



Environmental Noise Harvester For Low Voltage Power Supply

by

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LIST OF ABBREVIATIONS

| | |
|---------|---|
| ABS | Acrylonitrile, Butadiene, and Styrene |
| AC | Alternating Current |
| AlN | Aluminium Nitride |
| AlO-rGO | Flexible Nanocomposite |
| BF | Bias-Flip |
| BJTs | Bipolar Junction Resistor system |
| CMOS | Complementary Metal-Oxide-Semiconductor |
| DC | Direct Current |
| DCM | Discontinuous Mode |
| DSSH | Double Synchronized Switch Harvesting |
| dB | Decibel |
| EAI | Energy Aware Interface |
| ECs | Electrochemical Capacitors |
| EDLCs | Electric Double Layer Capacitors |
| EH | Energy Harvesting |
| EMHR | Electrometrical Helmholtz Resonator |
| EMF | Electromotive Force |
| ESSH | Enhanced Synchronized Switch Harvesting |
| ESR | Equivalent Series Resistance |
| ESU | Energy Storage Unit |
| F | Farad |
| FB | Full Bridge |
| FBDR | Full Bridge Diode Rectifier |
| Fe | Ferro |
| Ge | Germanium |
| g | gram |
| Hz | Hertz |
| Hr | Hour |
| HV | High Voltage |
| IC | integrated Circuit |

| | |
|--------|---|
| I/O | Input/Output |
| JFET | Junction Field-Effect Transistor |
| Kg | kilogram |
| Km | kilometer |
| KW | KiloWatt |
| LED | Light Emitting Diode |
| LIB | Lithium-ion Battery |
| M | Mega |
| m | Meter |
| mAh | milli-ampere hour |
| MEMS | Micro-electro Mechanical System |
| MFC | Macro Fiber Composite |
| MOSFET | Metal-Oxide-Semiconductor Field Effect Transistor |
| MPPT | Maximum Power Point Tracking |
| Mo | Molybdenum |
| mm | Millimeter |
| MnZn | Manganese and Zinc |
| mW | milliWatt |
| mV | millivolt |
| nV | nanoVolt |
| nF | nanoFarad |
| n/a | Not applicable |
| Ni | Nickel |
| NiMH | Nickel Metal Hydride |
| NMOS | Complementary Metal-Oxide-Semiconductor (N-Channel) |
| PCB | Printed Circuit Board |
| PCE | Power Conversion Efficiency |
| PEHs | Piezoelectric Energy Harvesting system |
| pk-pk | Peak to peak |
| PMM | Power Management Module |
| PMN | Lead Magnesium Niobate |
| P-SSHI | Parallel Synchronous Switch Harvesting on Inductor |
| PT | Piezoelectric Transformer |

| | |
|------------------|---|
| PT | Lead Titanate |
| PVDF | Polyvinylidene fluoride |
| PWM | Pulse Width Modulation |
| PZN | Lead Zirconate Niobate |
| PZT | Lead Zirconate Titanate |
| RF | Electromagnetic Interference |
| RFID | Radio Frequency Identification |
| rpm | Revolutions per Minutes |
| rms | Root Mean Square |
| SCRs | Silicon Controlled Rectifiers |
| SECE | Synchronous Electric Charge Extraction |
| Si | Silicon |
| SiO ₂ | Silicon dioxide |
| SPL | Sound Pressure Level |
| STM | Semiconductor Technology Microelectronics |
| SSDCI | Synchronized Switching and Discharging to a Capacitor through an Inductor |
| SSDI | Synchronized Switch Damping on Inductor |
| SSHI | Synchronous Switch Harvesting on Inductor |
| S-SSHI | Series-Synchronous Switch Harvesting on Inductor |
| SHE | Sound Energy Harvesting |
| TEGs | Thermoelectric Generators |
| μF | microFarad |
| μW | microWatt |
| VD | Voltage Doubler |
| VSSHI | Velocity Synchronous Switch Harvesting on Inductor |
| Wh | Watt hour |
| WSN | Wireless Sensor Network |
| WSNs | Wireless Sensor Network system |

LIST OF SYMBOLS

| | |
|-----------------|---|
| A | Flange diameter |
| a | Length side square |
| A_c | Cross-sectional area |
| B | Barrel |
| B_x | Tesla |
| C | Clearance |
| C_p | Parasitic capacitor |
| C_{sup} | Capacitance of supercapacitor |
| C_{piezo} | Capacitance piezo |
| $\{c^E\}$ | Elastic coefficients |
| D | Arbor hole Diameter |
| D_c | Diameter of circle |
| D_o | Internal Diameter Roll |
| D_1 | External Diameter Roll |
| $\{D\}$ | Electric Displacement Vector |
| E | Total Energy |
| $\{E\}$ | Electric Field Vector |
| $\{e\}$ | Dielectric Permittivity matrix |
| f | Vibration frequency |
| $f_{bandwidth}$ | Bandwidth frequency differ between higher and lower frequency |
| H | Height |
| h | Size of copper wire |
| $I_{charging}$ | Charging Current |
| I_{in} | Input Current |
| I_{out} | Output Current |
| I_{sc} | Short Circuit Current |
| $k\Omega$ | Kilo-ohm |
| L | Total length of the tape |
| l | Length of winding turn |
| N | Number of turns |

| | |
|----------------|--|
| n | Efficiency |
| P | Perimeter |
| P_{in} | Input Power |
| P_o | Internal Perimeter |
| P_{out} | Output Power |
| P_1 | External Perimeter |
| ρ | resistivity |
| Q | Coulombs Charge |
| R | Load Resistance |
| R_{opt} | Optimum Resistance Load |
| R_{dc} | Direct Current Resistance |
| R_{ESR} | Internal Resistance of Supercapacitor |
| R_p | Parasitic resistor |
| r | Radian of copper wire |
| $\{S\}$ | Strain Vector |
| $\{\alpha^s\}$ | Dielectric Matrix |
| s | Second |
| $\{T\}$ | Stress Vector |
| τ | Total Time constant |
| T | Traverse |
| $t_{charging}$ | Time charging |
| V_{dc} | Direct Voltage |
| V_{emf} | Electromotive Force Voltage |
| V_{in} | Input Voltage |
| V_k | Forward Voltage |
| V_{max} | Maximum voltage at center frequency of bandwidth graph |
| V_m | Max Voltage/ Peak voltage |
| V_{oc} | Open Circuit Voltage |
| V_{out} | Output Voltage |
| $V_{out(p)}$ | Peak Output Voltage |
| V_{pk} | Peak voltage |
| V_{pk-pk} | Peak to peak voltage |
| V_{rms} | Voltage Root Mean Square |

| | |
|------------------|----------------------------------|
| V_{sup} | Voltage rating of Supercapacitor |
| W | Overall Width |
| Z_i | Internal Impedance |

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Environmental Noise Harvester for Low Voltage Power Supply

ABSTRACT

There is an increased awareness nowadays regarding the potential shortage of fuel sources for electricity generation in the future, where various studies have been conducted about the usage alternative sources. Currently, the renewable energy has been prioritized for instance, through ambient energy scavenging. To achieve this goal, sound, being the most abundant energy in the environment, is likely the best candidate to fill the slot. The existing rectifying technique that has been used for energy transfer in energy harvesting is 'switch-only' and 'bias-flip' techniques which utilize an additional switches or switched inductors for speedy voltage rectification. However, such techniques depend on the timing accuracy and synchronization of the pulses of the switch whenever the changes in the currents' polarity generated by the piezoelectric harvester. The existing acoustics-based energy harvesting systems utilized a self-powered active rectifying diode circuitry technique to convert alternating current signal to direct current. The active MOSFET rectifier circuit has extra components and required an external DC supply to power the rectifying circuit. Thus it is not a good option for small scale harvester system and suffered some drawbacks in the implementation of the circuit. Although synchronous switch harvesting on the inductor (SSHI) and synchronous electric charge extraction (SECE) rectifiers possess high efficiency to extract and harvest the energy available from system, they have drawbacks of SSHI circuits such as the complexity of the circuit which can contribute to additional losses of power, threshold voltages, frequency selectivity and parasitic bandwidth filters. In this study, the developments of passive circuit including voltage multipliers (Dickson and Villard circuits) and step-up transformer were proposed and designed to rectify the low voltage acoustic voltage. The simulation of the proposed harvesting circuit was performed using Multisim and Portus simulator. For verification purpose, the PZT-5A piezoelectric transducer model has been chosen as the harvester due to the consistency. During the experiment, the resonance frequency of the harvester system was at 68 Hz with the 95 dB of acoustic pressure. The experimental results showed that the output closed-circuit voltage and the output power harvester can reach up to 3.894V_{rms} and 1.556mW respectively. The passive AC-DC harvesting circuits can probably achieve the overall energy conversion efficiency by 78.9% (Dickson circuit) (1.228mW), 70.5% (Villard circuit) (1.097mW), and 10.1% (step-up transformer) (0.1564mW) respectively. Based on the results presented above, the proposed energy harvesting systems seem to be promising and possess a good potential to be used in low power sensors such as wireless sensor networks.