designed to operate at 900 MHz were comprehensively analyzed and compared. As illustrated in Figure 5, the RF-to-DC conversion efficiency and the output voltage exhibit a consistent trend with respect to the input power level, and it was observed that the simulated and measured values were in close agreement. This correlation confirms the accuracy of the design methodology and the reliability of the component models used in the analysis.

To ensure effective power transfer, a matching circuit was incorporated into the rectifier structure. This network employs both lumped components and microstrip stub elements, enabling fine adjustment of the impedance characteristics around the target frequency. The measured return loss $S(1,1)$ was found to be below -10 dB across the operating frequency band, indicating that the reflection losses remained within acceptable limits and that the majority of the incident RF power was successfully delivered to the rectifier input.

An RF signal with input power levels ranging from -50 dBm to 7 dBm was applied to the rectifier during testing. This wide input range allowed evaluation of the circuit's behavior under both weak ambient signals and stronger, controlled sources. Additionally, the output load at 0.9 GHz was varied between 0Ω and 10 k Ω to assess the impact of load impedance on the harvested output power. The measurements demonstrated that the rectifier produced a usable DC output across a broad span of loading conditions, confirming the adaptability of the proposed design for different low-power electronic applications.

Overall, the results validate the effectiveness of the 900 MHz Dickson rectifier architecture and its matching network, highlighting its suitability for RF energy harvesting scenarios where stable performance, high efficiency, and compatibility with varying input conditions are essential.

6 Conclusions

As a result, in this study, a high-frequency rectifier circuit is proposed and designed to rectify the RF energy in the environment based on power spectrum analysis. With the results obtained, DC voltage is obtained efficiently by rectifying the electromagnetic waves emitted from the sources (Wi-Fi) in the environment. The matching circuit made with L-C and microstrip studs at the circuit input works harmoniously at 0.9 GHz frequencies. According to the simulation results, a DC voltage of 1.891V is obtained at the output with a 10Kohm load resistance against 5dBm input power. Low-power consumption sensors and sensor networks can be fed with the DC voltage obtained from the rectifier, or battery life can be extended by storing it.

RF energy harvesting provides several compelling benefits for modern electronic systems. Unlike solar or vibration-based energy harvesters, which depend on environmental conditions such as sunlight or motion, RF harvesters can operate continuously. Numerous infrastructures—such as mobile communication towers and television transmitters—constantly radiate RF energy, enabling reliable harvesting particularly in densely populated areas. Wireless communication technologies like GSM, WLAN, Wi-Fi, and Bluetooth operate within carrier frequency ranges of roughly 800 MHz to 2.5 GHz, and their signals can be exploited to generate microwatt-level power.

Because RF energy harvesting systems frequently employ isotropic or near-isotropic antennas, the amount of power received from the surrounding environment does not strongly depend on the relative phase alignment between the transmitter and the receiver. In other words, even if the electromagnetic waves arrive at different phases or from multiple directions, the antenna is still capable of capturing a meaningful portion of the available RF energy. This characteristic significantly simplifies system design, as it eliminates the need for precise orientation, directional tracking, or complex synchronization mechanisms that are typically required in other wireless power transfer methods.

Moreover, RF energy harvesting exhibits a high degree of resilience against environmental

fluctuations. Variations in temperature, humidity, or the availability of daylight—factors that strongly impact solar or thermoelectric energy harvesters—have only a negligible effect on the performance of RF-based systems. The primary requirement for stable operation is simply the presence of a sufficient level of ambient electromagnetic radiation, which is generally abundant in urban and semi-urban areas due to the widespread use of wireless communication technologies such as cellular networks, Wi-Fi routers, radio stations, and television transmitters.

These combined advantages—non-directional operation, independence from precise alignment, and robustness against environmental variability—underscore the strong potential of RF energy harvesting as both an alternative and complementary power solution for low-power electronic devices. By providing a continuous and maintenance-free energy source, RF harvesting can significantly extend device lifetime, reduce battery dependency, and enable long-term operation of wireless sensors, wearable electronics, and IoT nodes.

Declaration of Generative AI and AI-assisted Technologies in the Writing Process

The authors wrote, reviewed and edited the content as needed and verifies that none utilized artificial intelligence (AI) tools were used. The authors take full responsibility for the content of the publication.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

The authors contributed to the present research, at all stages from the formulation of the problem to the final findings and solution.

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Conflicts of Interest

The authors declare no potential conflicts of interest concerning the research, authorship, or publication of this article.

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