A Survey Study of Different RF Energy Sources for RF Energy Harvesting

Rajdevinder Kaur Sidhu
ECE Department
SLIET, Longowal
Sangrur, India
rajsidhu_33@yahoo.com

Jagpal Singh Ubhi
ECE Department
SLIET, Longowal
Sangrur, India
js_ubhi@yahoo.com

Alpana Aggarwal
ECE Department
TIET, Patiala
Patiala, India
alpana@thapar.edu

***Abstract*—Radio Frequency (RF) energy conversion and harvesting topologies gains much attention that promises to operate the low power devices. The base of any RF energy harvesting model is the selection of appropriate RF souce followed by other three main stages which include receiving antenna, converting into DC output and utilisation of that output in any low-power applications. In this context, we present an extensive survey on the various RF sources (DTV, GSM, Wi-Fi) available in the frequency range of 3KHz -3GHz. This paper aims to review the progress of ambient sources which is expected to be useful in designing the RF energy harvesting model.**

Keywords—Energy Harvesting, Power Density, Radio Frequency, Rectenna, RF source.

I. INTRODUCTION

The sources that emit radio frequencies are billions in number all around the world. These sources include very small appliances such as cell phones and hand held devices, and the gigantic setups such as a radio base station, mobile base station[1]. Most of the RF energy that is transmitted by these sources is transmitted omni-directionally irrespective of the coordinate position of receiver. Hence there is a lot of RF energy that is wasted away due to non reception by any device. This provides an idea of harvesting the excess of RF energy from the ambience that may be used for low power hungry wireless charging devices which may enhance the usability and reliability of that device[2].

The uses may further be extended to battery operated components and devices as it may provide extended life time of operation without replacement of batteries. Moreover, the devices that consume very less power can be designed to operate on the harvested energy itself and the batteries can be omitted. One of a major advantage is that the RF energy received continuously due to a very large number of radio frequency band energy transmitters. A large number of the devices can be thought of such as Mobile phones, that have crossed a mark of 6 billion worldwide, wifi systems and routers, laptops, Television/ Radio/ Mobile base stations, Satellite geo-transmission[3]. In case of urban environment, it can be seen that there is a possibility of many wifi routers at a single place or placed in the vicinity of each other. Each router may emit 50-100 mW in all directions although this emitted power is not fully utilized[4].

Most of the devices operate in unlicensed bands (5.8GHz, 2.4GHz, 915MHz and 868MHz). The traditional cellular communication systems had 3.6W as maximum transmitted power. Nowdays, the EIRP (Effective Isotropic Radiated Power) at 915 MHz frequency band is limited to 4W by the authorities. The similar case is with RFID (Radio Frequency Identification) based interrogation and detection systems[2][3].

This paper aims to review the progress of ambient sources which is expected to be useful in designing the RF energy harvesting model. Section II provides the basic information about the rectenna unit of RF energy harvesting system that converts the RF signal into the DC output. Various RF energy sources are discussed in section III of this context which involves DTV, GSM, Wi-Fi sources.

II. OVERVIEW OF RECTENNA CIRCUIT

The system designed for harvesting RF energy must have an additional antenna for receiving energy to be rectified and converted into dc voltage with help of intermediate circuit apart from reception antenna. The main antenna may be tuned to a particular frequency as per circuitry requirements whereas a secondary antenna must have capacity to receive whole radio frequency band to ensure the maximum reception of free power from ambience. The antenna deployed for the operation is nomenclatured as "Rectenna". Practically, this is part of original antenna deployed for communication. This could be a monopole or microstrip patch type or even PCB based antenna selected as per the requirement of main circuit operations without disturbing it[5]. Mostly, the rectifying circuit has any of the non linear operating devices such as Impact ionization Avalanche Transit-Time diode (IMPATT) & Schottky Diodes and MOSFETs. The researchers are finding various solutions in Complementary MOSFET (CMOS) technology to design circuits that are capable of rectifying the 3KHz to 3GHz spectrum.

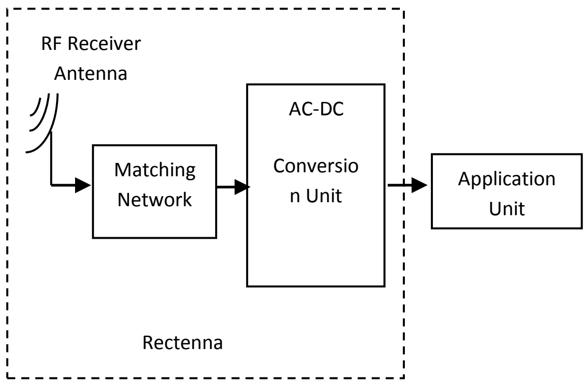

Fig. 1. Block diagram of RF Energy Harvesting Model

The rectennas are coupled efficiently and effectively with rectifying circuits using some of the impedance-matching techniques to deliver maximum power and the harmonics mostly in multiples of frequencies of RF signal are blocked using appropriate filters[6].

One of a prominent properties of operation of circuit is conversion efficiency of the circuit developed for RF harvesting. Although it is majorly dependent on the combine coupling of antenna and rectifying circuit as well as the RF-to-dc conversion non-linear devices used for rectification[7][8]. The electromagnetic waves consist of E and M components that may carry information in any of these components but in harvesting, the induced current due to skin effect provides the desired energy [9]. After the successful conversion of RF signal into DC voltage, the so converted DC voltage is stored in storage unit or can ce directly used in low power applications.

III. RF Energy Sources

As the RF energy has a wide range, this circuit must be able to switch and operate in whole of RF range approximately. The free energy emitted in the environment can be summarized in Table 1.

The ambient RF energy sources have very less power density (0.2nW/cm^2-1µW/cm^2) as compared to abundance of solar energy and main advantage of such sources is the continuous availability of radiations throughout the clock and its availability in indoors and outdoors[10]. The technological development is at its peak and the number of wireless connected devices are increasing day by day especially the cellular communication systems[11]. Hence the availability of energy for harvesting is going to increase in near future.

Figure 2 presents a power density of spectrum used in communication systems. This includes RF sources starting from range of Digital Television transmission near 500MHz, GSM spectrum of 900MHz and 100MHz. and Wi-Fi transmission near to 2.4GHz[6].

To design an effective and efficient harvesting model that should operate in any environment (In/Out), either a single spectral density reception system can be designed or the whole spectrum reception can be thought of[12].

TABLE I. Range of RF Energy Operating Devices

3KHz-30KHz	*30KHz-3GHz*	*3GHz-300GHz*
AC Household and Industrial Power	AM/FM Channels	µW Communication
	Television	Satellite Communication Systems
	Cell phones/ Computers	
	Cell phone Base Stations	

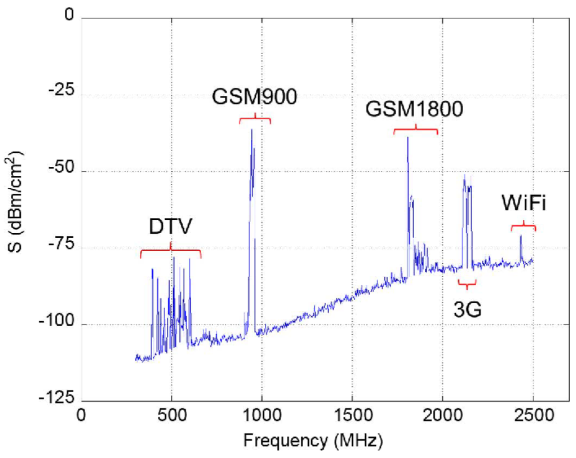

Fig.2. Typical Power Density radiated in atmosphere[7]

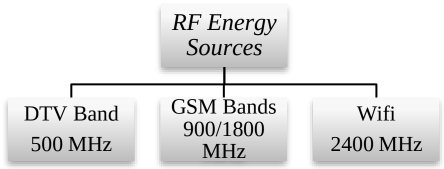

Fig. 3. Various RF Energy Sources

To design an effective and efficient harvesting model that should operate in any environment (Indoors/Outdoors), either a single spectral density reception system can be designed or the whole spectrum reception can be thought of[12]. Although the spectrum properties are different and there are different effects of atmospheric variations such as humidity, temperature, etc. on the range and availability of spectrum, yet a system may be able to absorb a selective band or tuneable to selective band of frequency [13].In general, the commination market is much developed radio waves are omnipresent at each point of human crowded area of the planet which gives rise to RF energy harvesting. As per London RF survey [7], DTV, GSM 900/1800 and Wi-Fi were regarded as the most convenient RF energy harvesting sources as shown in Figure 3 and those are briefly discussed below:

A. DTV Band power sources

The researchers have designed various circuits to harvest RF from terrestrial Television broadcasting systems and base stations since 2009. In 2009, a periodic antenna was designed that provided the gain of 5dBi for WISP(Wireless Identification and Sensing Platform) and the rectenna had 5.0v as its open circuit voltage[14]. In 2010, wireless sensor nodes were powered by harvesting RF from Television broadcased airwaves by designing a very efficient rectenna[15] and various prototypes and circuits are then designed time to time. Similarly, RF energy harvesting systems from DTV (Digital Television Broadcasting) are also designed since 2009, when about 60µW was harvested from a 960kW broadcasting tower at the distance of nearly about 4kms[15].Mikeka et.Al[16]presented an RF energy harvesting rectenna in which the conversion efficiency of

18.2% for -20 dBm input and 0.4% for -40 dBm input, respectively. A power of -44dBmand +3dBm was measured in Tokyo from broadcasting towers situated at 400m and 4km respectively measured. A major advantage as discussed is the 24 Hrs availability that makes RF harvested energy a sustainable source of power.

B. GSM Band Power sources

These recent years have seen a boon in mobile phone technology with extending the features and usage of handheld devices. With the introduction of user friendly platforms and operating systems such as Android, the applications of cellular technology has not limited upto theaudio communication between end users but has greatly emphasized on data trans-reception. So an exponential growth in number of users is seen which ultimately increases th RF transmitters from where RF energy is harvested to utilise in any low power applications.

This means many more devices, towers and Base stations are radiating RF energy than before. There are basically two operating frequencies in Global System of Mobile(GSM) i.e. GSM900 and GSM1800. These systems work on 900MHz and 1800MHz respectively. GSM900 is mostly used for harvesting as the efficiency in long distance transmission with a very low path loss is seen in signal [17][18][19].

C. Wi-Fi Power sources

In the era of development in RF energy harvesting, number of wifi devices has increased exponentially. All the computers and laptops are equipped with wireless internet connectivity that made the mobility possible [20]. Most of the mobile phones also use Wi-Fi because of higher data rates. In 2012, a system was designed that provided a 76.35µW DC power that could be used in operating low power devices such as LEDs etc. The model achieved an efficiency of 33.7% by placong the Wi-Fi router at a distance of nearly 40cm[21].

Another researcher has powered Humidity and Temperature sensors by designing a 3×3 antenna array of very small dimensions and harvesting Wi-Fi power[22]. A Crockfort-Walton rectifier provided a 2V from a Wi-Fi signal at 2.48GHz[23]. Recently a novel system designed as POWIFI(Power Over Wi-Fi) harvester successfully and efficiently harvested 2.4GHz operating router [24]. This system has powered battery chargers, and temperature sensors [25][26]. Hence it is seen that the Wi-Fi systems that operate around the clock in an arena are sustainable and powerful source of RF energy.

IV. CONCLUSION

The study concludes that there is abundance of free RF energy in atmosphere naturally emitted by devices and machines that is wasted. Morover, it adversly affects the environment and surroundings which have to be encountered. RF energy harvesting can provides an very efficient and alternative solution which not only remove the harmful RF energy from atmosphere but also utilised it in low power electronics applications. Providing clean and green energy to the devices, extracted from wasted RF energy is called the RF energy harvesting. By selecting the appropriate source of RF power from the abundance and with the help of proper matching circuitry for rectenna, the self powering or charging devices may be developed in near future embedding RF harvester circuitry along with main circuit. This is really a challenging job because the energy density of RF signal is very low but also it meets the technological and social demands for betterment of the environment if harvested and utilised successfully. Therefore, RF harvesting has a bright scope of research in future.

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