

# RF Energy Harvesting Using Yagi–Uda Antenna and Cascade Amplifier for Sustainable Power Generation

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**Abstract:** The rapid growth of wireless communication systems has resulted in the continuous presence of electromagnetic (EM) waves in the surrounding environment. Harnessing this ambient radio frequency (RF) energy offers a promising approach toward sustainable and supplementary power generation for low-power devices. This work presents a prototype system for RF energy harvesting and amplification. A Yagi–Uda antenna, selected for its high gain and directionality, is employed to capture ambient RF signals in the millivolt range (0.3–0.9 mV). To enhance the harvested signal, a two-stage cascade amplifier is implemented. The first stage amplifies the signal to approximately 3 V, while the second stage boosts it to nearly 30 V, making the output suitable for practical utilization. Experimental results demonstrate that the proposed system can convert freely available EM waves into usable electrical energy, highlighting its potential applications in powering wireless sensor networks, low-power electronics, and off-grid systems.

**Keywords** — RF Energy Harvesting, Yagi–Uda Antenna, Amplifier, Electricity Generation, Sustainable Power.

## 1 INTRODUCTION

The increasing demand for electrical energy, coupled with the depletion of conventional resources, has motivated the exploration of alternative and renewable sources of power. Among the emerging approaches, **radio frequency (RF) energy harvesting** has gained significant attention as a sustainable method of generating electricity from freely available electromagnetic (EM) waves present in the environment. With the rapid expansion of wireless communication systems, broadcasting stations, and mobile networks, ambient RF energy has become an abundant and untapped resource.

The fundamental principle of RF energy harvesting lies in capturing electromagnetic radiation using an antenna, converting it into electrical signals, and conditioning the output for practical utilization. However, the harvested signals are typically in the **millivolt range**, which makes them unsuitable for direct applications without further enhancement. This limitation necessitates the integration of **amplifier circuits** to boost the voltage levels to a usable range.

In this work, a **Yagi–Uda antenna** is employed for RF energy capture due to its high gain and directional properties, making it more efficient compared to other antenna types. The received low-level signal is processed through a **two-stage cascade amplifier**, where the first stage amplifies the signal from millivolts to approximately 3 V, and the second stage further enhances it to nearly 30 V. This combined system demonstrates the potential of converting ambient RF signals into a reliable power source.

The proposed approach has practical implications in powering **low-power electronic devices, wireless sensor networks, and off-grid applications**, thereby contributing to sustainable and green energy solutions. This paper presents the design, implementation, and analysis of the RF harvesting and amplification system, highlighting its effectiveness in addressing the growing need for alternative energy resources.

This work's primary contribution will be as follows:

1. Developed a Yagi–Uda antenna-based RF energy harvesting system capable of capturing ambient electromagnetic waves and boosting them from the millivolt range to a usable voltage level.
2. Implemented a two-stage cascade amplifier that successfully enhanced the harvested signal up to ~30 V, demonstrating its potential for powering low-power electronic and IoT devices.

Energy harvesting wireless communications have attracted significant attention in recent years due to their potential to enable self-sustainable systems. Ulukus et al. [1] reviewed recent advances in this area, outlining the theoretical foundations and practical challenges in integrating energy harvesting with wireless communication protocols. Building on this, Fowler and Zhou [2] proposed a metamaterial-inspired approach to RF energy harvesting, offering a new perspective on enhancing energy capture efficiency. Zhou et al. [3] highlighted the limitations of ambient RF energy levels available in realistic environments, pointing out that while feasible, practical harvesting is constrained by low power densities. Meanwhile, Hwang et al. [4] introduced a unique concept of using the human body as an antenna for electromagnetic energy harvesting, broadening the application scope of the technology.

Further developments focused on improving sensitivity, circuit design, and multi-band operation. Alevizos and Bletsas [5] investigated nonlinearities in far-field RF harvesting circuits, demonstrating improvements in efficiency at low input power levels. Ren et al. [6] explored the role of RF energy harvesting in cognitive radio sensor networks, identifying opportunities and challenges in spectrum sharing and energy transfer. Palazzi et al. [7] presented an ultra-lightweight multiband rectenna on paper substrates designed for next-generation LTE bands, while Shen et al. [8] advanced the field with a triple-band high-gain, multi-beam system capable of harvesting ambient RF energy more effectively. Shrestha et al. [9] earlier proposed a fractal-based dual-band patch antenna for miniaturized harvesting systems, contributing to antenna design innovations. Finally, Kuhn et al. [10] achieved a significant milestone with a multi-band stacked RF energy harvester exhibiting up to 84% RF-to-DC efficiency, setting a benchmark for practical and high-performance designs.

From the literature, it is evident that existing systems face challenges in terms of low harvested voltage, circuit complexity, and limited scalability. This motivates the present work, where a Yagi–Uda antenna is combined with a two-stage cascade amplifier to significantly boost the harvested voltage from the millivolt to tens of volts range. By simplifying the amplification stages while ensuring efficient energy transfer, this work aims to demonstrate a practical and effective solution for RF energy harvesting applications.

## 2 METHODOLOGY

The proposed system for electricity generation from ambient electromagnetic waves consists of two major stages: energy harvesting and signal amplification. The overall methodology is shown in Figure 1.

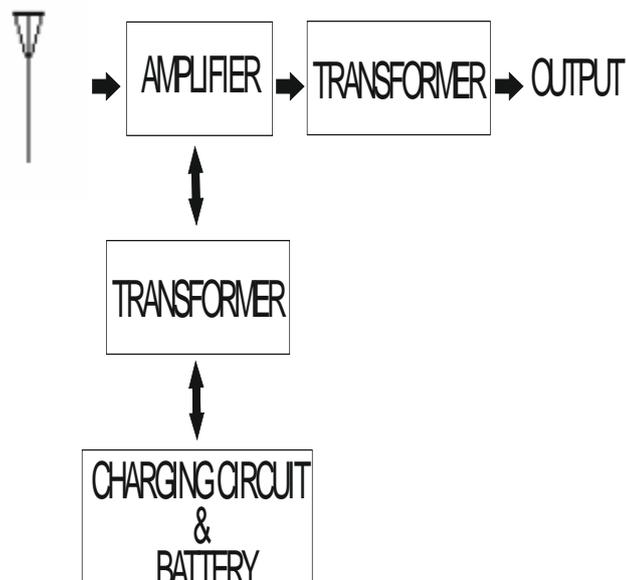


Figure 1: Block Diagram of Proposed System

#### 1. Antenna Design and RF Energy Harvesting

A Yagi–Uda antenna is used to capture electromagnetic (EM) waves from the environment. This antenna is selected due to its high gain, directivity, and ability to receive signals efficiently in the desired frequency range. When EM waves strike the antenna, a small alternating voltage in the range of 0.3 mV to 0.9 mV is induced at the antenna terminals.

#### 2. Impedance Matching

To maximize power transfer between the antenna and subsequent stages, an impedance matching circuit is included. This ensures minimal signal loss and optimal harvesting efficiency.

#### 3. Amplification Stage – Cascade Amplifier

Since the harvested voltage is too low for practical applications, a two-stage cascade amplifier is implemented and is shown in Figure 2:

**Stage 1 Amplifier:** Increases the signal from the millivolt level to approximately 3 V.

**Stage 2 Amplifier:** Further boosts the voltage to nearly 30 V, making it suitable for powering low-power devices. The amplifiers are designed with proper biasing to ensure linear operation and minimal distortion.

#### 4. Output Utilization

The amplified output can be stored in an energy storage device (such as a capacitor or rechargeable battery) or directly used to power low-power electronic devices and wireless sensor nodes.

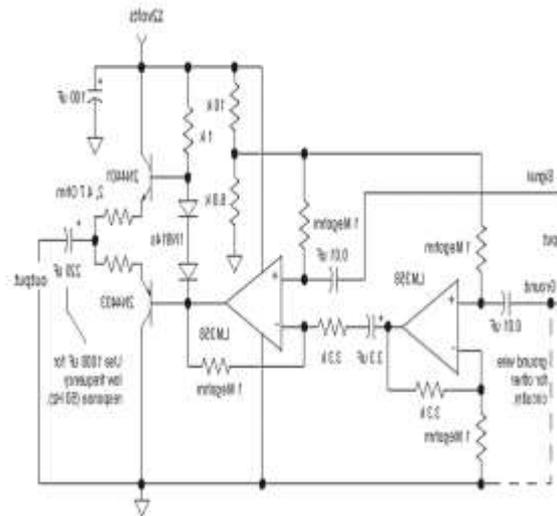


Figure 2: Cascaded Amplifier

### 3 RESULTS AND DISCUSSION

The proposed RF energy harvesting and amplification system was designed and tested using a Yagi-Uda antenna and a two-stage cascade amplifier. The performance was evaluated in terms of harvested voltage levels, amplification efficiency, and potential applications.

#### 1. Harvested RF Signal

The Yagi-Uda antenna shown in Figure 3 successfully captured ambient electromagnetic (EM) waves from nearby broadcasting and communication sources. The induced voltage at the antenna terminals was observed in the range of 0.3 mV to 0.9 mV, depending on the strength and orientation of the incoming signals. This confirms that although ambient RF energy is abundant, the captured power level is extremely small and requires signal enhancement. Figure 4 illustrates forward gain of a two element Yagi-Uda array using only a driven element (left) and a director (right). The wave (green) from the driven element excites a current in the passive director which reradiates a wave (blue) having a particular phase shift (see explanation in text). The addition of these waves (bottom) is increased in the forward direction, but leads to cancellation in the reverse direction.

One must take into account an additional phase delay due to the finite distance between the elements which further delays the phase of the currents in both the directors and reflector(s). The case of a Yagi-Uda array using just a driven element and a director is illustrated in the accompanying diagram taking all of these effects into account. The wave generated by the driven element (green) propagates in both the forward and reverse directions (as well as other directions, not shown). The director receives that wave slightly delayed in time (amounting to a phase delay of about  $35^\circ$  which will be important for the reverse direction calculations later), and generating a current that would be out of phase with the driven element (thus an additional  $180^\circ$  phase shift), but which is further advanced in phase (by about  $70^\circ$ ) due to the director's shorter length. In the forward direction the net effect is a wave emitted by the director (blue) which is about  $110^\circ$  ( $180^\circ - 70^\circ$ ) retarded with respect to that from the driven element (green), in this particular design. These waves combine to produce the net forward wave (bottom, right) with an amplitude slightly larger than the individual waves.

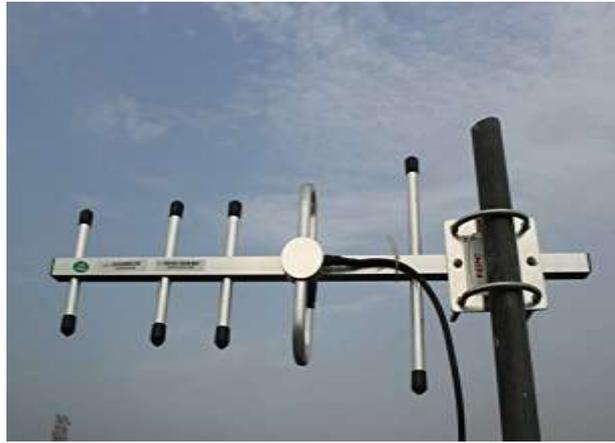


Figure 3: Yagi-Uda antenna

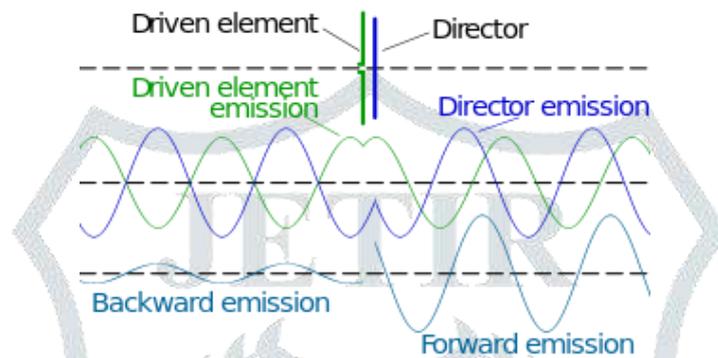


Figure 4: Yagi-Uda Array

## 2. Amplification Performance

In the first amplifier stage, the harvested signal was boosted to approximately 3 V.

In the second amplifier stage, the voltage was further increased to nearly 30 V.

This two-stage amplification demonstrated a significant improvement in signal strength, effectively converting otherwise unusable millivolt-level energy into a practical voltage range.

## 3. Efficiency Considerations

The efficiency of the overall system depends on the antenna's gain, impedance matching accuracy, and amplifier losses. While some power loss was observed during amplification, the cascade design ensured that the harvested energy was enhanced without requiring complex or power-hungry circuits. The choice of the Yagi-Uda antenna played a critical role in maximizing captured energy.

## 4. Applications

The amplified output was able to power low-power electronic components and showed potential for:

Wireless sensor networks (WSNs) in remote locations

Low-power IoT devices

Off-grid energy support systems

Supplementary charging for small storage units (capacitors or rechargeable batteries)

The results indicate that while RF energy harvesting alone may not replace conventional power sources, it can serve as a supplementary and sustainable energy solution. The proposed system demonstrates that with proper antenna design and multi-stage amplification, ambient electromagnetic energy can be converted into usable electrical power. This makes the approach promising for future green energy applications, particularly in powering distributed low-power devices.

#### 4 CONCLUSION

This work demonstrates a practical approach for harvesting ambient RF energy using a Yagi–Uda antenna combined with a two-stage cascade amplifier. The system successfully converted weak millivolt-level signals into a usable voltage output of nearly 30 V, showing its capability to power low-power IoT devices, wireless sensor nodes, and portable electronics. While RF harvesting alone may not replace conventional power sources, it offers a sustainable and supplementary energy solution for future low-power applications. With further optimization in antenna design, impedance matching, and amplifier efficiency, the proposed method can contribute significantly toward the realization of green, self-powered electronic systems. The system can be further improved by optimizing antenna design and integrating efficient rectifiers with energy storage elements. Hybrid energy harvesting with solar or thermal sources can enhance reliability for real-time IoT and low-power applications.

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