ISSN(O): 2456-6683
[ Impact Factor: 7.148 ]
January - 2024

DOIs:10.2017/IJRCS/202401031 --:-- Research Paper / Article / Review

# Towards sustainable wireless communication: Investigating SWIPT for RF energy harvesting

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***Abstract:*** *As our dependence on wireless technologies grows, so does the need for sustainable and efficient power solutions. This paper introduces the realm of Simultaneous Wireless Infor- mation and Power Transfer (SWIPT) and RF Energy Harvesting (RF-EH), offering a glimpse into their working principles and underlying technologies. We delve into the core concept of SWIPT, where radio waves carrying data simultaneously deliver energy to power low-power devices. Over the past decade, advancements in RF-EH and its related technologies, including WPT-assisted techniques and Simultaneous Wireless Information and Power Transfer (SWIPT), have been significant. By providing a foundational understanding of these emerging technologies, this paper paves the way for further exploration and innovation in the field of green wireless communication.*

***Key Words:*** *SWIPT, RF-EH, WPT.*

## 1. INTRODUCTION:

Continuous and uninterrupted power supply is a major requirement of modern gadget based society. To meet this need, several energy harvesting approaches are being adopted for different purposes, using renewable energy resources, such as solar, wind etc. However, the intermittent and unpredictable nature of such energy sources makes energy harvesting crit- ical for applications where quality-of-service (QoS) is of paramount importance. The limitation with conventional har- vesting technologies is that they are applicable under certain environments such as daylight, wind flow, water flow etc. Radio Frequency (RF) signals for energy harvesting maybe used to tackle this shortcoming, and called Wireless Power Transfer (WPT). Under WPT the RF radiation is used to produce electricity to charge batteries [1]. It is of interest to integrate such RF energy harvesting technologies into communication networks. WPT is centered around near-field energy transmission through inductive coupling (e.g., used for charging cell-phones, medical implants, and electrical vehicles). With sensors and wireless transceivers getting ever smaller and more energy efficient, radio waves reaching them can become an alternate source of energy for operating these devices. It implies that at a communication network, information and energy transmission aspects get unified. So both ways i.e. a RF communication network can be used to carry energy and vice a versa a power network can carry information signals. Together both these techniques coined the term of Simultaneous Wireless Information and Power Transfer (SWIPT) [2].

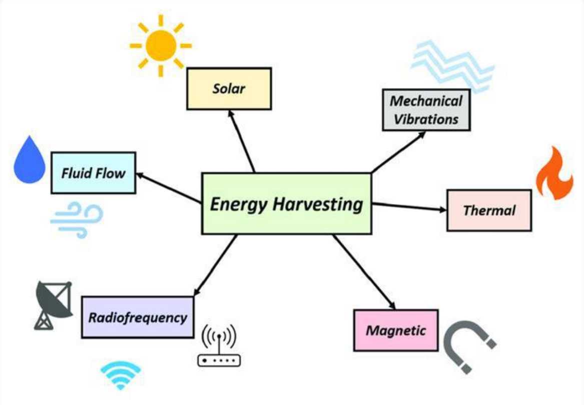


**Fig. 1. Energy harvesting sources**

SWIPT can yield in significant gains in terms of spectral efficiency, time delay, energy consumption, and interference management by superposing information and power transfer. Under SWIPT two functional blocks works :-

i. EH block for energy harvesting and
ii. ID block for information decoding sent by the transmitter, by use of splitting mechanism, i.e. transferring received RF signal to ID path and EH path.

First functional aspect is called Power Splitting (PS), uses signal power distribution for ID path and EH path using power split ratio. The second part is Time Switching (TS) using which a received RF signal gets divided alternatively between the EH and ID paths.

## 2. MODULATION TECHNIQUES :

Modulation is a process by which some characteristics of a carrier is varied in accordance with a modulating signal. In Digital communication, the modulating signal consists of M-ary encoding of information mainly binary (M=2), which is used to modulate a carrier wave. The channel may be a telephone channel, microwave radio link, satellite channel or an optical fiber [3]. In Digital communication, the modulation process involves switching or keying the Amplitude, Frequency or Phase of the carrier in accordance with the input data. There are three basic modulation techniques for the transmission of digital data :-

- Amplitude Shift Keying (ASK)
- Frequency Shift Keying (FSK)
- Phase Shift Keying (PSK)

The three basic forms of Signalling Binary Information are shown in Fig.1.1

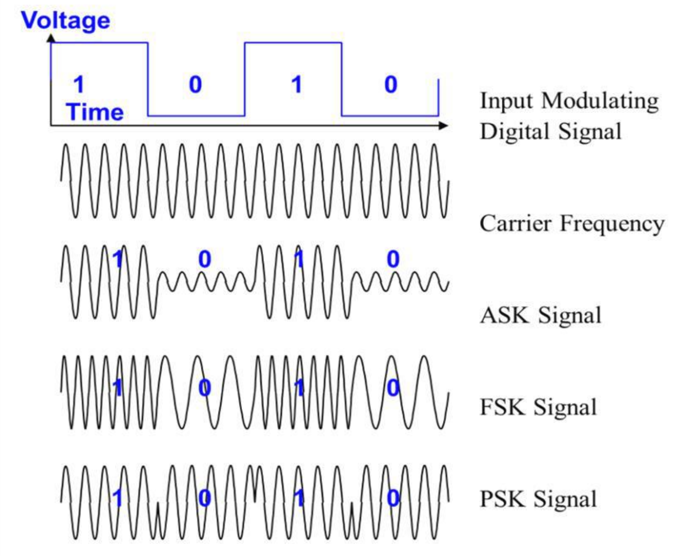


**Fig. 1.1. The three basic forms of signalling binary information**

## 3. SIMULTANEOUS WIRELESS INFORMATION AND POWER TRANSFER (SWIPT)

Wireless devices communicate with each other using RF electromagnetic radiation. Generally such gadgets are equipped with a limited supply of battery life. With a large number of energy-constrained wireless sensors, especially those entrenched in remote, isolated or high-risk environments, recharging or replacing batteries cannot be carried out very easily. Especially in IoT based systems where a large number of servers are isolated in remote places are installed, battery replacement or recharge is costly affair. To cater this need, the primary focus is given on wireless Energy Harvesting (EH) techniques. Under such applications natural resources of energy such as solar, thermal and wind energy can be used to perform EH but their size and cost is much higher than sensor. Further, the random and impulsive nature of these resources makes them unreliable to be used for applications where Quality-of-Service (QoS) is a must requirement. Here, RF energy harvesting offers significant advantages as it is wireless, has low cost, and terminals harvest energy from electromagnetic radiation. It harvests the energy from ambient electromagnetic sources or from sources that intentionally transmit electromagnetic energy for energy harvesting purposes [4].

Wireless Power Transfer (WPT) is an innovative technology employed for enhancing the energy sustainability of wireless devices. Hence integrating, WPT with wireless communication transmission leads to the idea of

Simultaneous Wireless Information and Power Transfer (SWIPT) that is to transfer information and power to wireless devices simultaneously. It shall result in a drastic increase in efficiency of the network. The benefit of EH is centred at the concept of Radio Frequency (RF) signals carrying energy and information together, thus enabling the energy-deficient nodes for decoding information and scavenging energy simultaneously. The two fundamental approaches, Wireless Power Transfer (WPT) and Wireless Information Transfer (WIT), can be used for power- only and communication-only, respectively. On the other hand, Simultaneous Wireless Information and Power Transmission (SWIPT) is a combined proposition that can transfer power and carry information at the same time. It gently grows and provides conciliation between the two basic approaches and uses the RF spectrum adequately to initiate communication and energize the system. This technique facilitates and enables trillions of low-power wirelessly connected devices, e.g., IoT, to communicate and get energy anytime and anywhere.

**a) WPT COMPONENTS**

Exchanging power via electromagnetic fields can be classified into three distinct cases:

i. Near-field Wireless Power Transfer (NF-WPT) utilizes non-radiative coupling mechanisms, such as inductive, capacitive, or resonant, to efficiently transfer electrical energy over short distances, typically up to one meter (sub-wavelength), at power levels ranging from milli-watts to tenths of watts. This localized energy transfer eliminates concerns about electromagnetic interference and radiation exposure, making it ideal for applications requiring precise targeting and safety. There are several applications related to near field wireless charging, such as wireless charging of electric cars, cell phones or other hand-held devices.

ii. Far-field WPT operates in the non-radiative regime, utilizing directional antennas to transfer power in the milliwatt range over distances of several meters within both indoor and outdoor environments. However, precise antenna alignment is crucial for efficient power delivery.

iii. Far-field RF energy harvesting operates in the micro- watt range, relying on scavengers to opportunistically capture RF emissions from existing transmitters like base stations and broadcasting stations. This approach enables long-range communication (several kilometres) but requires careful consideration of path loss and energy conversion efficiency.

A wireless power receiver (Fig.2.1) consists of the following components: A receiver antenna or antenna array, a Matching Network, a Radio Frequency to Direct Current (RF-DC) converter or rectifier, a Power Management Unit (PMU) and the energy storage unit [5]. Upon the successful charging of the energy storage unit, the storage unit, usually a recharge- able battery or a super capacitor will provide power to the Central Processing Unit (CPU), the sensors and the low duty cycle communication transceiver. Complete schematic of this module is depicted by Fig.2.1.

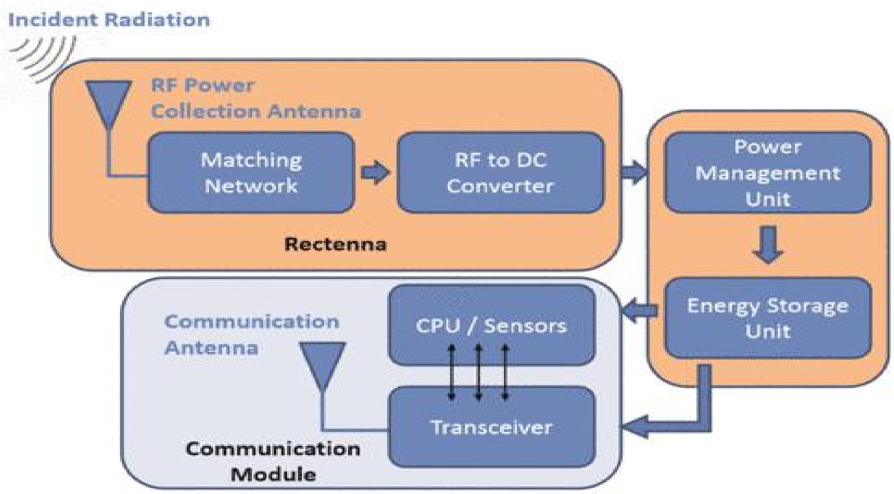


**Fig. 2.1. Block diagram of power receiver module powering a communication transceiver**

**b) WIT COMPONENTS**

Under state-of-art technology of communication systems, modules like transmitters and receivers or transceivers plays key role in transferring and receiving the data. A Radio systemincludes a source of electromagnetic wave with a planneddestination for that message. A source radio is referred toas the transmitter while the destination radio is called thereceiver. They are designed and assembled from core modularlevel components. There are many wireless transmitters and receivers modules available such as RF, Zigbee, Bluetooth,GT (FM), etc., which are interfaced to process the data from source to destination.

- **Design and Construction of Transmitter Modules**

  The transmitter modules like RF, RFID, GPS, etc., are constructed with Mixer or modulator, crystal oscillator, power amplifier and filter circuits. The transmitters work with the analog signals therefore it cannot directly inter- face to the digital devices like microcontrollers/processors hence an external device called a decoder is needed. The Transmitter module is interfaced with the microcontroller using such a decoder. The microcontroller sends digital data to the decoder, which converts them into a current signal which passes through the modulator wherein high-frequency signals from the oscillator are also received. These two signals gets mixed, and then passed through the amplifier. Amplifying the transmission signals through an amplifier increases the strength of the signals. The band pass filter allows the signals with two specific frequencies like 900 MHz – 915 MHz to pass and reject the frequencies outside the range. The antenna radiates power in the air [6]. The entire process schematic is shown at Fig.2.2. The block diagram mainly consists of three blocks; microcontroller block, digital to analog converter and transmitter blocks.

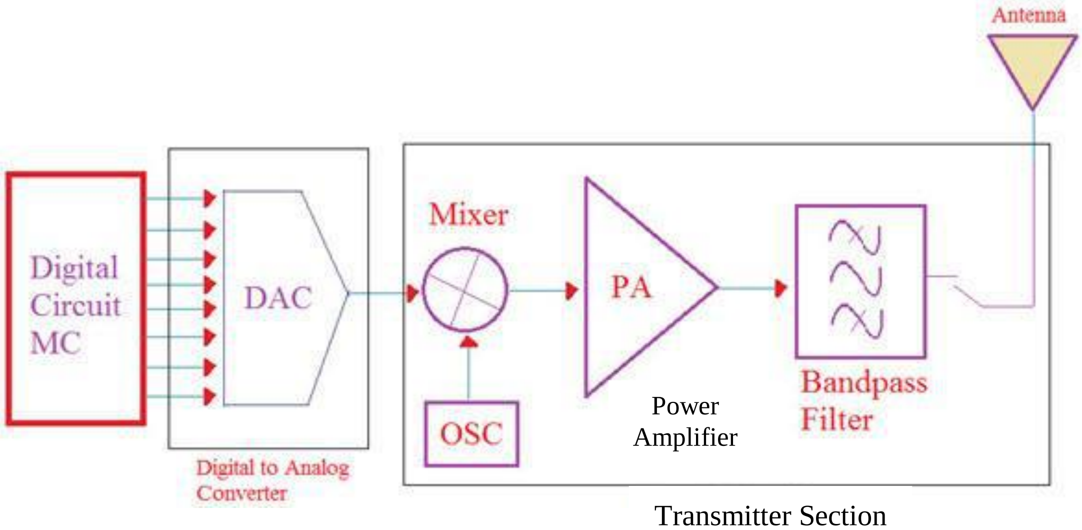


**Fig. 2.2. Wireless Transmitter Modules**

- **Wireless Communication with Receivers**

  The Receiver modules consists of Band-pass filter, Low-noise amplifier, Mixer, low- pass filter and an analog to digital converter. During the process, receiver encounters analog signals such as current/voltages signals which are decoded to recover digital information. A receiver module is interfaced to the microcontroller with the help of an encoder. The band pass filter allows desired frequency signals only as being transmitted by valid transmitter. It uses a low-noise amplifier for increasing the signal strength and reducing the noise. The mixer generates high frequency signal by mixing the week signal with the high frequency signal (OSC). The ADC converts the current signals into digital signals like 0 and 1s format to control the applications by the processor [6]. Entire schematic is depicted by Fig.2.3. A wireless receiver mainly comprises of three blocks: microcontroller, analog to digital converter and receiver blocks.

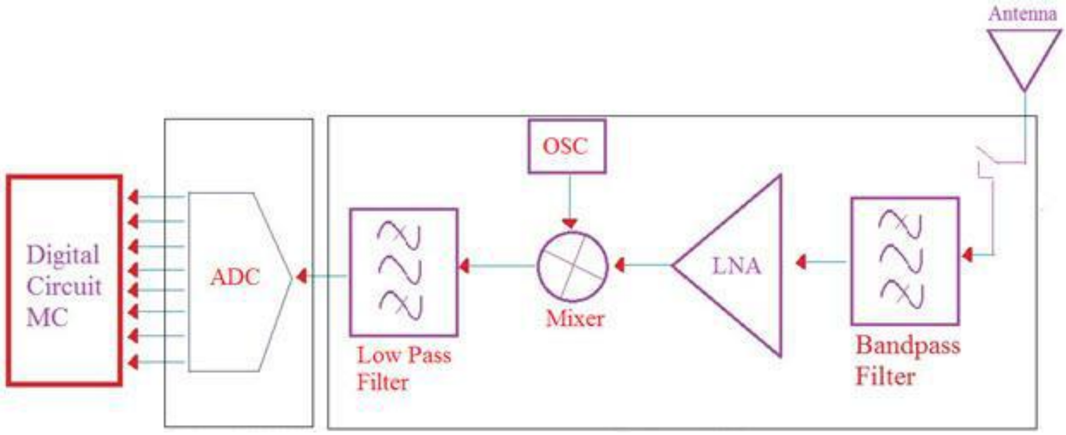


**Fig.2.3 Wireless Receiver Module**

ISSN(O): 2456-6683
[ Impact Factor: 7.148 ]
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## 4. RF ENERGY HARVESTING

Energy harvesting, a term that indicates recovering energy by scavenging ambient power available in surroundings. It is a process of extracting the energy from one form into other i.e. RF energy dissipated when transferred from transmitter to receiver i.e. from EM form into electrical form. The energy can be in any form such as thermal, voltaic, solar, hydro electric, RF, wind, etc. The harvest of RF energy is quite different from harvesting other types of energy. The controllable and predictable nature of RF energy and its independency on environmental conditions differentiate this form of energy harvesting over other renewable resources. In wireless (RF) energy harvesting, electromagnetic energy from multiple sources received by an antenna, is converted into an electric energy and the converted energy can be used as a source of power for other devices. This paper explores RF Energy Harvesting and Wireless Power Transfer (WPT). Maxwell first formulated the first about wireless power transfer and two centuries later Nikola Tesla described transfer of energy between two points without the need for a physical connection to a power source [7]. Brown proposed a rectifying antenna named "Rectenna" using wireless communication technologies. As a consequence the concept of microwave power emerged. Fig.3 illustrates a typical RF energy harvesting system comprising of Transmission Antenna and a Rectenna. Rectenna comprise of Receiving Antenna, an Impedance Matching Network (IMN), a Rectifier, and a Power Management circuit [8]. A Rectenna (rectifying antenna) is a combination of a jointly working antenna and an RF-to- DC rectifier. The antenna captures the RF electromagnetic energy, while the rectifier converts the input AC voltage into DC voltage that can be used for low-power battery-operated devices. Additionally, another component called impedance matching network between the RF-to-DC rectifier and the antenna, functions to adjust the impedance between these two subsections [9].

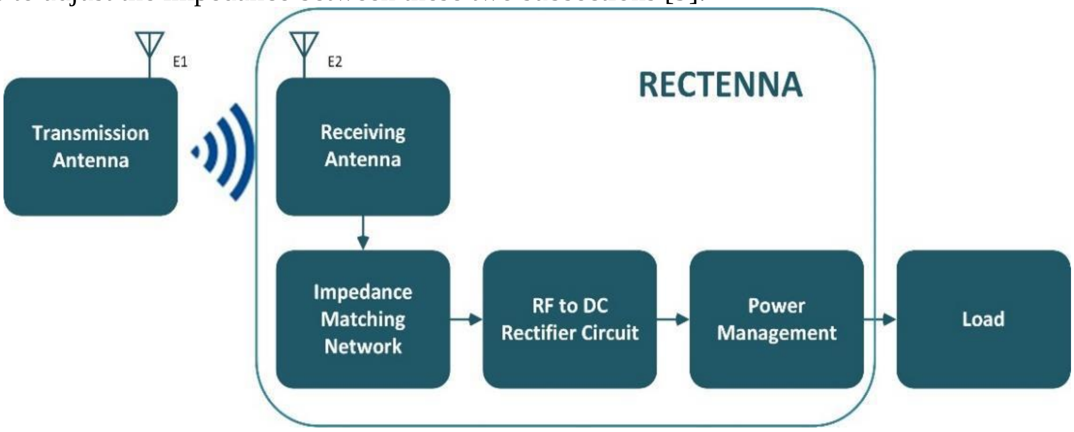


**Fig.3 Block diagram of a typical RF harvesting system**

There exist several methodologies to harvest RF energy namely Simultaneous Wireless Information and Power Transfer (SWIPT), Wireless power transfer (WPT) , Power Splitter method, Time Reversal techniques, etc. The source of RF energy is variable and unpredictable. This uncertainty leads to reduced RF – DC Conversion efficiency in energy harvesting circuits. Interestingly, the overall RF-to-DC con- version efficiency of the rectenna (Energy Harvester) is not only a function of its design but also of its input waveform. This alternative, Wireless Power Transmission (WPT) uses an intentional signal, transmitted to power up the receiver devices. The efficiency of such conversion is affected by waveform used for transmission. Energy efficiency shall be of critical role in near future communication systems now started emerging. It shall be one of the major design objectives for 5G and Beyond 5G (B5G) radio access networks. Limited energy storage devices (such as battery) life span has always been a critical aspect of modern wireless technologies [10].

Battery needs to be replaced after every few months or years, depending upon the energy efficiency of the device and battery size. It requires considerably high operational cost, as well as difficulty in replacing or recharging device batteries in scenarios, such as wireless sensors for medical purpose. Under such cases, the devices are placed inside the human body or embedded into a building structure. Therefore schemes that empower such devices to harvest energy from the adjoining environment, become supportive and especially if it could be done without wires i.e. wireless. Energy harvesting is very attractive technique for a large number of self-powered microsystems. Examples of such systems are wireless sensors, implantable medical devices, military surveillance devices, remote weather stations, calculators, watches, Bluetooth, or even mobile phones. There are already companies on the market that have launched mobile phones that charge using RF energy harvesting. With the great development of the Internet of Things (IoT) in recent years, the RF energy harvesting will play a very important role because RF signals are all around us and are inexhaustible [10]. A rectenna system will be very useful in Smart Cities and Smart Homes which is also a huge new scientific field.

It aims to solve the power supply problem of the countless sensors used in the IoT to monitor and develop data collection, thus contributing to the need to reduce their battery or power supply.

**5. CONCLUSION:**

Simultaneous Wireless Information and Power Transfer (SWIPT) and Radio Frequency Energy Harvesting (RF-EH) have emerged as revolutionary paradigms for powering and sustaining the ever-expanding network of wireless devices in our increasingly connected world. This research paper has explored the fundamental principles and technologies under- pinning these exciting fields, highlighting their potential to address the growing challenge of battery limitations in wireless communication systems. While significant advancements have been made in recent years, both SWIPT and RF-EH are still evolving fields with vast potential for further innovation and optimization.

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