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# Flexible Rectenna- A Survey

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**ABSTRACT:** In this current scenario of wireless devices, Rectenna-(rectifier + Antenna), has attained significance like a substitute of energy source to the devices related to Internet of Things (IoT). A rectenna transforms ambient EM energy to DC energy, but the design faces the issues of low conversion efficiency value and large size curbing its use in wireless applications. To get over this, substrates which are lightweight, less in cost, recyclable &flexible substrates just as paper, PET etc can be used. Here, different compact rectennas as energy harvesters are discussed. Also, its main parameters in the design - conversion efficiency, DC voltage &size are considered.

***Index Terms*:** RF energy Harvesting, IoT(Internet of Things), rectenna, substrate

## I. INTRODUCTION

Now-a-days, most of the energy resources like gas, oil and nuclear industries which do not last for distant future and whose prices also vary from time to time. In addition to these, they aren't an environmental–friendly. So to avoid the disadvantages of current energy resources, the alternate ones are to be needed. Regarding this greener, cleaner & safer energy resources, there have been ample researches going on currently [1]-[3].A lot of means from where the energy can be gathered includes vibration ,wind energy, solar energy and ambient electromagnetic signals. Newly, the rectenna concept has earned importance by becoming an substitutive energy source to the IoT devices .This is a green and effectual way to replace conventional batteries which power wireless devices. Rectennas can be a possible energy source in circumstances where the batteries are required to be replaced from time to time. It also helps in the situations, where the placement of the batteries is not possible due to economic reasons and/or involving considerable risks to human life.The main advantage for rectenna is its lifetime which is nearly unlimited and it doesn't need any replacement .Also it is green for our environment .Sources of RF Energy are a unit FM radio systems ,TV Transmission ,Cell Tower Trans-mission, Wi-Fi ,AM Transmission and mobile phones etc. Cell towers may be used as an eternal supply of green energy, since they can transmit for24 hours.

## II. RECTENNA

For the RF energy harvesting, a device named "Rectenna" is used which is the combination of rectifier and an antenna. It basically converts electromagnetic energy to DC. It comprises of a radiator, an impedance -matching circuit, a rectifier, a DC filter and a load.Rectenna catches ambient electromagnetic (EM) signals. Then it converts them into dc voltage which can power low power devices like wireless sensor [6]. Rectenna contains of a radiator, rectifier, a filter & a load. This can be viewed in following fig. 1.The radiator receives the EM signals. There are several antennas having various structures like bipolar, microstrip, Helical, dipole, array, planar, parabolic etc. Because of having different design structures and properties, they can be utilized for various different applications.

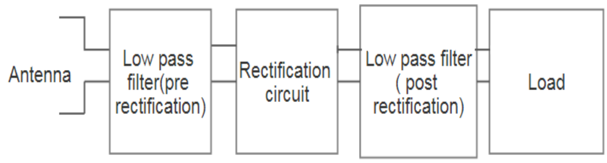


Fig.1 General Rectenna structure

The RF signals captured by the antenna include harmonics which giving rise to signal loss& interference. A low pass filter helps in reducing the harmonics generated. It rejects the harmonics to remove losses in the signal power. For the obtained smooth ac signals, rectification is required. With the help of rectifying diodes ,a rectifier rectifies the signals. Essentially there are 3 rectifier configurations–1.single diode, 2. Voltage multiplier and 3. Bridge of diodes. Bridge rectifiers and single diode rectifier are able give output voltage to the load. Nevertheless, the rectified signal is low compared to the received signal. The voltage multiplier configuration can produce amplitude which is twice that of the signals which are received. A load is placed as the last component. During the design, the load is adjusted, to get high dc voltage.

## III. FLEXIBLE ANTENNA

Size of the embedded devices is one of the challenges faced in a RF energy harvesting system .They must be small in size to be fixed in low power devices. As mentioned earlier, an energy harvester needs a radiator to capture RF energy, an impedance matching network and a rectifier. The antenna's measurements affects the energy harvester's output. A very high impedance loads (e.g., 5M),are needed to get high values of voltage.

Organic , flexible or printed electronics are very effective and related research fields [1].In Flexible electronics, the design can be done on a flexible and environmental-friendly substrates. This provides a variety of applications. When compared to the fabrication technique cost of the silicon industry, printed electronics is less. Another interesting thing is the development of IoT. In many areas (domestic, space, military, medical,), the usage of sensors has increased, mostly in limited access or dangerous places. The normal battery power require cyclic replacement and also it is high cost to reprocess. Wireless transfer energy is a method to harvest RF energy. This technique of wireless transfer of energy was worked by Heinrich Hertz in the year 1888 [2],and then followed by Nicola Tesla in the year 1899. From then this technique has become remarkable research topic.

With reference to the rectenna design, research has been carried out on the following choices of flexible substrate to name a few:

1. Textile-based substrate
2. Polymer-based substrate
3. Paper-based substrate

Relying on the kind of application, the above can be utilized. These substrates have got importance in research for flexibility.

**TEXTILE BASED SUBSTRATE:** Textile antennas are the result of combination of the normal textile materials and latest technologies. Currently these are becoming an active part in the wireless communication systems [1], aiming applications such as mobile computing, tracking and navigation [2], and others [3]. In addition, wearable antennas are to be light in weight, thin, robust, easily maintainable, and low in cost for huge production &development [4]. Towards this, the microstrip patch type & planar antennas have been proposed for garment applications and these antennas present all above mentioned characteristics, and are adaptable to any type of surface [5].

Wireless Body Sensor Networks (WBSN) which helps in monitoring daily activities of a person uses the textile antenna. Textile antennas help in common monitoring, energy harvesting and storage too. A smart coat with a dual-band textile antenna was presented [6] for RF energy harvesting, at the GSM 1800 band and DCS 900 band. The antenna is fully fixed in the garment, smart coat. The gains obtained before and later the additions of the radiator into the garment are 1.8 dBi and 2.06 dBi respectively. The radiation efficiency of the operating frequency bands-lowest is 82% and the highest is 77.6%.

In recharge wearable devices like Wireless body Sensor Networks, the combination of textile antennas with smart clothing could be a remedy. Embedding radiators in clothing helps for the advancement of the electronic devices into smart clothes easily. Also, this one showed an uninterrupted substrate of the radiator.

In[15] , the author presents a rectenna at 2.45 GHz using textile for harvesting. A flexible substrate, Polycotton of 350 μm thin, a flexible substrate was utilized. Screen printing technique was applied to map various layers. To make the surface smooth, a 310 μm interface layer was first printed on either sides of poly cotton. To connect the antenna & rectifier, a silver layer was printed. To analyze the substrate at the 0.5-4.5 GHz , the two-line method was used. A loss tangent of 0.06 &relative permittivity of 3.23 were achieved at 2.45GHz.A microstrip antenna which was matched 50 Ω and also a dual-polarized energy harvester were designed. The return loss S11 of the patch antenna showed an acceptable similarity to that of the simulation results. The performances of the polycotton antenna and rectenna were analyzed& then correlated with that of the FR4.The radiation efficiencies of polycotton antenna& FR4 are 11% &30% respectively. The polycotton rectenna gave an output of 300mv& 100 µW, which is 15 cm from a 100 mW Equivalent Isotropically Radiated Power (EIRP) transmitter.

**POLYMER BASED SUBSTRATE:** The author in [7] designed a cost beneficial, energy harvester integrating a rectenna with a solar cell .The design is able to harvest EM energy. Using the EM analysis for modeling& optimizing the designed circuits, the antenna & solar cell shared the same area. It results in compact dimensions of the structure. In this paper, to increase the efficiency of the device rectenna, along with the solar cell, a non-linear harmonic balance optimization was used . In addition, a low priced& a flexible polyethylene terephthalate, also known as PET substrate & a flexible amorphous silicon solar cell were chosen. They provide low priced and a consistent structure too. After the solar cell illuminated with solar radiance, A prototype generated a maximum power of 56mW. The dual-band rectenna showed an efficiency of 15% around 850 & 1850 MHz when powered with a microwave beam was presented. The energy harvester, receives the EM power from multiple frequencies. If the harvesting is done from multiple frequencies, the rectenna must be able to work efficiently at all those frequencies. Regarding this an author [8] proposed an advanced antenna. This antenna encompasses one fixed part and another movable part which can change the antenna's frequency as per the requirement.

An antenna was designed operating at three frequencies 2.4 GHz,1800 MHz & 1900 MHz was proposed. On a flexible substrate, the antenna was designed by printing a patch with conductive ink. With this arrangement, the antenna was effective to be stacked or taken out from any package. Then the rectifier was also held stable within the system packaging. This made the whole circuit easily to get installed. With this set-up, frequency was modified easily. The radiation pattern of the designed antenna was directional with a gain of around 4.5dBi, the simulated efficiency of around 80%.

**PAPER BASED SUBSTRATE:** Paper is the cheapest materials currently available on the planet, Earth [9]. As a comparison, paper substrate is cheaper when compared to an equivalently sized FR4 substrate. In [10], an optimized design of a 2.45GHz rectenna, circularly polarized one, to be inkjet printed on the paper substrate was shown. This proposed antenna was a shorted ring slot where the ground plane had been optimized by using a mesh design to decrease the size of the area that requires inkjet printing. Thus, minimizing silver nano particle ink which had to be put on. Inkjet printing, an additive process in which conductive nano particles are deposited on a selected substrates like paper. To obtain an optimum inkjet printed structure, it is required to shrink the quantity of required conductive nanoparticles. A mesh rectenna design was designed to diminish surface that to be inkjet printed. The proposed rectenna is a circularly polarized shorted ring slot structure together with a rectifier element [5]. The presented design results presented that it is feasible to bring down the amount of conductive material and still maintain a good performance. At 2.45GHz frequency, the conversion efficiency was is 39- 45 % when the rectifier is receiving -15 dBm .

In [11], a novel ultra-compact rectenna was illustrated. Designing & fabrication of the antenna was done with a paper substrate while rectifier was developed considering a low input power. Thus the circuit can be suited for energy harvesting applications, especially in the Wi-Fi band (2.4-2.5Ghz). At a low input power ($P_{avg}$ = -15dBm), A rectenna with a tapered annular slot & one diode rectifier was developed to operate in the Wi-Fi band. A double-layered architecture was considered in order to attain a compact structure. According to this, the annular slot's inner metal surface was plied as a ground plane of the rectifier circuit. Consequently, a rectenna with dimensions of 40 x 33 $mm^2$ and an efficiency within 26.5 - 28 % was achieved. After the fabrication process of the antenna, It was evaluated in an anechoic chamber. The rectifier was designed &simulated with (ADS) Advanced Design System suite. An investigation analysis of an energy harvester, low-powered on a paper substrate was done by an author[12]. A description of both energy harvester's prototype &its experimental setup have been reported. Simulation & measurement results are observed to be in good agreement. In particular, its efficiency of 28% was at -15 dBm of accessible input power. As the energy harvester was designed on a flexible substrate, it is more vulnerable to get bended. Regarding this, bending of the radiator over the radiation performance study was carried out by means of EM simulation. It showed to a small bend (i.e., radius of the curvature >70 mm), the radiator functioning was considerably stable. Although the increased bending declining the input matching of the radiator but the result was adequate. The Wi-Fi band was nevertheless covered for a curvature's radius less than 20 mm. In addition to this, the antenna's estimated maximum gain reduced to < 1 dB. The rectenna showed an output of 10%-22% at around -10 dBm, of 28% around -15dBm, and of 40 % around -10 dBm relative to an output voltage of the order 60,240 & 320 mV respectively.
Last decade witnessed enormous growth for the wireless communication networks centered on IoT. These led to the rise an efficient connectivity within various devices which can operate in license free ISM band of frequencies.

These developments aimed to enable an efficient interconnectivity between the different devices to operate in the license-free ISM bands. In the recent trends, various applications are contingent on the IoT technology like energy harvesting, home automation etc. In case of heterogenous IoT devices, to improve their wireless connectivity, multiple antennas are required. Procuring the required space to confine such antennas into a single small device is the main problem. In this the main problem lies on finding enough space to hold such antennas into a single small device. Grounded on this, an author in [16] proposed a good solution that was based on using single compact-size antenna printable on a flexible substrate. To increase bandwidth, this flexible antenna was subjected to multilayer & annealing techniques. This printed-antenna was capable to operate over various bands of wireless communication. This paper[16] also showed the advantages and benefit of Inkjet printing technique for a microstrip wideband antenna with flexible substrates. This flexible antenna was paper-based and get suited to be integrated inside Iot devices since it provides efficient size& low priced fabrication process. This antenna, monopole operates upon a wide frequency ranges and provided with power loss, low. Its dimensions were 35 x 37.5 mm. This showed reflection under -10 dB at 2.4 &5.8 GHz frequencies to a printed layer which is single. By applying multilayered printing & thermal treatment, the above antenna can operate at various frequency bands. This antenna can work at various frequency bands with multilayer printing & thermal treatments. This technique allows various bands like PCS, RFID, WiMAX, UMTS and DCS. As the designed antenna operates at a wide range i.e., from 100MHz to over 13 MHz ,it can be part of various IoT devices. Antenna's radiation pattern was omnidirectional. The author tested this designed antenna in a practical scenario substituting a typical 3-dB monopole router antenna and measured signal's strength. Its performance showed that inside 4 mts away from a connected router over a Wi-Fi network, the reception rate of 100%.

To summarize, the flexible substrates are weightless & can be easily bent when compared to that of microwave substrates. This makes them a good substrate choice for using them in wearable antennas where measurements & conformity to the body are basic factors. Organic & polymeric substrates having values of low permittivity [13] can increase the antenna's size. But it also helps in bandwidth enhancement and decreasing the surface wave propagation. This in turn increases the antenna's radiation capability [14].

## IV. CONCLUSION

In future , this RF energy harvesting technology will play an important role in replacing batteries. The properties of being harmless, abundantly available in free space and good ability to penetrate through soft tissues make these RF waves as a good alternative source of energy to replace batteries in many applications. Considering the latest improvement in the technology of IoT, electronic apparatuses are used everywhere. As a result next generation sensors will be embedded in the items (modules).This will cause hindrance and difficult to reach. So battery replacement will be difficult or sometimes completely impractical. For this, the rectenna is the best solution. For IoT sensors, a compact antenna with high gain & a wide bandwidth is preferred. Different types of rectenna designs using flexible substrates such as textiles, polymer, and paper are discussed. Their advantages and disadvantages too have been presented. The parameters of the rectenna, radiation efficiency, size etc are discussed. Besides progressive achievement in the recent years, there is still a variety of rooms to further optimize this RF technology such as increasing PCE, minimizing the system's size, reducing transmission losses etc. To make this technology more success full, a fine manufacturing and packing process with cost effective production is required.

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