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ENERGY HARVESTING FROM TELEVISION FREQUENCY: CASE STUDY OF RECTIFYING ANTENNAS

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Abstract: **Various research trends have tended to investigate the viability of powering these circuits using either a dedicated RF source from television frequencies (TF) or free energy harvested from ambient electromagnetic space due to the rapid development of wireless systems and demands for low-power integrated electronic circuits. In order to enable battery-free sustainable wireless networks, radio frequency energy harvesting (RFEH) and radiative wireless power transfer (WPT) have gained a lot of attention. Rectenna is primarily a combination of a receiving antenna and a rectifier circuit used to convert RF energy into usable DC electrical energy. The foundation of WPT and RFEH systems, rectifying antennas (rectenna), play a crucial role in the quantity of direct current power delivered to the load. The radiation to AC harvesting efficiency of the rectenna directly affects the gathered power, which can vary by orders of magnitude. The television frequency in the study area is taken into account in this essay so that it can be converted to usable dc voltages and currents.**

Key words: **Antennas, AC, Current, DC, Efficiency, Rectifying, RFEH, RF, TF, Voltage, WPT.**

I. INTRODUCTION

Photovoltaic (PV) and thermal solar cells are mostly used at an industrial scale to extract energy from electromagnetic (EM) waves. However, neither of these approaches makes use of the radio spectrum's wave-like properties. On the other hand, this wave nature has been utilized for communication and informational purposes in gadgets like radios, televisions, and phones for more than a century. Nothing prohibits the development of electrical devices that can collect ultrahigh frequency (UHF) wavelengths greater than radio frequencies (RF), both theoretically and practically. A portion of the energy carried by EM waves can be captured by rectifying this oscillating signal into a direct flow of electronic charges. Devices suitable for this activity include rectenna, also known as rectifying antennas. They consisted of two primary components: a rectifying circuit that operated at the frequency of the gathered radiation, and an antenna made to fit the size of the wavelength to be harvested. According to [12], the physical properties of the propagation medium, air, have hampered Omni-directional long range WPT. Therefore, near-field non-radiative power transfer for wireless consumer electronics charging or short-range radiative Radio Frequency Identification (RFID) has been the two main applications of commercial WPT. It has become more practical to power sensor nodes utilizing ambient Radio Frequency Energy Harvesting (RFEH) or distributed low-power Omnidirectional transmitters as semiconductor device and wireless sensor node power consumption continues to decline [13, 2]. Thanks to the expansion of edge devices and extensive implementation research, WSNs have a wide range of applications, from remote applications to body area networks. A typical WSN's objective is to monitor the environment using sensors, microcontrollers, transceiver data storage, and energy storage facilities (batteries). A node's battery provides power, and a WSN's battery capacity decides how long it will last. Energy harvesting is thought to be an acceptable answer to the problem created by the battery's short lifespan. According to the applications, numerous researchers have recently tried to produce EH utilizing different energy harvesters. Numerous EH sources, including as the sun, wind, heat, vibration, temperature, electromagnetic, and others, are present at the same time. For instance, the most accessible, pervasive, and dependable energy source is RF energy [1]. A basic block diagram of the RF harvesting system is shown in Figure 1. A typical Rectenna consists of a matching network, an energy conversion unit, a load/storage device, and a transceiver antenna. The ambient RF signal is initially detected by the antenna. The rectifier picks up an AC signal because of how sensitive to RF signals.

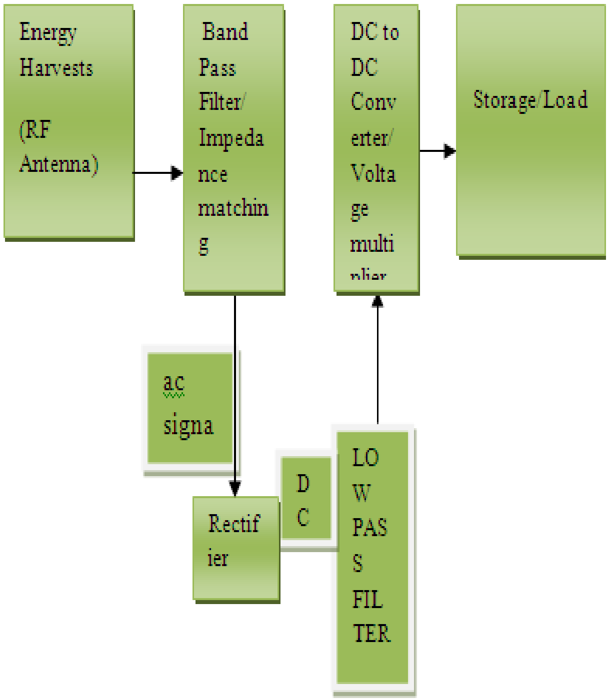

Figure 1: shows an example block diagram of an RF energy harvesting system.

One or more diodes in the rectifier have quick switching capabilities that are utilized to convert AC signals into DC. A low pass filter is utilized to get the best power transfer for the antenna and rectifier's impedance matching. For output voltages with a higher level, a voltage multiplier can be utilized. Micro strip patch antennas, dipole antennas, bipolar antennas, array antennas, planar antennas, Yagi-Uda antennas, Helix antennas, parabolic antennas, and many other types of antenna designs exist. These antennas can be utilized for a variety of applications because they have various designs, structures, and qualities. RF signals can be captured by the antenna. The signals do, however, contain some harmonics that result in interference and signal losses. Low-pass filtering is used to reduce harmonics that are produced. Harmonic rejection is a function of the low-pass filter that helps to reduce power losses. After producing the smooth AC signals, rectification is required. Signals are rectified using rectifying diodes in a rectifier. Three different rectifier arrangements exist: bridge of diodes, voltage multiplier, and single diode. DC voltage can be delivered to the load using single diode and bridge rectifiers. The output signals' amplitude, however, is less than the received signals'. The voltage multiplier is utilized because it may increase the received signals' amplitude by twofold. The load resistance is the final phase of the rectenna design. In order to attain high output DC voltage, load resistance is regulated during design. The storage and control unit serves as an ongoing power source. Because they don't need to move mechanically, RF harvesters are more powerful than conventional energy harvesters [3].Cellular transceivers, wireless LAN, TV broadcasts, and radio (FM and AM) transmitters all emit RF as background radiation [4]. Although it is possible to collect ambient signals using straightforward electronic circuits, RF harvesters have a number of challenges. Because RF signals are available over a wide frequency range, the RF harvester must offer proper impedance matching in order to maximize power transmission. The RF should employ large broadband antennas in order to collect sound energy from signals distributed across a wide area. The harvesting circuits must be located near to the RF power source due to insufficient ambient levels. Due to the low energy density and low efficiency, even a high-gain antenna cannot generate considerable power densities. With compact, high gain, impedance-matched broadband antennas and a dedicated RF energy supply mechanism, energy harvesting in low-power WSNs seems to be more feasible and promising. The spectacular growth of mobile phones and Wi-Fi networks has increased the importance of RF energy in cities [5]. An antenna and a rectifier are combined to form a rectenna. The RF should employ large broadband antennas in order to collect sound energy from signals distributed across a wide area. The harvesting circuits must be located near to the RF power source due to insufficient ambient levels. Due to the low energy density and low efficiency, even a high-gain antenna cannot generate considerable power densities. With compact, high gain, impedance-matched broadband antennas and a dedicated RF energy supply mechanism, energy harvesting in low-power WSNs seems to be more feasible and promising. The spectacular growth of mobile phones and Wi-Fi networks has increased the importance of RF energy in cities [5]. An antenna and a rectifier are combined to form a rectenna**.**

II. CONCEPT AND REVIEW OF RELATED WORKS

The provision of affordable and clean energy is the seventh Sustainable Development Goal (SDG), which aims to satisfy the rising demand for energy while reducing the carbon footprint and stress on the environment [6]. One of the best methods for reaching this goal seems to be energy collecting. EH stands for a method of obtaining and preserving energy from naturally occurring sources in our world. EH, often referred to as Energy Scavenging (ES), makes it possible to avoid the inconvenience of frequently replacing batteries [7] while being more cost-effective and environmentally friendly. For wireless nodes and other low power loads that must be continually powered, EH is a viable alternative. Several attempts have been made to create EH schemes based on the availability of energy sources such solar, piezoelectric, wind, hydropower, and RF signals. The most suitable technology is RF-EH since the energy source is readily and abundantly available in transmitted energy. Additional significant benefits include application in small form factors, economic viability, and environmental friendliness [8]. RF-EH has the potential to revolutionize low-power applications, particularly for WSNs. Excessive battery consumption necessitates disposal, which adversely pollutes the environment [9]. Utilizing RF-EH, power may be constantly provided and node lifespan can be increased [10]. Due to its sustainability, RF-EH and passive energy scavenging nodes without batteries will power the next generation of WSNs [11].

III. THEORETICAL FRAMEWORK

Designing an RF-EH system requires a thorough understanding of EM waves. Regarding length, frequency, and conducting environment, EM waves can be extensively classified. To get the most out of the design, the designer must decide on the EM wave characteristics based on the application. The relationship between electromagnetic waves and separation from a transmitting antenna is divided into near-field and far-field categories. The wavelength of the radio wave is the value of the Fraunhofer distance, which bears Joseph von Fraunhofer's name. The boundary between the near and far fields can be found at this distance.

$$\text{Reactive Near field} \leq 0.62 \times \sqrt{\frac{D^3}{\lambda}} \qquad 1$$

$$\text{Reactive Near field(Frensel region)} \leq \frac{2D^2}{\lambda} \qquad 2$$

$$\text{Far field} \geq \frac{2D^2}{\lambda} \qquad 3$$

Where $\lambda = \frac{c}{f}$ taking c to be speed of light at 3×10^8ms and f the frequency and D is the maximum dimension of the antenna.

Friis Equation provides the received power for a transceiver antenna in the far-field. $P_r = \left(\frac{\lambda}{4\pi R}\right)^2 G_r G_t P_t$

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Where R is the distance between the antennas, G_t is the gain of the receiving antenna, and G_r is the gain of the transmitting antenna. P_r is the power received, P_t is the power broadcast by the antenna.

Also P_r can be express in term of power flux density and efficiency as

$$P_r = Wf.\frac{\pi Dr^2 \eta}{4} \qquad 5$$

Where D_r is the receiver antenna diameter, η is the antenna efficiency, λ is the wavelength and Wf is the power flux density and can be express as

$$Wf = \frac{PL_l G_t l_a}{4\pi S^2} \qquad 6$$

L_a is the Transmission path loss, P is the transmitter power, L_l is the line loss and S is the Path length therefore the power received can be express also as

$$P_r = \frac{PL_l G_t L_a}{4\pi S^2} \times \frac{\pi Dr^2 \eta}{4} = \frac{PL_l G_t L_a \pi Dr^2 \eta}{16\pi S^2} \qquad 7$$

Gain of the receiving antenna is express as

$$G_r = 20Log\pi + 20LogD_r + 20Logf + 20Log\eta - 20LogP_r \qquad 8$$

π =3.142 and f is the frequency of operation,

IV. RESEARCH METHODS

The accessible television frequency and the design of the rectifying antenna to fit the available TV frequency are the two main factors taken into account in this research work.

A. Area under Study

Ondo State Radio Vision Corporation (OSRC), one of the state's chosen television stations, can be found on UHF Channel 23 at Latitude 7.30°N and Longitude 5.16°E. Its receiving antenna is situated at Akure Sunday bus stop on Ijoka Road at Latitude 7.21°N and Longitude 5.19°E, 10.73 kilometers away from the broadcasting station.

B. Antenna Design

A dipole antenna is therefore being employed in this study since an ultra-high frequency television station is being investigated. According to theory, the dipole is the most basic kind of antenna. The feed line is connected between two conductors that are typically of similar length and arranged end to end. Resonant antennas that use dipoles are common. An antenna of this type will be able to resonate at a specific frequency if the feed point is shorted, much like a plucked guitar string. The antenna's length is dictated by the intended wavelength (or operating frequency), as using it at or near that frequency is favorable in terms of feed point impedance (and consequently standing wave ratio). The center-fed half-wave dipole, which is little under a half-wavelength long, is the most widely utilized. The half-wave dipole's radiation pattern is most intense perpendicular to the conductor and diminishes to zero in the axial direction, resulting in an omnidirectional antenna when put vertically or (more frequently) a weakly directional antenna when installed horizontally. Since the primary purpose of the dipole antenna we are studying is to receive energy radiated from the transmitter.

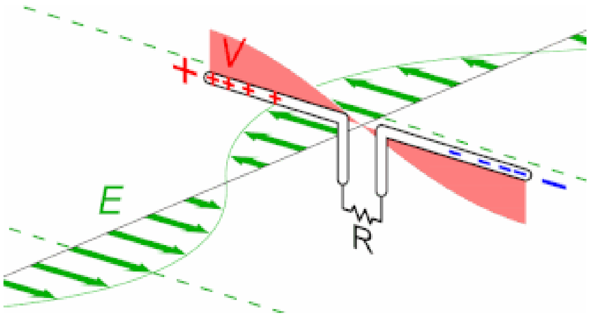

Figure 2: A dipole Antenna

The effective length of the dipole antenna is calculate as

$$V = L_e E \qquad 9$$

Therefore $L_e = \frac{V}{E}$

Where V is the induced voltage at the terminal of the receiving antenna while E is the induced field strength.

Power delivered

$$W_{max} = \frac{V^2}{4R_r}, \qquad 10$$

Recal $L_e = \frac{V}{E}$

$V = EL_e$

$$W_{max} = \frac{(EL_e)2}{4\pi R_r} \qquad 11$$

Maximum Effective Aperture

$$(Ae)_{max} = \frac{\text{maximum received power}}{\text{power density of incident wave}} \qquad 12$$

$$(Ae)_{max} = \frac{v^2}{4R_rP} = \frac{E^2 L_E{}^2}{4R_rP} \qquad 13$$

Since $P = \frac{E^2}{Z_0}$

$$(Ae)_{max} = \frac{E^2 L_E{}^2}{4R_r\frac{E^2}{Z_0}} = \frac{L_E{}^2 Z_0}{4R_r} \qquad 14$$

D. Rectification Circuit

The arrangement of a rectifier Signal rectification can be accomplished using diodes, transistors, or complementary metal-oxide-semiconductor (CMOS) technology. Using a rectifier, radio frequency signals received by an antenna are converted from alternating current (AC) to direct current (DC). The many signal rectification topologies include the following:

1. Half-wave (HW) rectification refers to the process of allowing only the positive or negative half of an alternating current wave to travel while blocking the other half. Rectifiers generate pulsing, unidirectional direct current (DC).

Half Wave Rectifier equations and values

Average voltage, $V_{average} = V_m/\pi$
Average Current, I average = I_m/π
Rms Voltage, $V_{rms} = V_m/2$
Rms Current, $I_{rms} = I_m/2$
Ripple factor = 1.21
Maximum efficiency = 40.6%
Transformer utilization factor (TUF) = 0.287
Form factor = 1.57
Peak factor = 2

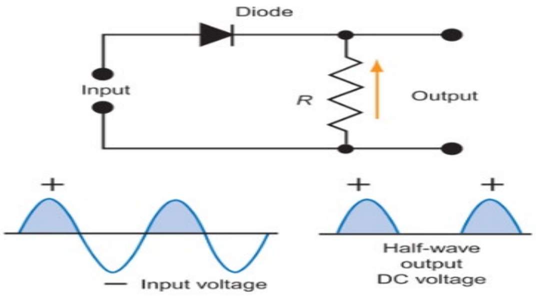

Figure 3: Half-wave (HW) rectification

Half-wave rectifiers emit greater ripples than full-wave rectifiers, which calls for the employment of substantially more filtering to exclude harmonics of the alternating current frequency from the output. The most widely used half-wave rectifying circuit is made out of a single diode in a serial configuration. Schottky diodes and other built-in voltage-lower diodes can typically attain higher conversion efficiencies than built-in voltage-higher diodes. It is possible to lower the diode loss, which is expressed in terms of the diode junction resistance, using the series and shunt single diode topologies. There are three (3) distinct designs of the half-wave rectifier namely (a) shunt, (b) series, and (c) full-wave rectifier.

Schottky diodes have been employed on occasion, and the Dickson charge pump topology is the most popular one. However, because of the high threshold voltage of diodes, obtaining an efficient output is difficult. The metal-oxide semiconductor field-effect transistor (MOSFET), which has the ability to overcome the limitations of diodes, has emerged as a potential replacement for rectifiers. The maximum voltage that can be produced at the output is this.

$$\mathrm{Vout(dc)} = 2\mathrm{Vin(RF)} - \mathrm{Vth}$$

2) A technique called full-wave (FW) rectification turns the complete input waveform into an output waveform with constant polarity. (either positive or negative). An input waveform that has been fully rectified becomes pulsating direct current (DC) in both polarities and has a greater average output voltage.

Full wave Rectifier equations and values

Average voltage, $V_{average} = 2V_m/\pi$
Average Current, $I_{average} = 2I_m/\pi$
RMS Voltage, $V_{rms} = V_m/\sqrt{2}$
RMS Current, $I_{rms} = I_m/\sqrt{2}$
Center tap rectifier, Transformer utilization factor (TUF) = 0.693
Bridge rectifier, Transformer utilization factor (TUF) = 0.812
Ripple factor = 0.482
Maximum efficiency = 81.2%
Form factor = 1.11
Peak factor = $\sqrt{2}$

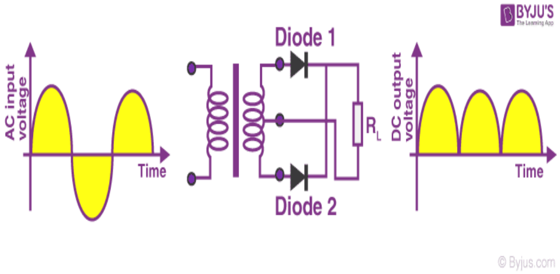

Figure 4: Full-Wave (FW) rectification

3) **Full wave Bridge Rectifier four diode**

Four diodes are required in an FW bridge rectifier system in order to reduce overall losses and keep the number of diodes to a minimum. It was discovered that a full-wave rectifier is a good replacement for higher input power-density levels since the output can be decreased by taking the losses brought on by the diodes into consideration. When the power obtained is inadequate to power the circuit, the rectifier input needs to be increased. A multiplier-rectifier circuit can be used as a substitute in some circumstances. The three different types of rectifier circuit designs are the voltage doublers, which uses capacitors and two diodes, the voltage multiplier, and the primary rectifier, which uses a capacitor and a single diode.

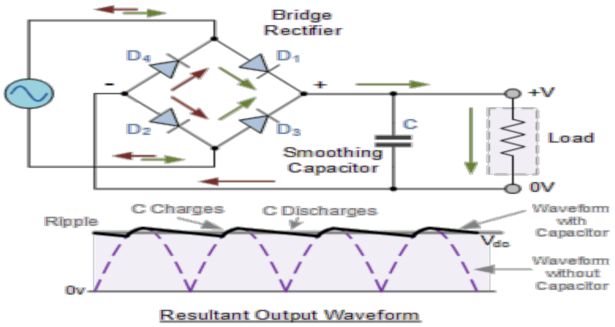

Figure 5: Full wave Bridge Rectifier

E. RF INPUT FILTER

RF Filter Design

A filter is used to remove specific harmonics from the RF input signal from the TV station that are unnecessary there given the sampling frequency. Because it allows a specific frequency range or UHF Group to pass while attenuating everything else, a band pass is required. These can be used to filter out unwanted signals or interference. However, one needs to be aware of the frequencies that the TV transmitter broadcasts on in order to choose the right filter. Since the TV station using UHF 23 with a carrier frequency of 487.25 is running beneath the study area, a Group A Band pass Filter is required. Group A Band pass Filters may filter frequencies between 470 and 606 MHz for UHF channels 21 to 37. Group A is generally represented by the color red. The frequencies outside of a Group A band pass filter are muted as these frequencies pass through it.

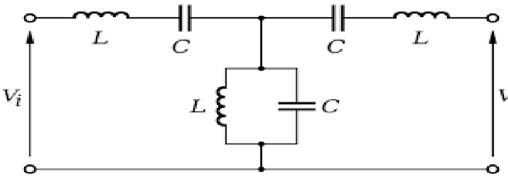

Figure 6: Group A band pass filter

F. IMPEDANCE MATCHING

In order to prevent standing waves and to ensure effective power transfer from the source to the load, it is essential that impedances in RF circuitry be matched. Single-Band Impedance Matching and Multiband Impedance Matching are the two fundamental impedance matching networks.

i. Single-Band Impedance Matching

Impedance matching, the connection between the antenna and the rectifier circuit, sends the most power from the antenna to the rectifier circuit. Numerous approaches have been used to study impedance matching topologies thus far. When compared to the L-type, this type impedance matching performs better. Additionally, while effective impedance matching (IM) is simpler to establish for single-band rectenna, it is considerably more difficult for multiband and broadband rectenna to achieve. A single band impedance matching network was utilized in this situation.

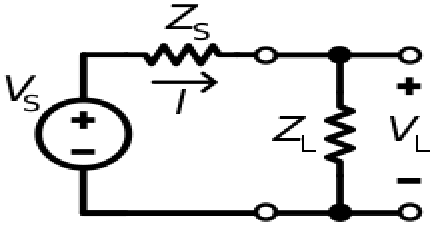

Figure 7: Single-Band Impedance Matching

G) Power Management section of rectifying antenna

Based on the energy harvested, a power management section (PMS) makes sure the load receives the proper power conditions. A commercial or customized power management system can be utilized, depending on the design limitations, whether the load requires a controlled or accurate voltage or if the load requires precise running times. Finally, because to their high power density, quick loading and unloading, extended cycle life, small size, and lower cost compared to batteries, super capacitors are chosen in Energy Harvesting systems. The PMS's main objectives are to maximize the quantity of energy transmitted from the antenna to the reservoir in real-time and to accurately and effectively control the supply voltage of the sensor node.

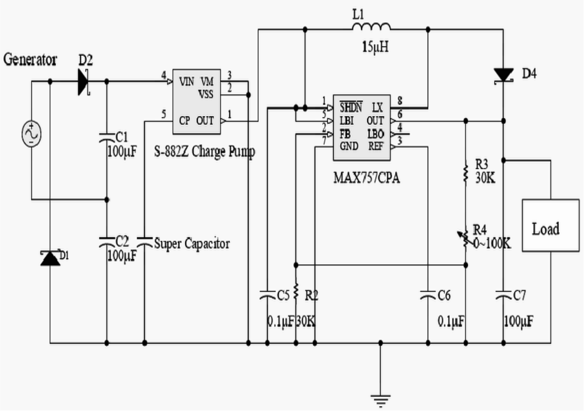

Figure 8: Power Management section of rectifying antenna

V. CONCLUSION

Since a few years ago, the idea of light rectification for energy production or photo detection has entered a proof-of-concept stage. Due of its extensive multidisciplinary nature and the applications it provides, this topic of study is quite intriguing. Research in this area necessitates the integration of numerous cutting-edge technological building blocks from various fields, including molecular electronics and nanophotonics. This combination of abilities is advantageous to all the scientific groups involved since it raises new issues regarding the symbiosis of previously optimized technological components and their interaction and integration. A new sector of creative solutions for the production of energy from sunlight or photo detectors may become available in the next years as a result of the convergence of these various sorts of knowledge. The SDGs make the energy crisis unavoidable, and resources will take advantage of it. Energy scavenging is the preferred method for extending the node's lifespan in a low-power device that is installed remotely. This work takes into account widely accessible and cost-free RF signals to collect from the UHF television band. A dipole antenna is chosen as the antenna type for this frequency.

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