Wireless Power Generation in Sustainable Technology

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Abstract: This paper presents comparative study associated with Wireless power generation using sustainable technology. From survey and review of different papers, different methods for conversion of Radio Frequency (RF) and Microwave Frequency into electric power are presented. The qualitative comparison of different existing methods in production of electric power is being discussed. The approach for harvesting ambient electromagnetic energy through the electronics, converting such electromagnetic energy into electrical power, and retaining this power for utilization of wide range of electrical/electronic circuits are presented. It is possible to power a simple electronic device wirelessly which could be a valuable tool for future use.

Keywords: Radio Frequency, Microwave Frequency, Electromagnetic energy, Electric power, Wireless Power.

I. INTRODUCTION

Recently much work has been done on providing sustainable technology in the field of energy. Nowadays, wireless power generation is a field of great interest. The one application of wireless power generation is to supply personal electronic devices with power without the use of cables. By removing the need of cable for a device would make it wireless. By doing so large amount of cables can be saved in the process of sustainable development. The second application is in the field of renewable energy or green energy which includes the idea of harvesting solar energy from space. Nowadays, the main sources of energy are fossil fuels, nuclear power, hydro- electric power, solar power, wind power. The fossil fuel is responsible for air pollution, harming the ozone layer and contributing for global warming whereas nuclear energy waste is also dangerous for life on the earth. So, renewable resources of energy are desirable these days. Electromagnetic (Radio Waves) as the energy source is one of the renewable and sustainable approach of energy generation which will remove the dependence on climatic intermittency.

In present study different papers presented on wireless power transmission were reviewed and discussed with emphasis on the antennas and receiving circuitry presented in the papers [1-4].

II. METHODS AND SYSTEMS FOR ENERGY RECLAMATION AND REUSE

For wireless power generation in sustainable technology, methods for conversion of electromagnetic radiation energy especially radio frequency energy and microwave frequency energy into electric energy are described. Ronald S. et al. US. Pat. No. 6,882,128 B1 [3] converted electromagnetic radiation energy into electric power by using Energy Reclamation System [ERS], Energy Harvesting System [EHS], Energy Conversion System [ECS] and Energy Storage System [ESS]. Energy Reclamation System [ERS] concept is shown in fig. 1. This figure shows the ERS, the ERS 100 includes three parts or subsystems: an Energy Harvesting Subsystem (EHS) 130, a Power or Energy Conversion Subsystem (ECS) 160, and a Power or Energy Storage Subsystem (ESS) 190.

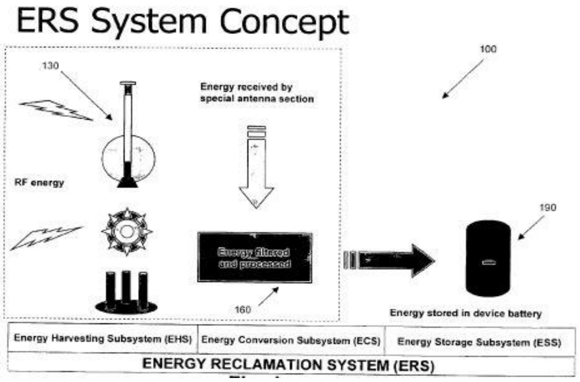

Fig. 1

Through Energy Reclamation System we can gather ubiquitous ambient energy over a desired frequency range. In a preferred embodiment, the desired range is 500 KHZ—2.4 GHZ. For frequencies above 2.4 GHZ and for deliberately radiated high power harvesting applications, the ERS can assimilate the rectenna technology, such as that revealed in US. Pat. No. 5,043,739, into the EHS and the ECS for attachment to the ESS. The main objective of the ERS 100 is concentrated on the gathering of ambient RF energy present in the ambient environment in the range of 5 Watts and below and transforming that energy into reusable energy to power many electronic devices. The transformed energy can be full-Wave or half-Wave rectified, filtered using capacitor and using voltage regulator constant direct current can be obtained. The charging strategies rely on how the ECS 160 is used and its reuse needs. The output of the ECS 160 can be dispensed for reuse to several various types of circuitry. In one embodiment, the transformed power may be fed to a trickle charger circuitry that charges a standby energy storage device in the ESS 190 that is comprised of a battery, capacitor, etc. While any surfeit power is distributed to a charging circuitry for the primary power storage component. Another way to dispense the ECS output power is to feed it directly into circuitry suitable for affecting indeterminate operation of the electronic device in a standby or sleep mode.

The three subsystems of the ERS system are now described in further details.

A. Energy Harvesting Subsystem (EHS)

The EHS for RF energy collection is comprised of a single antenna of any physical design and shape (e.g., dipole, Yagi, ContraWound Toroidal Helical Antenna, etc.) or an array of such antennas to gather RF energy from any frequency or bands of frequencies. Suitable baluns (i.e., balanced to unbalanced converters) and impedance matching techniques may be integrated to maximize power transfer into the energy conversion circuitry of the ECS. For the ERS to reclaim the maximum amount of energy, the energy-harvesting antenna is preferably designed to be a Wideband, omnidirectional antenna or antenna array that has maximum efficiency at selected bands of frequencies containing the highest energy levels. The EHS is comprised of an array of antennas, each antenna in the array can be designed to have maximum efficiency at the same or different bands of frequency from one another. The collected RF energy is then transformed to usable DC power using high speed switching semiconductor devices or a diode-type (schottky diode) or other suitable rectifier. This power may be used to drive, for example, an amplifier/filter module attached to a second antenna system that is optimized for a particular frequency and application. One antenna acts as an energy harvester while the other antenna acts as a signal transmitter/receiver. Transforming and/or storing the power accumulated by the ERS technology over time makes those devices engaging such technology more effectively and enlarging battery life. The antenna design and construction starts with defining a Wide band of frequencies over which gathering will be required. Next, optimal length or element size is calculated to attain maximum efficiency over that frequency range. Antenna efficiency relies on number of factors related to, for example, the physical design and shape of the antenna. Other factors influencing the amount of energy gathered include signal strength at the receiving location from the transmitting source, which in turn relies on the paths from the transmitting source to the ERS. Once the optimal length or element size of the antenna is calculated, it is eventually minimized to a fraction of a Wavelength while integrating semiconductor amplification and impedance matching circuits in the construction of the antenna elements. The antenna circuit elements are preferably constructed using microprocessor Wafer manufacturing techniques and shaped for integration or encapsulation in the antenna elements. This proposed design approach minimizes the physical size of the antenna while retaining the energy collection efficiencies of a larger antenna. Antenna efficiency of 50% or more is preferred, for higher antenna efficiency resulting in higher energy collection. FIG. 2 shows a high level schematic diagram of an Energy Harvesting Subsystem (EHS). The EHS includes a Wideband omnidirectional antenna or antenna array 255 for energy harvesting. The antenna 255 may be used to gather energy from RF signals 3 and/or RF power transfer signal 2 from a remotely-located, intentional power source. It may also be used to simultaneously receive the desired communication signal 1 along with the energy harvesting signals 2 and 3. The combined signals are then separated by filter bank 250. FIG. 2 also shows that other energy harvesting technologies for collecting ambient solar, acoustical, and mechanical energy can be integrated as part of the EHS to supply electrical energy into the ECS. The electrical energy supplied by these other energy harvesting technologies may interface with the rectifier 162 and/or filter circuitries 250, which is then fed to filter 275 in the ECS.

For ambient solar energy, an array of solar cells or a solar energy conversion device 260 known in the art (such as a MEMS solar/heat electric generator) is preferably used to absorb solar energy from the environment and transform it to electrical energy.

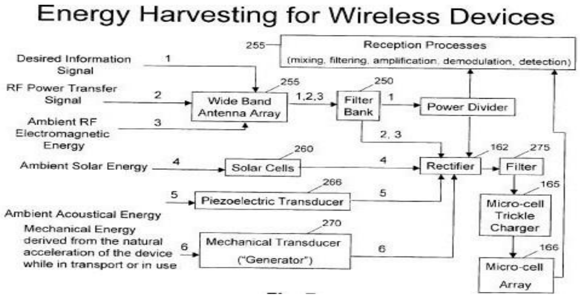

Fig. 2

This energy is then supplied to a rectifier 162 of the ECS. An array of solar cells may be used to produce enough power for a variety of applications. For ambient acoustical energy, a piezoelectric transducer 266 known in the art can be used to absorb ambient or intentional sound from the environment, which in turn causes a crystal to vibrate and through the piezoelectric effect produce an output voltage. The output energy is then delivered to the rectifier 162 of the ECS. An array of transducers may be used to produce enough power for a variety of applications. For mechanical energy, the energy is preferably transformed to electric energy through a MEMS Mechanical Transducer (Generator) 270 known in the art. The MEMS Mechanical Transducer 240 takes mechanical energy acquired from the natural acceleration of a thing or person while in transport (e.g., person Walking) or in use. These devices can Wind a spring, force a piston to move or use some other method to accumulate and transform acceleration energy collected into electrical energy. The output energy is then supplied to the rectifier 162 of the ECS. An array of such transducers may be used to produce enough power for a variety of applications.

B. Energy Conversion Subsystem (ECS)

The ECS for RF energy collection is comprised of a power charger and other circuitry for performing RF to DC power conversion. Because the energy harvesting is focused mainly on retrieving small amounts of energy over long periods of time, charging energy storage devices (rechargeable batteries, etc.) may be done over a period of time by trickle charge. Trickle charging is a charging scheme in which a power storage component is charged at a fraction of its capacity rate. Fig. 3 shows an ECS 160 for use in conjunction with the EHS to perform RF to DC power conversion.

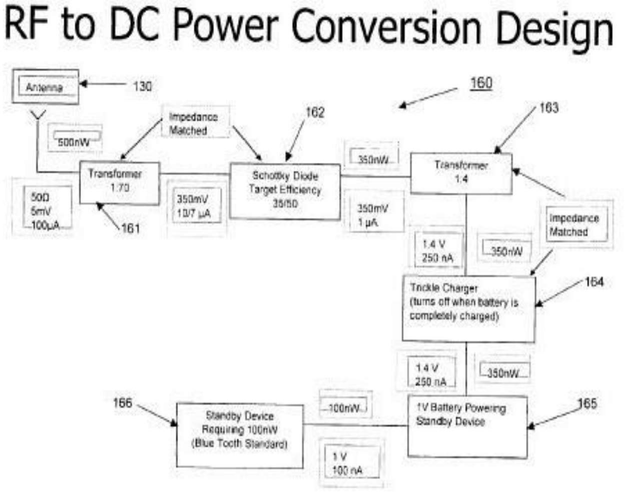

Fig. 3

The ECS 160 preferably includes a transformer 161 attached to an energy harvesting antenna 130 for receiving the RF energy. The transformer 161 is also connected to a diode rectifier circuit 162. The transformer 161 and the rectifier circuit 162 are designed to match impedance with one another to halt unwanted energy loss between these two elements. After rectification, the transformed energy is sent through another transformer 163 and onward to a trickle charger 164. Again, the second transformer 163 and the trickle charger 164 are designed to match impedance with one another to halt unwanted energy loss between these two elements. The trickle charger 164 is then used to provide power to a battery 165 for storage and use with an electronic device, such as a standby device 166. The battery is a part of the ESS. If an array of energy harvesting antennas is used to collect the RF energy, the power gathered from all channels (i.e., the power density at all antenna inputs) can be integrated, rectified and redirected to the trickle charger 164. The power available in each channel is related; thus, for example, if 100 N new is required for a load, the power collected in N channels at 100 nW each can be integrated to generate the desired power. The transformed and rectified power may be fed through a filter for signal purification prior to sending it to the transformer 163 and onward to the trickle charger 164. Fig. 2 shows the use of such filter 275, with like numbers for like elements shown in Fig. 3. It should be noted that Fig. 2 illustrates a broad overview of the ERS concept. Therefore, the figure does not show all detailed components of the ECS as shown in Fig. 3. Fig. 4 shows an ASIC chip implementation of the ECS circuitry shown in Fig. 3. The RF input 280 corresponds to the antenna 130 of Fig. 3 for receiving harvested RF energy; the MEMS RF transformer 281 corresponds to the transformer 161 of Fig. 3; the RF power ASIC 282 corresponds to the rectifier circuit 162 and the trickle charger 164 of Fig. 3 and any other desired circuitry for the ECS, such as filters, impedance matching circuitry, etc.; and the micro-cell battery 285 corresponds to the battery 165 of Fig. 3. The battery 165 or 285 is a part of the ESS.

C. Energy Storage Subsystem (ESS)

The ESS is comprised of a rechargeable battery 165, which can be a complete battery or an array of micro-cells of battery. If battery 165 is comprised of a complete battery, the trickle charger 164 preferably provides a larger potential difference between terminals and more power for charging during a period of time. If battery 165 is comprised of individual battery cells, the trickle charger 164 preferably provides smaller amounts of power to each individual battery cell, with the charging proceeding on a cell by cell basis.

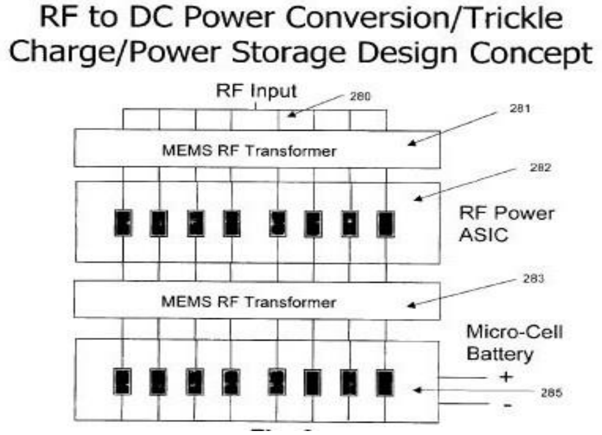

Fig. 4

III. METHODS ON SIMULTANEOUS WIRELESS INFORMATION AND POWER TRANSFER

The concept of simultaneous information and power transfer (SWIPT) was originally proposed in [5]. Later, in [6], SWIPT was regarded for transmitting both power and information concurrently by introducing fundamental changes in the receiver design. The suggested two receiver architecture uses SWIPT techniques to gather energy and decode information using the radio frequency (RF) signals, which can carry both energy and information at the same time, received from the transmitters in the network. Recent SWIPT technologies have distinct received signal in the domains of time, power, antennas, and space etc.

A. SWIPT: A two user MISO Interference Channel

A single antenna is used at both source and destination in typical wireless communication networks, which originate obstructions in the communication link with multipath effects. Obstructions generated by multipath wave propagation can be minimized by multiple input single output (MISO) technology, having two or more antennas with the transmission of multiple signals at the source. In MISO, the most magnificent optimal transmission strategy for the best scenario has been studied where the two receivers in the communication system concurrently harvest energy and decode information [7] to execute self sustained wireless communication networks. It is also worthwhile to note that cross-link signals are useful in enhancing energy gathering of the receivers in spite of the fact that it limits the feasible sum rate [7]. Thereafter, observing the current limitation of circuit technology, two practical schemes based on Time Division Multiple Access (TDMA) were recommended, where the receiver perform information decoding or energy gathering at each time slot. The first scheme, TDMA of scheme A, splits each transmission interval into two time slots, where one slot is used to implement energy harvesting by both receivers and afterwards to execute information decoding in the next time slot. The transmission time of TDMA of scheme B divides into two time slots, as in scheme A, with the difference that, in every time slot, one receiver implements information decoding whereas the other receiver implements of energy gathering concurrently. The achievable sum rate of these suggested TDMA schemes A and B in ideal conditions was studied via simulations. It was proved that the ideal scheme, which uses ideal receivers, is sometimes not the best proposal with reference to sum rate maximization [7]. In interference limited system, TDMA of scheme A offers a better sum rate as compared to the ideal scheme. When one of the receivers requires comparatively higher energy than the other one, TDMA of scheme B provides a higher sum rate than TDMA of Scheme A. Overall simulation results and the conclusion are varying from the previously reported results [8] in the absence of the ideal receiver, which always performs better.

B. SWIPT - Multiuser MIMO systems

In the multiple inputs and multiple outputs (MIMO) network, all receivers/user terminals are battery limited devices, and batteries need to be recharged to extend the network lifetime. Energy harvesting is performed by the individual receivers through dedicated power transmission from the transmitters in the network.

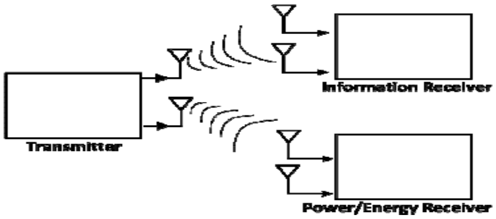

Fig. 5 A MIMO broadcast system

Most of the work that tried to integrate SWIPT in MIMO wireless networks presumes that there are two defined groups of users to be served, one for receiving information and another for receiving power to recharge their power sources. A three-device (one transmitter and two receivers) MIMO wireless broadcast system is considered, figure 05. Using the signal sent by a transmitter, energy receiver gathers energy while other receiver performs information decoding. Two different scenarios in the MIMO broadcast system have been examined in [8], namely separate and co-located information decoding and energy harvesting receivers.

IV. WIRELESS POWER TRANSMISSION USING MICROWAVE TECHNOLOGY

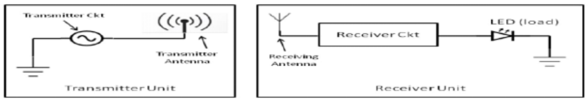

Fig. 6

The design [2] process for the project involved breaking down everything into three primary units: the receiver, transmitter, and the antennas [4]. These units were given specific requirements for inputs and outputs needed so that an entire system could be created that would meet all of the functional requirements. The requirements that the team was given were simple. It was required that the prototype transmit power wirelessly a minimum distance of 1 cm in order to power a simple electronic load. To simplify the design it was decided that microwave technology would be used at 2.45 GHz because it is a frequency range in which many components are made to work and it is within a range that the FCC allows for scientific research. A top-level overview of the prototype can be seen in Figure 6. In the figure it can be seen that the transmitter circuit creates a signal that is inputted into the transmitting antenna. The signal then propagates out into free space, is received by the receiving antenna, and converted into a DC signal that is used by the LED load.

The voltage controlled oscillator (VCO) and 5W output amplifier were commercially bought. The transmitter circuitry receives power from a DC power supply, the VCO uses the power to create an oscillating signal at the desired frequency and the amplifier ensures that the signal to the antenna is 5W in strength.

The receivers’ job is to take in high frequency energy and convert it DC energy to operate the simple electronic load. To accomplish this there are multiple important parts included in the receiver design. These parts are the simple electronic load, low pass filter, rectifying circuit, DC blocking capacitor, matching network, and the antenna. The simple block diagram [2] below shows the receiver.

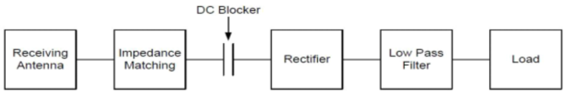

Fig. 7

The functional requirements state that the prototype is to power a simple electronic load by wireless power over a distance of at least 1 cm. An LED (Light Emitting Diode) was chosen to be the simple electronic load to simplify testing. This device can operate on low power, and since it emits light it is easy to tell when the circuit is working. The chosen LED is red and needs only 60mW of power in order to operate at maximum luminosity. A rectifier was needed to generate the DC energy from the high frequency energy. The rectifier chosen was a Schottky diode. Diodes are non-linear, and when a high frequency signal comes into contact with a non-linear device the signal is broken up into its harmonics including DC. The Schottky diode is necessary because it switches faster than a regular diode. In order for the rectifier to work, it must be able to switch faster than the highest frequency you want to rectify. Since the rectifier allows more than DC energy to pass, and the LED can't handle the high frequency energy, a low pass filter (LPF) needs to be added between the rectifier and LED. For the design a two pole LPF using lumped elements was used. This circuit was chosen due to its simplicity and sufficient rejection for the LED. This is one area where the design could be improved upon—it is possible that other filters or components can provide better results. The remaining parts needed are the DC blocking capacitor and the input matching network. The DC blocking capacitor is placed just before the rectifier in order to ensure that all DC energy created by the rectifier flows toward the load. The matching network is used to ensure a maximum flow of power from the antenna into the receiving circuitry. Various circuits were tested, but again simplicity won out, producing a mixed lumped element and transmission line circuit to do the matching and a separate DC blocking capacitor to direct the DC energy. The diodes and DC blocking capacitor were relatively easy to figure out, but the LPF and matching network involved more thought and consideration. As stated there are many usable circuits and the best one was found by research and simulation. The restrictions upon both circuits proved to be similar. If too much transmission line was in either circuit it had the effect of reducing the efficiency by increasing the line loss. On the other hand finding lumped elements that worked reliably at 2.45 GHz was surprisingly difficult. There are only a small number of values of capacitors and inductors that can be found to work at that frequency. This meant that a balance had to be found between the use of transmission line and the lumped elements that the team was able to find.

V. FUTURE SCOPE

Various ways of wireless power generation are described which are based on sustainable technology. Currently we are using very limited non conventional sources of energy e.g. Solar Energy or Wind Energy and harnessing electric energy from these depends on their availability. But being an intermittent energy sources they cannot be able to meet continuous energy requirements. Utilizing ubiquitous electromagnetic energy (Radio Frequency) for electric power and storing this electric energy in Micro–Cell Batteries is very beneficial sustainable technology for meeting the continuous energy needs as it can be harnessed every time and everywhere. Using Rectennas high power harvesting applications and large scale requirements can be fulfilled for which the frequencies are above 2.45 GHz. According to Plank's equation, $E = hv$ where E is energy, h is Plank's constant; v is frequency of electromagnetic radiations. Hence Energy and Frequency are inter-convertible and one form of energy can be converted into another form of energy. Here we are harnessing Electrical Energy from Radio Frequency. Presently, new technology simultaneous information and power transfer (SWIPT) is emerging using which we can either receive electric power and information using single receiver by Time Division Multiple Access (TDMA) as in (MISO) technology or receive electric power and information continuously using (MIMO) network. In future, we can use advanced modulating and baseband signal receiving techniques by making the use of Energy Reclamation System [ERS] through Frequency Division Multiple Access (FDMA) or Time Division Multiple Access (TDMA).

VI. CONCLUSION

Energy Reclamation System [ERS] can be integrated with Transmitters and receivers which can not only be used to meet continuous and large electric energy requirements for various electronic devices and house hold appliances but also be used to meet the RF carrier signal as well as electric power requirements for transmitting and receiving information signal or information decoding over large distances. Radio Frequency can also be used to charge various electronic devices wirelessly. Energy harvesting from Radio Frequency is a very useful wireless sustainable technology.

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