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ENERGY HARVESTING SYSTEM AND METHOD

Field of the Invention

[0001] The present invention relates to energy harvesting. Specifically, the present invention relates to a system and method for harvesting recyclable energy, in particularly, low recyclable energy.

Background

[0002] There are known system and method adapted to harvesting various different types of environmental energy and converting it to useful DC power. Most of these system and method, however, does not store the energy captured long enough due to the leaky nature of the circuit, and the output power is generally insufficient for any useful application.

[0003] For example, the maximum converted DC power voltage using the conventional harvesting technique, such as rectenna arrays, can generally reach by most a few hundred mV even with carefully designed matching between the components. It is because of the inherent losses in the rectification process. The output voltage level is usually suitable for extremely low power sensors, which is insufficient for most practical electronic devices that operate at 1 V and above.

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Summary

[0004] In one aspect, the present invention seeks to provide an energy harvesting system for harvesting recyclable energy and rectifying said energy and storing it as DC power charge. The energy harvesting system comprises a plurality of harvesting modules, each harvesting module includes an energy harvesting means and a voltage doubler, wherein the energy harvesting means is operable to capture the recyclable energy for transmitting to the voltage doubler for rectifying into the DC power charge and storing in capacitors thereof; and a charge accumulator connected to the plurality of harvesting modules in series, the charge accumulator includes a power bank for storing the DC power charge, and a switch for controlling the DC power charge -to be transferred from the capacitors to the power storage bank. The switch is on for allowing the DC power charge stored in the capacitors to be transferred into the power storage bank when a resultant voltage across the plurality of harvesting modules is higher than a threshold voltage of the switch.

[0005] In another aspect of the present invention, there is provided a method of harvesting recyclable energy and rectifying said energy into DC power charge. The method comprises capturing the recyclable energy through a plurality of energy harvesting means; rectifying the recyclable energy into direct current (DC) power charges; storing the DC power charges into capacitors; and transferring the DC power charges stored in the capacitors to a power storage bank when a resultant voltage across the plurality of harvesting modules is higher than a threshold voltage of the switch.

[0006] In yet another aspect of the present invention, there is provided a system for the present invention provides a system and method of harvesting recyclable energy. In one embodiment, the system and method can be used for harvesting electromagnetic energy. The power that harvested achieves a higher voltage rating than the currently available system. In another embodiment, the energy harvesting system has a plurality antenna module and a charge accumulator connecting in series for collecting the electromagnetic energy. Each antenna module may include an antenna and a voltage doubler. The antenna may be used to collect/harvest the electromagnetic wave energy from the ambient, and the voltage doubler is adapted to rectify the electromagnetic wave energy into a DC power in a form of charge. The harvested energy charges may be stored in voltage doublers and are transferred to and stored in the charge accumulator when a resultant voltage is reached.

Brief Description of the Drawings

[0007] This invention will be described by way of non-limiting embodiments of the present invention, with reference to the accompanying drawings, in which:

[0008] **FIG. 1** illustrates a schematic diagram of an energy harvesting system in accordance with one embodiment of the present invention;

[0009] **FIG. 2** illustrates a circuit diagram of an energy harvesting system in accordance with another embodiment of the present invention;

[0010] **FIG. 3A** illustrates an experimental configuration for testing an energy harvesting system in accordance with yet another embodiment of the present invention;

[0011] **FIG. 3B** is a graph of resulting DC voltage across a storage capacitor versus time of an experiment under the configuration of **FIG. 3A**; and

[0012] **FIG. 3C** is a graph of resulting DC voltage across a storage capacitor versus time of another experiment under the configuration of **FIG. 3A**.

Detailed Description

[0013] In line with the above summary, the following description of a number of specific and alternative embodiments is provided to understand the inventive features of the present invention. It shall be apparent to one skilled in the art, however that this invention may be practiced without such specific details. Some of the details may not be described at length so as not to obscure the invention. For ease of reference, common reference numerals will be used throughout the figures when referring to the same or similar features common to the figures.

[0014] **FIG. 1** illustrates a schematic diagram of an energy harvesting system **100** in accordance with one embodiment of the present invention. The energy harvesting system **100** is a device for collecting and converting electromagnetic wave energy into useable DC power. The energy collection system **100** comprises a plurality of antenna modules **110** and a charge accumulator **120**. The antenna modules **110** are connecting to the charge accumulator **120** in series. Operationally, the energy harvesting system **100** is used as a power source that supplies direct current power via the charge accumulator **120**.

[0015] The antenna modules **110** are adapted to harvest generally low power electromagnetic wave in a form of alternating current (AC) power, rectify the harvested AC power into direct current (DC) power and accumulate the DC power charge. Once the accumulated DC power charge reaches a predetermined voltage level, the accumulated power charge from antenna modules **110** is transferred to the charge

accumulator **120**. The charge accumulator **120** includes a switch for managing the power charge transfer. The charge accumulator **120** further includes a power bank for storing the power charge transferred from the antenna modules **110**. The output power from the charge accumulator **120** can be used directly.

Each antenna module **110** is generally an electromagnetic wave energy-collector comprising an antenna **111** and a voltage doubler **112**. The antenna and voltage doubler can be specifically designed for optimal performance for specific frequency band (usually higher frequency is preferred due to size of antenna). Operationally, the antenna **111** captures/receives incident electromagnetic wave and converts the same into a small alternating current (AC) power. The small AC power is fed to the respective voltage doubler **112** to rectify into a small DC power at each antenna module **110**. The voltage doubler **112** includes generally two low turn-on voltage diodes and two capacitors. One of the objectives of the voltage doubler **112** connected after the receiving antenna is to compensate for the forward voltage drop on the diode of the voltage doubler **112**. Voltage tripler and quadrupler can also be used but it will result in more losses through the diodes and the capacitors.

[0017] **FIG. 2** illustrates **a** circuit diagram of the energy harvesting system **100** in accordance with another embod**iment** of the present inven**tion**. The energy harvesting system **100** comprises five antenna modules **110** connecting to the charge accumulator **120** in series. Each of the five antenna modules **110** harvests its own DC power and the total DC power is collectively fed to the charge accumulator **120**. The total DC power that can be harvested through the antennas is determined by **the** number of antenna modules **120** provided. Operationally, capacitors of the antenna mo**dules** **110** store charges until a resultant voltage across the **plur***al*ity of antenna modu**les** **120** reaches level to turn on the charge accumulator **12*0***.

[0018] The charge accumulator **120** comprises a switch **210** and a **storage** capacitor **220**. The charge accumulator **120** includes a transistor switch with a specific turn-on threshold voltage. **When** a resultant output voltage from the serially connected antenna modules **120** exceed a voltage across the storage capacitor **220** by the specific turn-on threshold voltage, the switch **210** is turned on or closed. Accordingly, the charges stored in the capacitors of antenna modules **110** are transferred to the storage capacitor **220** through the switch **210**. The storage capacitor **220** has a larger capacitance that that of the capacitors of the antenna module **110**.

[0019] When the difference between the resultant output voltage of the antenna modules **120** and the voltage across the storage capacitor **220** drops below the turn-on threshold voltage, the switch **210** is turned off or opened. The opened switch **210** stops the charge transfer process which allows the capacitors of the antenna modules **110** to charge up until the resultant output voltage reaches the turn-on threshold voltage to turn on the switch **210** and the charge transfer process repeats.

[0020] The charge accumulator **120** provides the charge transfer cycle via the switch **210**. The charge transfer cycle is stopped when the voltage of the storage capacitor **220** reaches the resultant output voltage.

[0021] Depending on a voltage required in a specific application, the number of antenna module **110** can be chosen accordingly. To meet the power requirement, more

than one large valued storage capacitors can be connected in parallel in the charge accumulator **120**.

[0022] In another embodiment, each voltage doubler **120** includes two diodes and two capacitors. The 2N2222A silicon NPN transistor can be used as rectifier diodes. The NPN transistor has a forward voltage and a reverse leakage current of 0.35V and 0.02μA, respectively. Two 1μF low loss tantalum capacitors are employed to store the rectified power in each voltage doubler **120**.

[0023] In accordance with yet another embodiment, the antenna **111** is a helix antenna operating at 80 MHz.

[0024] In a further embodiment, the switch **210** is a MOSFET switch. For example, an NMOS and a PMOS can be configured as the MOSFET switch for the above embodiments. The commercially available MOS with product serial number BSH105 and BSH205, for example, can also be selected. A 0.33mF tantalum capacitor can be used as the storage capacitor **220** with 1μF capacitors used for the voltage doublers **112**. Under the current configuration, operationally, when the resultant DC output of the antenna module **110** is higher than the MOSFET threshold of 0.4V, the MOSFET switch turns on and the charges stored in the in the capacitors of the voltage doublers **112** will be transferred to the 0.33mF storage capacitor. The charge transfer process repeats until the voltage across the 0.33mF capacitor reaches the resultant DC output of the antenna module **110**.

[0025] An experiment was carried out to illustrate the performance of the energy harvesting system **100** of one embodiment of the present invention as shown in **FIG. 3A**. The experiments were carried out in a semi-anechoic chamber **350**. The energy harvesting system **100** comprises five helix antennas **310** connecting to a charge accumulator **320**. The helix antennas **310** were used as receiving antennas. To emulate a low power wireless transmission, a bi-conical antenna **330** is connected to an 80MHz signal generator **340**. While generating the 80MHz signal, the output power of the signal generator **340** was increased gradually until a noticeable voltage at the 0.33mF storage capacitor of the charge accumulator **320** was detected. Then, the output power of the signal generator was maintained. The DC voltage across the storage capacitor was recorded at every 30 seconds interval for ten-minutes.

[0026] **FIG. 3B** illustrates a graph of the resulting DC voltage across the storage capacitor versus time of the experiment under the configuration of **FIG. 3A**. The distance between the energy harvesting system **100** and the bi-conical antenna **330** was one meter. The energy harvesting system **100** began to work when the output/transmitting power of the signal generator **340** is 18.6dBm (72mW). With the signal generator **340** maintained at 18.6dBm, the DC voltage reached 2V within 30 seconds and the storage capacitor charged up to a steady-state value at approximately 2.55 V.

[0027] **FIG. 3C** illustrates a graph of the resulting DC voltage across the storage capacitor versus time of the experiment under the configuration of **FIG. 3B**. The distance between the energy harvesting system **100** and the bi-conical antenna **330**

was three meters. At the current configuration, the required output power of the signal generator **340** was found to be 22.25dBm (168mW) for three meters. Similarly, the DC voltage reached 2V within 30 seconds and the storage capacitor charged up to approximately 2.7 V at its steady-state.

[0028] Through the experiments, it was shown that the energy harvesting system **100** in accordance with the present invention is able to acquire around 2.5V DC power from a low transmission power, i.e. less than 1W, which is sufficient for most of the commercially available electronic devices. Further, for higher power requirements, more storage capacitors can be connected in parallel in the charge accumulator **320**.

[0029] It is understood that the present invention described above is suitable for harvesting electromagnetic wave energy and used it as a power source for any electronic applications. A person skilled in the art would appreciate that the present invention can also be adapted to harvest other recyclable energy, generally small scale energy sources. Some of the possible energy sources are provided herewith below:

[0030] With piezoelectric devices, in one embodiment, the energy harvesting system of the present invention can be adapted and installed under common furniture to convert mechanical strain into electrical power. For example, when the energy harvesting system is placed under a seat, when seated, the body weight is converted into electrical energy and store in the charge accumulator which can be used to power up some electrical devices such as solid state lighting etc. It is also possible to adapt

electroactive polymers (EAPs) which have a large strain, elastic energy density, and high energy conversion efficiency, for energy harvesting.

[0031] With thermopile, in another embodiment, heat energy can be converted into electrical energy and stored more efficiently. Such application can be widely used automotive industries.

[0032] With solar cells, in a further embodiment, solar energy can also be converted into electrical energy and stored more efficiently.

[0033] The energy harvesting system can be used as a replacement of batteries or the like, which are generally toxic for disposing. The energy harvesting system is ideal for low power applications, such as sensors, digital clock, RFID, just to name a few. The energy harvesting system can also be used as a supplemental power source for some electronic application, such as the electronic devices that consume relatively higher power, to reduce the number of battery module required.

[0034] In yet a further embodiment, low temperature co-fired ceramic (LTCC) technology or printable electronics can be employed to integrate the antenna module and the charge accumulator circuit to miniaturize the energy harvesting system.

[0035] The present invention provides an efficient energy harvesting system that is easy to design and can easily be adapted and altered to suit different applications. It can be achieved by at least connecting several antenna-doublers in series and

followed by a charge accumulation and lock device. It is suitable for converting low power electromagnetic energy, typically in a range of 0.1 to 0.2 W power to a DC voltage power source that has a higher voltage that a standard 1.5 V battery. The DC voltage level is proportional to the number of antenna-doublers employed. The electrical circuit does not require any external power source to charge the storage capacitor. It is self-charge through harvesting energy through the environment. As such, one can continue to accumulate the charges from the environment, and store it in a charge storage device such as capacitors for future use. In some applications, it is possible that such power source can be used as a permanent self-charged power supply as long as electromagnetic wave energy is in existence.

[0036] Several advantages and improvements over existing methods and devices can be realized through the present invention. It has the flexibility of meeting various DC voltage requirements by simply altering the number of voltage doublers module connecting in series. When a higher power supply is required, it is possible to connect additional storage capacitors in parallel to increase the power storage capacity. Yet, as there is no power source needed, it is suitable for mobile/portable applications.

[0037] While specific embodiments have been described and illustrated, it is understood that many changes, modifications, variations and combinations thereof could be made to the present invention without departing from the scope of the invention.

Claims

1. An energy harvesting system for harvesting recyclable energy and rectifying said energy into DC power charge, said system comprising:

a plurality of harvesting modules, each harvesting module includes an energy harvesting means and a voltage doubler, wherein the energy harvesting means is operable to capture the recyclable energy for transmitting to the voltage doubler for rectifying into the DC power charge and storing in capacitors thereof; and

a charge accumulator connected to the plurality of harvesting modules in series, the charge accumulator includes a power bank for storing the DC power charge, and the a switch for controlling the DC power charge to be transferred from the capacitors to the power bank,

wherein the switch is on for allowing the DC power charge stored in the capacitors to be transferred into the power bank when a resultant voltage across the plurality of harvesting modules is higher than a turn-off voltage of the switch.

2. The energy harvesting system according to claim 1, wherein the number of harvesting module connecting in series determines a voltage level that can be acquired by the energy harvesting system.

3. The energy harvesting system according to claim 1, wherein the switch comprises a MOSFET.

4. The energy harvesting system according to claim 1, wherein the power bank includes a storage capacitor.

5. The method according to claim 1, wherein the recyclable energy include electromagnetic wave energy which is harvested through an antenna.

6. The method according to claim 1, wherein the recyclable energy include solar energy which is harvested through a solar cell.

7. A method of harvesting recyclable energy and rectifying said energy into DC power charge, the method comprising:

capturing the recyclable energy through a plurality of energy harvesting means;

rectifying the recyclable energy into direct current (DC) power charges;

storing the DC power charges into capacitors; and

transferring the DC power charges stored in the capacitors to store in a power bank when a resultant voltage across the plurality of harvesting modules is higher than a turn-off voltage of the switch.

8. The method according to claim 7, wherein the number of the harvesting means connecting in series determines a voltage level that can be acquired.

9. The method according to claim 7, wherein the power bank includes a storage capacitor.

10. The method according to claim 7, wherein the recyclable energy include electromagnetic wave energy which is harvested through an antenna.

11. The method according to claim 7, wherein the recyclable energy include solar energy which is harvested through a solar cell.

12. The method according to claim 7, wherein the recyclable energy include electromagnetic wave energy which is harvested through an antenna.