

A self-powered remote control deviceField of the Invention

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This invention relates to a hand-held remote control device employing a power generation unit. In particular, it relates to the construction and architecture of the remote control device, as well as that of the power generation unit.

10 Background of the Invention

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Remote control devices have been widely applied for a great variety of applications. These days, hand-held remote control devices are used to control various electrical appliances at home. They are also used with vehicles, industrial equipment, and other devices that may not be conveniently wired, or where wiring is aesthetically not suitable. Conventional hand-held remote controls are traditionally powered by batteries, but inherent in battery-powered systems is the issue of inoperability when the battery's charge has been exhausted. Battery-powered devices can also be damaged by the leakage of battery fluids. In addition, large quantities of spent batteries are being disposed into the environment and the disposal of these batteries with hazardous compositions raises genuine health and environmental concerns.

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To alleviate the aforementioned problems, hand-held remote control manufacturers have recently experimented with mechanically powered remote controllers. Specifically, mechanical energy is derived from a human user pushing on a button, and this mechanical energy is converted into electrical energy through the use of a piezoelectric energy generator. However, several problems limit the practicality of these remote controllers.

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- (1) The amount of energy generated through a user's pushing of a button is quite limited, and is often insufficient for powering remote controllers over an extended period of use. Repeated pushing of the button is also tedious and can become uncomfortable for the user.



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(2) A complex mechanical structure is required to build the push-button mechanism, thus increasing manufacturing costs.

(3) Because the impedance of piezoelectric energy transducers is high, it is difficult to obtain a matched impedance to the load of the circuit, and thus the generated electrical energy is not efficiently transferred to the load, which in this case would be the encoding device and the wireless transmitter.

(4) The materials used in creating the piezoelectric units are currently made of toxic lead-based ceramic materials, which itself comprises an environmental pollutant when the piezoelectric units or the remote controls are ultimately disposed of.

The amount of electrical energy required for transmitting an RF signal depends on several factors, such as, *inter alia*, the length of the digital signal, the frequency of the RF signal, the range required, the terrain of the transmission medium, and the sensitivity of the receiver. The energy required for a typical transmission over a range of 50 meters is about 100 μJ based on currently available RF transmitter ICs and encoder ICs. Similarly, the amount of electrical energy required for transmitting an infrared signal also depends on many factors. Based on current technology, an infrared transmission over a range of about 5 meters could require 350 μJ . There is thus a need for a piezoelectric powered remote controller that can achieve these requirements without strenuous exertion of force from the user.

Ongoing design and manufacturing improvements in piezoelectric powered devices are improving efficiency and practical usage of these devices, but there remains significant room for further improvement in the design and architecture of these devices.

Summary of the Invention

The present invention aims to provide a new and useful remote control device.

In general terms, the invention proposes a hand-held remote control device powered by energy derived from the user shaking the device. A movable body resides inside the remote control device, and electrical energy is generated when the movable body strikes

a piezoelectric energy transducer as the remote control device is being shaken. In contrast to current piezoelectric powered devices where the user has to push a button repeatedly to charge the device, the shaking operation of the invention allows the user to apply a much larger force to the remote control device in an ergonomic and comfortable way. In addition, the invention may have fewer moving parts than conventional piezoelectric powered devices, and thus this simplified structure reduces manufacturing costs.

A second aspect of the invention proposes to improve upon the efficiency of the piezoelectric transducer through the use of multiple piezoelectric layers within a single transducer, where individual layers are laminated in series mechanically, and electrically connected in parallel. This architecture allows for better impedance matching with typical loads. This arrangement also reduces the output voltage of the transducer such that a step-down transformer is not usually required when coupling to storage circuitry.

A third aspect of the invention proposes to further improve upon the efficiency of the piezoelectric transducer through the use of curved ceramic disks. This allows bending-mode deformation of the ceramic for additional electrical energy generation.

A fourth aspect of the invention proposes to improve upon the durability of the piezoelectric transducer through subjecting the transducer to compressive stress in the plane perpendicular to the direction of impact.

A fifth aspect of the invention proposes the use of non-toxic piezoelectric material in the construction of the piezoelectric transducer, thus mitigating environmental concerns associated with current commercial piezoelectric units which are made of toxic lead-based ceramic materials.

Brief Description of Drawings

The advantages of this invention can be more readily ascertained from the following description of the embodiments of the invention when read in conjunction with the accompanying drawings in which:

Figure 1(a) and 1(b) are diagrams showing a remote control device with a power generator unit, which is a first embodiment of the invention.

Figure 2 is a circuit diagram showing a step-down transformer circuit coupled to the output of the power generator unit.

5 Figure 3 is a diagram showing a second embodiment of the invention having a power generator unit comprising an additional second piezoelectric energy transducer.

Figure 4 is a circuit diagram showing a second step-down transformer circuit which may be used as a replacement to that in Figure 2 in embodiments of the invention.

10 Figure 5 is a diagram showing a third embodiment of the invention having a power generator unit with curved piezoelectric transducers.

Figure 6 is a diagram showing a fourth embodiment of the invention having the power generator unit with multilayered piezoelectric transducers.

15 Figure 7 is a circuit diagram showing schematically an arrangement which may be used in certain embodiments of the invention, including a piezoelectric transducer with a plurality of layers coupled directly to the storage capacitors, without the need for a step-down transformer circuit.

Figure 8 is a photograph showing two fabricated power generator units, with one power generation unit in an assembled state and the other power generation unit in an unassembled state from the second embodiment of the invention.

20 Figure 9 is a graph showing the accumulation of energy stored in the storage capacitors when the user shakes the remote control device from the first embodiment of the invention.

Figure 10 is a graph showing the accumulation of energy stored in the storage capacitors in an arrangement such as that shown in Figure 4.

25 Figure 11 is a graph showing the electric energy generated by both a flat and a curved piezoelectric transducer from both the first and third embodiment of the invention.

Figure 12 is a graph showing the electric energy generated by both a single-layered and a multi-layered piezoelectric transducer from both the first and fourth embodiment of the invention.

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Detailed Description of Embodiments

Embodiment 1:

An embodiment of the invention will now be described with reference to Figure 1(a) and 1(b). Here, a remote control device 1 comprises a power generator unit 2, an electric power storage device 3, a voltage regulation unit 4, a control unit 6 (which is a digital encoder in this embodiment) coupled to at least one input device 5 (which are pushbuttons in this embodiment) disposed on a front panel of a housing of the remote controller, and a wireless signal transmitter 7.

The power generator unit comprises a movable body 8 having a mass of at least 3 grams confined within a cavity in a casing 10, and a piezoelectric energy transducer 9 attached to the casing 10. In this embodiment, the movable body 8 is connected to one end of the casing with a body of elastic material 11, preferably a spring. The movable body 8 could be a stainless steel ball. At rest, the movable body is pressed against the piezoelectric transducer due to compressive force coming from the spring, as shown in Figure 1(a).

The piezoelectric transducer 9 can be made of a lead-free piezoelectric material, and be in the form of a ceramic disk, with two electrode layers coated on its opposing surfaces. The piezoelectric transducer is affixed to one end of the casing using an adhesive 12 such as epoxy. It is also preferable that the piezoelectric transducer is surrounded by epoxy so that compressive stress is applied to the piezoelectric ceramic disk due to contraction of the epoxy during the curing process. In addition, a protective layer 13, such as a metallic plate, may be adhered to the surface of the piezoelectric transducer 9 which is being impacted by the movable body 8.

When the remote control device 1 is shaken by the human user along its longitudinal axis, i.e. along the length of the housing of the device, the movable body 8 oscillates with assistance from the spring. When the movable body 8 moves towards the spring, kinetic energy from the movable body 8 is converted to elastic potential energy and stored in the compressed spring, as shown in Figure 1(b). The elastic potential energy stored in the compressed spring is then converted back to kinetic energy as the spring pushes the movable body 8 away. In addition, because the user is also now shaking the device 1 in the opposite direction, the user is accelerating the device 1 in the opposite direction of the movement of the movable body 8. Thus the movable body 8 is accelerated relative to the device 1 by both the compressive force of the spring as well as the acceleration of

the device 1 in the opposite direction caused by the human user.

The movable body 8, which is a ball in this embodiment, now returns at high velocity and impacts the piezoelectric transducer 9. The ball's momentum causes a strain in the piezoelectric material, and this generates electric energy through the piezoelectric effect. The electric energy generated is stored in the electric power storage device 3, which in turn supplies power to the control unit 6 and wireless signal transmitter 7.

In this embodiment, there is also a voltage regulator unit 4 which comprises a voltage monitor 14, switch 15, and voltage regulator 16, as shown in Figures 1(a) and 1(b). The voltage regulator unit 4 is coupled to the output of the electric power storage device 3 and performs two functions: firstly, it ensures that the power stored within storage capacitors of the electric power storage device 3 is of a sufficient voltage before closing the switch 15 connecting the storage capacitors 22 and voltage regulator 16, and secondly, the voltage regulator 16 component itself provides a constant supply voltage to enable proper operation of the control unit 6 (digital encoder) and the wireless signal transmitter 7.

Next, when the user initiates a manual input, such as by pressing a pushbutton on the input device 5 of the remote control device 1, the control unit 6, which is a digital encoder in this embodiment, will perform an encoding operation and generate an output to the wireless signal transmitter 7. The wireless signal transmitter 7 then sends out a wireless signal according to the output received from the control unit 6.

The wireless signal transmitter 7 may comprise, but is not limited to, a radio frequency ('RF') transmitter or an infrared transmitter. RF transmission of signals for remote controller applications is well known in the art. Advantages of RF transmission over infrared transmission include lower energy consumption, a relatively longer transmission range, and non line-of-sight signal propagation. A wireless signal transmitter 7 utilizing an RF transmitter can be implemented using a suitable encoder and antenna. The encoder produces a digital signal according to the state of the pushbuttons on the remote control device 1. The digital signal from the encoder modulates the RF output signal of the RF transmitter. The output of the RF transmitter is typically connected to an antenna (not shown) for efficient radiation of the RF output signal. The RF output signal

is then picked up by a corresponding RF receiver located in the vicinity.

Alternatively, the use of an infrared transmitter may be deemed more suitable in applications where cost is critical, where a shorter transmission range is feasible, or where the wireless signals need to be confined within a room. The circuitry required for transmitting infrared signals is well known in the arts. For example, infrared signal transmission can be achieved by the use of a suitable encoder integrated circuit ('IC') and a transistor to control the on-off flashing of an infrared light emitting diode ('LED'). The information intended to be sent is coded into the flashing pattern of the infrared diode which would then be picked up by a corresponding infrared detector and decoder IC located in the vicinity.

A method of creating the piezoelectric disks will now be described. The piezoelectric ceramic disk here has a lead-free composition of $(1-x)\text{K}_{0.5}\text{Na}_{0.5}\text{NbO}_3\text{-}x\text{LiNbO}_3$ ('KNN-LN'). x is a value which may be in the range 0 to 0.1. KNN-LN ceramic disks are prepared from raw materials of K_2CO_3 , Na_2CO_3 , Nb_2O_5 and Li_2CO_3 , through a solid state reaction process. As the carbonate powders are moisture sensitive, they are first dried prior to use and subsequently weighed according to formula $(1-x)\text{K}_{0.5}\text{Na}_{0.5}\text{NbO}_3\text{-}x\text{LiNbO}_3$ ($x = 0$ to 0.1) and subsequently dispersed in ethanol with ultrasonic irradiation to form a slurry. After the slurry is dried and milled, the mixture powder was calcined at 850 °C to form KNN-LN perovskite phase. After ball-milling and mixing with polyvinyl butyral ('PVB') as a binder, the calcined powder was uniaxially pressed into disks and sintered at 1050 °C in air. The ceramic disk samples obtained after sintering had a diameter of 8.6 mm and a thickness of 0.8 mm. The two main surfaces of the ceramic disks are then polished, and coated with silver paste fired at 550 °C to form the two electrodes. The samples with electrodes were poled at 120 °C for 30 min at 40 kV/cm. For the disk of $(1-x)\text{K}_{0.5}\text{Na}_{0.5}\text{NbO}_3\text{-}x\text{LiNbO}_3$ where $x = 0.06$, a piezoelectric coefficient d_{33} of 184 pC/N was obtained.

Alternately, the piezoelectric ceramic disk can have a lead-free composition of $\text{Ba}_{0.85}\text{Ca}_{0.15}\text{Zr}_{0.1}\text{Ti}_{0.9}\text{O}_3$ (BCZT). The ceramic disks of BCZT were prepared from the raw powder of BaCO_3 , BaZrO_3 , CaCO_3 , and TiO_2 through a similar solid state reaction process as described above. The calcination temperature for BCZT is 1350 °C, and the final sintering temperature is 1450 °C. After the electrode coating and electrical poling, a

piezoelectric coefficient d_{33} of 323 pC/N was obtained for BCZT ceramic disks.

It is pertinent to note that lead-free piezoelectric ceramic disks typically have very high electrical impedances. Thus upon impact by the movable body 8, the disk typically generates an electrical output of high voltage but with a small current. Figure 2 shows the construction of the electric power storage device. In order to lower the voltage and improve the utility efficiency of the electrical energy generated in the piezoelectric transducer 9, a step-down transformer 20 may be included in the electric power storage device 3. The piezoelectric transducer 9 outputs are coupled to the input terminals of the transformer 20, which then outputs the stepped-down voltage to a pair of diodes 21 and storage capacitors 22, as shown in Figure 2. The step-down transformer 20 circuit improves impedance matching between the power generator unit 2 and the electric power storage device 3. The alternating current ('AC') from the output of the step-down transformer 20 circuit is then rectified by the pair of diodes 21. The storage capacitors 22 connected to the diodes allow the accumulation of electrical charge, with one of the capacitors accumulating the electrical charge during the positive phase of the AC and the other capacitor accumulating the electrical charge during the negative phase. The two storage capacitors 22 are connected serially, and the output voltage across the two storage capacitors 22 is the cumulative sum of the voltages across each storage capacitor.

Comparing the current embodiment with a four-diode full wave bridge rectifier electric power storage circuit coupled to a single capacitor as known in the prior art, the embodiment as shown in Figure 2 has the advantages of doubling the energy accumulated by the storage capacitors under constant input voltage, reducing the number of diodes required by the electric power storage circuit by two (from four to two), and reducing the energy loss due to the diode's forward voltage drop.

Embodiment 2:

Another embodiment of the invention is shown in Figure 3, where the movable body 8 is not connected to any elastic material, and where there are two piezoelectric energy transducers 9 instead of one. The movable body 8 in the cavity inside the casing 10 of the power generator unit 2 is accelerated relative to the casing 10 by a human user's

shaking of the remote control device 1. Electrical energy is generated when the moving body 8 strikes either of the two piezoelectric transducers 9 affixed at the two ends of the casing 10. The electrical energy is then stored in the electric power storage device 3, and supplied to the control unit 6 and the wireless signal transmitter 7 as required.

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Figure 4 shows one possible circuit diagram of the electric power storage device 3 when two piezoelectric transducers 41 are utilized. Each of the piezoelectric transducer 41 is connected to an individual step-down transformer 42, and each step-down transformer 42 is connected to a pair of diodes 43. Both the two pairs of diodes are connected to the same pair of storage capacitors 44. In a similar manner, the pair of storage capacitors can be connected to multiple step-down transformers if more piezoelectric transducers were to be added.

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Embodiment 3:

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This embodiment is similar to that in Embodiment 2, except for the use of piezoelectric ceramic disks with a convex top surface 51 and a concave bottom surface 52, as shown in Figure 5. The piezoelectric transducers 9 are placed such that the movable body 8 strikes the convex top surface 51 of the ceramic disks. The curved surface allows for bending-mode deformation in the piezoelectric ceramic disks for additional electric energy generation. The concave bottom surface 52 of the piezoelectric ceramic disk can be bonded to a solid base with an adhesive layer such as epoxy. To protect the ceramic disk, the sides of the ceramic disk can be surrounded with epoxy 12. This results in protective compressive stress being applied to the disk due to volume contraction of the epoxy during the curing process.

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Embodiment 4:

In this embodiment, the remote control device 1 has two piezoelectric transducers 9, each comprising multiple thin layers of piezoelectric material 62 laminated together but connected in series, as shown in Figure 6. Preferably, the piezoelectric transducers comprise multiple layers of thin piezoelectric lead-free ceramic. The multiple layers of piezoelectric material 62 are called a piezoelectric multilayer. The purpose of using the piezoelectric multilayer is to reduce the impedance of the piezoelectric transducer 9 and

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to improve energy generation efficiency. Energy generated is also more efficiently transferred to the electric power storage device 3 since the lower impedance improves impedance matching between the power generator unit 2 and the electric power storage device 3. To significantly lower the impedance of the piezoelectric multilayer transducers, the piezoelectric thin layer should have a thickness preferably below 100 μm and the multilayer should consist of at least 5 layers, and preferably more than 10 layers, of piezoelectric material 62. Piezoelectric ceramic multilayers can be produced with ceramic-metal (as the electrode layers) co-firing methods which are known in the art. Before co-firing at a high temperature, the ceramic-metal multilayer can be formed by a ceramic tape-casting process followed by alternately laminating the ceramic tapes with printed electrodes. The electrodes are then interdigitated, and the odd-numbered layers are connected to one common terminal while all the even-numbered layers are connected to a second common terminal. Thus, the individual piezoelectric layers are laminated in series mechanically, and electrically connected in parallel. It is because of this configuration that the impedance of the piezoelectric energy transducers can be reduced.

In general, the smaller the thickness of the piezoelectric material, and the higher the number of piezoelectric layers, the greater the reduction in the impedance and voltage output of the transducer. When the thickness of the piezoelectric ceramic layer is in the millimeter or sub-millimeter range, the voltage generated from an impact can be in the order of 100V. But by using multiple piezoelectric layers, each with a thickness in the 10 μm range, the output voltage can be reduced to just several volts but with significantly improved voltage and current characteristics. Therefore when using multiple piezoelectric layers, the step-down transformer, as shown in Figures 2 and 4, is not necessary. The multilayer piezoelectric ceramic transducer can be directly connected, through a pair of rectifying diodes 72, to the electric power storage capacitors 71, as shown in Figure 7.

Other Embodiments:

It should be noted that in other embodiments the movable body 8 can be a ball, a cylinder, or a cylinder body with two spherically protruded surfaces 61, as shown in Figure 6. It should be known to the person skilled in the art that the shape and mass of

the movable body can be configured to maximize energy generation efficiency within the physical constraints of the power generation unit 2.

Experimental Results:

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Figure 8 shows two fabricated prototype power generator units for the invention. The fabricated units are from embodiment 2. One of the generator units is shown assembled, and the other is shown disassembled. Two types of movable bodies are also shown, a stainless steel ball and a brass pill. In test trials, the energy collected by the storage capacitors in an embodiment with only one piezoelectric transducer (such as that illustrated in Figure 2) is shown in Figure 9. Each of the capacitors in the electric power storage device had a capacitance of 10 μF . A total energy of 400 μJ was obtained in the storage capacitors. In a different test, the energy collected by the storage capacitors in an embodiment with two piezoelectric transducers (such as that illustrated in Figure 4) is shown in Figure 10. In that embodiment, a total energy of more than 530 μJ was obtained.

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Figure 11 is a graph of the result from numerical simulation showing the difference in the energy generated by both a flat and a slightly curved KNN piezoelectric disk upon impact by the movable body. The results show a substantial improvement when using a curved KNN disk with a convex top surface 51 and a concave bottom surface 52 (as illustrated in Figure 5) as compared to using a flat KNN disk, such as that of the piezoelectric transducer 9 in Figure 3. This is because an additional bending-mode deformation is excited when the curved piezoelectric ceramic is utilized.

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Figure 12 shows the result from numerical simulation comparing the energy generated by both a piezoelectric transducer of a single KNN thick disk with a thickness of 0.8 mm, as well as a KNN multilayer piezoelectric transducer with 10 thin layers but having the same overall thickness. A load resistor of 300 Ω was used in this test. The multilayer piezoelectric transducer and the single layer piezoelectric transducer both generated similar energy given an infinite resistance (open circuit load). However, when a finite load impedance is factored in, the efficiency of the multiplayer piezoelectric transducer is significantly better, as shown in Figure 12. The simulation also showed that the peak voltage is reduced from ~ 200 V for the single layer piezoelectric transducer to ~ 20 V for

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the multilayer piezoelectric transducer. As discussed above, a multilayered piezoelectric transducer has a reduced impedance and this provides for better impedance matching with the load. In addition, the lower output voltage of the multilayered piezoelectric transducer eliminates the need for a step-down transformer.

Claims

1. A self-powered remote control device comprising:

- 5 a power generator unit, wherein said generator unit comprises a casing and a movable body confined within said casing, said movable body configured to move relative to said casing upon said casing being driven by motion of a user, a first piezoelectric energy transducer comprising piezoelectric material being attached to said casing and configured to be impacted by said movable body, whereby impact of said movable body with said first piezoelectric energy transducer generates electrical energy
10 from kinetic energy of said movable body;
- an electric power storage device for receiving energy from said generator unit;
- an input device for receiving a user operated manual input;
- a control unit for performing an encoding operation according to said manual input to generate an output; and
15 a wireless signal transmitter powered by said storage device and for transmitting a signal based on said output.

2. The device according to claim 1, wherein said movable body is connected to an end of said casing by an elastic material for urging said movable body towards said first piezoelectric energy transducer; whereby upon said movable body being initially pressed
20 against said first piezoelectric energy transducer, shaking of said remote control device causes said elastic material to deform and store elastic energy, and upon said movable body moving towards said first piezoelectric energy transducer the elastic energy is converted into kinetic energy of said movable body for generating electrical energy upon
25 striking said first piezoelectric energy transducer.

3. The device according to claim 2 in which the elastic material is a spring.

4. The device according to claim 1, wherein a second piezoelectric energy transducer is
30 attached to said casing.

5. The device according to any one of the preceding claims, wherein said first piezoelectric energy transducer has a convex top surface which is to be impacted by said movable body and a concave bottom surface.

6 The device according to claim 5, in which the concave bottom surface of the piezoelectric transducer is bonded to the said casing with an adhesive layer.

5 7. The device according to any one of the preceding claims, wherein said first piezoelectric energy transducer comprises a plurality of layers of said piezoelectric material.

8. The device according to claim 7, wherein the piezoelectric transducer comprises
10 multiple piezoelectric ceramic layers.

9. The device according to claim 7, wherein the piezoelectric transducer comprises multiple piezoelectric polymer layers.

15 10. The device according to claim 7 wherein each layer of piezoelectric material has a thickness below $100\text{ }\mu\text{m}$.

11. The device according to any one of the preceding claims, wherein said first piezoelectric energy transducer is subject to compressive stress in the plane
20 perpendicular to the direction along which the movable object strikes the piezoelectric transducer.

12. The device according to claim 11, wherein said compressive stress in said first piezoelectric energy transducer is generated by adhesive material around said first
25 piezoelectric energy transducer.

13. The device according to any one of the preceding claims, further comprising a protective layer disposed on the surface of said first piezoelectric energy transducer.

30 14. The device according to any one of the preceding claims, further comprising a step-down transformer coupled to the output of the power generator unit.

15. The device according to any one of the preceding claims, wherein said storage device comprises a plurality of diodes and a plurality of capacitors, at least one of said

plurality of capacitors being configured to accumulate electric charges during the positive phase, and at least one of said plurality of capacitors being configured to accumulate electric charges during the negative phase of the charging current, and said plurality of capacitors being configured to discharge electric charges serially.

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16. The device according to any one of the preceding claims, further comprising a voltage regulator unit coupled to the electric power storage device.

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17. The device according to any one of the preceding claims, wherein said voltage regulator unit comprises a voltage monitor component, a switch component, and a voltage regulator component.

18. The device according to any one of the preceding claims, wherein said wireless signal transmitter is a radio frequency transmitter.

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19. The device according to any one of claims 1 to 17, wherein said wireless signal transmitter is an infrared transmitter.

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20. The device according to claim 1, wherein the piezoelectric material is a lead-free piezoelectric ceramic.

21. The device according to claim 20, wherein the lead-free piezoelectric ceramic has a composition of $(1-x)\text{K}_{0.5}\text{Na}_{0.5}\text{NbO}_3-x\text{LiNbO}_3$, in which $x = 0$ to 0.1 .

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22. The device according to claim 20, wherein the lead-free piezoelectric ceramic has a composition of about $\text{Ba}_{0.85}\text{Ca}_{0.15}\text{Zr}_{0.1}\text{Ti}_{0.9}\text{O}_3$ (BCZT).