Design of Autonomous Interface Circuit for Piezoelectric Micro-Power Generator

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Abstract:- **Piezoelectric energy harvesting has attracted wide attention due to its advantages such as high power density, architectural simplicity, and scalability. Piezoelectric materials can be used to convert oscillatory mechanical energy into electrical energy. . size -based classification provides a reliable and effective basis to study various This technology, together with innovative mechanical coupling designs, can form the basis for harvesting energy from mechanical motion. The size of a piezoelectric energy harvester affects a variety of parameters such as its weight, fabrication method, achievable power output level, and potential application areas. Consequently, piezoelectric energy harvesters. Single Piezoelectric transducer are used to harvest Piezoelectric energy. Generally, a vibration source can be equipped to PZT array inorder to harvest more power.Due to electromechanical coupling characteristics of PZT, it can generates low efficiency, an interfacecircuit along with rectifier bridge and capacitor is developed.**

I. INTRODUCTION

The increasing demand for electrical energy, depleting fossil energy reserves and the increase in energy prices have necessitated to use the current energy resources more efficiently. Energy harvesting from mechanical vibrations using piezoelectric harvesters has the potential to make self-powered applications. Vibration Energy Harvesting based on Piezoelectric harvesters has attracted great interest due to its high power density and easy integration. The Piezoelectric harvester has an internal capacitor and generates an AC voltage related to the input vibration. In addition to the Piezoelectric harvester, the practical Piezoelectric energy harvesting system also needs an efficient interface circuit. The Piezoelectric energy harvesting circuit should be able to rectify the Piezoelectric AC voltage into DC voltage and maximize the Piezoelectric power delivered to the load. On the other hand, several industries have increased their power-level needs, urged mostly by economy of scale (production levels and efficiency), causing the development of new power semiconductors, converter topologies, and control methods.Portable electronic devices connected to a common network have become ubiquitous owing to the growth in intelligent machine-to-machine interfaces. Although energy consumption of such systems has drastically shrunk in the last decade, they still rely on bulky batteries for reliable operation. Considering their limited capacity and lifespan, batteries need to be charged or replaced for the sake of operation continuity; however, this may not be achievable in some applications due to location of the device or extensive maintenance cost. Energy scavenging provides an opportunity to power wireless sensor networks (WSNs) while eliminating usage of ponderous batteries. Harvesting energy from ambient sources can be carried out with thermal, vibration, photovoltaic, or RF methods. Energy harvesting from vibrations is prominent due to abundance of vibration sources in environment.Piezoelectric energy harvesters (PEHs) are broadly preferred transducers to convert mechanical vibrations into electrical energy as they possess superior output voltage and power levels, and are relatively easy to integrate compared to other vibration based harvesters. MEMS technology plays an important role in fabrication of PEHs since it paves the way for miniaturization in complete harvesting systems and helps realizing self-sustained medical devices. PEHs generate AC voltage, which obstructs their usage to power up electronic loads directly in WSNs. Therefore, an interface circuit is utilized for AC/DC conversion and voltage regulation. Full bridge rectifier (FBR) and active doubler are common AC/DC converters owing to their simplicity. Nonetheless, their performance suffers from small inherent PEH capacitance that needs to be charged up to the level of output load voltage before charge transfer can start. Voltage drops across diodes in standard rectifiers significantly reduce power conversion efficiency, especially in micro-power generators. Various nonlinear switching techniques have been developed as alternatives to improve output power

.Synchronous electric charge extraction (SECE) technique utilizes an external inductor to extract and deliver energy to output load when deflection of PEH beam is at maximum. SECE configuration with multiple bulky inductors proposed in enhances power conversion efficiency over FBR without load dependence. In this modified SECE, energy is extracted and transferred to the load with multi-stage process instead of a single one, which reduces conduction losses.

2. METHODOLOGY

Kinetic energy harvesters benefit from environmental motions present nearly everywhere. This is why they have attracted more attention as alternative power supplies to maintain appropriate WSN operation in contrast to other harvesting sources which are relatively less common. Like other motion based energy harvesters, PEH generates AC voltage from ambient vibrations. However, it is not possible to utilize this AC voltage directly to power up WSNs that require stable DC voltages. For AC-DC conversion purposes, different interface circuits has been proposed to both yield reliable DC voltages and enhance output power from PEHs by altering the charge on piezoelectric material.In the beginning of piezoelectric energy scavenging development, researchers focused on mechanical transducer design rather than its interface circuit. They tried to find adequate material to convert mechanical energy into electrical one and this material should also be compatible with standard fabrication processes. Therefore, simple rectifier circuits such as full bridge rectifiers and voltage doublers were used to achieve AC-DC conversion

FULL BRIDGE RECTIFIER

Energy transfer from piezoelectric capacitance C_{PZ} to storage capacitor CS parallel with resistive load R starts when voltage difference between C_{PZ} reaches $V_{RECT} + 2V_D$ where V_D represents diode opening voltage. It was observed that efficiency in terms of power extraction from PEH was poor. This is because piezoelectric capacitance C_{PZ} needs to be charged up to some voltage level, the diodes should be eliminated for obtaining a reasonable power conversion efficiency which is $V_{RECT} + 2V_D$, before charge relocation to C_S begins. Moreover, voltage drops on.

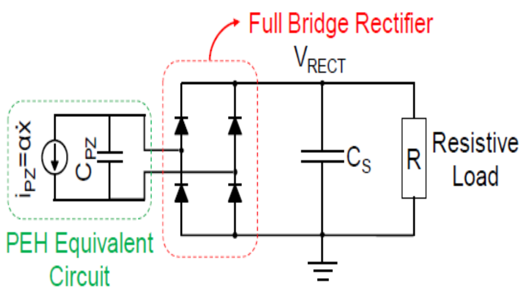


Figure 1

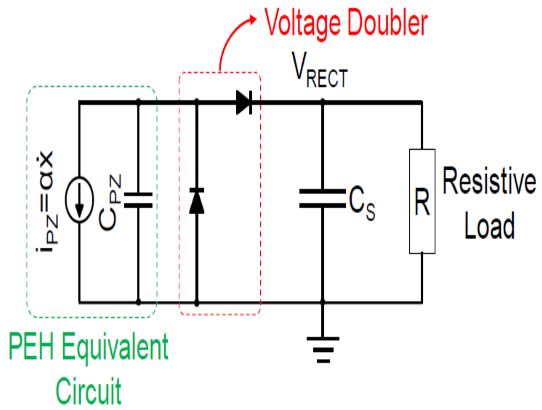


Figure 2

Unlike FBRs, voltage doubler circuit employs two diodes as shown in Figure 3.2 that reduces required voltage level to $V_{RECT} + 2V_D$ that piezoelectric open circuit voltage VPZ should overcome threshold voltage. Still, voltage doubler suffers from the same problems standard FBR faces. Voltage drops on diodes limit minimum operation voltage of PEHs. Active diodes composed of a MOSFET switch and comparator can be used to get rid of voltage drops but residual voltage on C_{PZ} after charging makes it difficult to attain V_{RECT} voltage again in the negative cycle.

SYNCHRONOUS ELECTRIC CHARGE EXTRACTION CIRCUIT

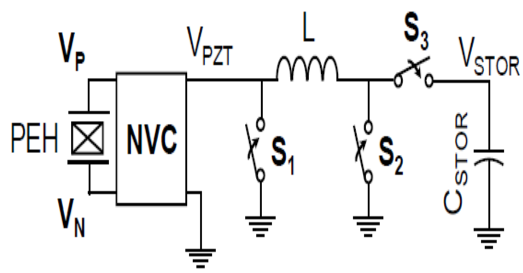


Figure 3

Nonlinear switching methods in energy harvesting literature have been developed to match the internal impedance of PEHs to output load and transfer all the available energy harvested from ambient environment. For that purpose, they are using external inductor to compensate the impact of large inherent piezoelectric capacitance C_{PZ}. SECE technique uses external inductor to store and deliver energy from C_{PZ} into storage capacitor. Three switches S_1, S_2, and S_3 turn ON and OFF in a synchronous manner to carry out SECE. In the first phase, charge generation takes place on piezoelectric capacitance C_{PZ} with PEH movement. AC voltage occurs between terminals of PEH and this voltage is rectified through negative voltage converter (NVC). When deflection on piezoelectric beam reaches its maximum point, rectified piezoelectric voltage V_{PZT} attains its maximum level. At that point, SECE circuit goes into second phase by turning switch S_2 ON and energy accumulated on C_{PZ} transfers into the external inductor L.

At the end of the second phase, S_2 turns OFF to avoid any reverse current from L to C_{PZ}. During phase 3, energy transferred to *L* is now delivered to storage capacitor with helps of switches S_1 and S_3 which corresponds to the load charging phase. After phase 3, circuit returns back to phase 1 by turning all switches OFF. Although SECE provides load independent energy extraction via decoupling output load from PEH, output power improvement is inferior compared to other nonlinear switching techniques. It has achieved only 60 % efficiency. It also employs a bulky external inductor that enlarges overall harvesting system volume.

OPERATIONAL PHASES OF SSHCI SYSTEM

Ambient vibrations lead to deflection on cantilever beam, which converts mechanical stress into electrical energy due to piezoelectric coating. During energy conversion process, electrical charge is accumulated on PEH intrinsic capacitance CPZ (Phase I). Built-up AC voltage on CPZ due to charge accumulation is henceforth rectified through the negative voltage converter (NVC).

At the instant when rectified piezoelectric voltage VRECT surpasses storage voltage VSTOR, charging of storage capacitor CSTOR through transistor MP is started by reverse current detector (RCD), and system goes into phase II. RCD ends charging process when VRECT recedes below VSTOR, and enables charge flipping detectors (CFDs) which will be explained in the next paragraph. S1 power switches turn ON to transfer residual charge on CPZ to external flipping capacitor CEXT during phase III (CEXT = CPZ for maximum energy transfer).When there is no charge to transfer from CPZ to CEXT, CFDs turn S1 switches OFF. Then, PEH terminals are shorted via S0 switch to nullify any remaining charge on CPZ after energy transfer (phase IV). In phase V, temporarily stored charge on CEXT is delivered back to CPZ in reverse polarity to complete two-step flipping. At this time, again CFDs in use control flipping process through S2 switches. Upon completion, SSHCI circuit to go back to phase I and disposes of any residual charge on external components.

Depicts simulation waveforms of VPZ, VSTOR, inductor current iI ND, and CPZ shorting pulse observed during operation. Negative voltage converter (NVC) aims to rectify AC piezoelectric voltage VPZ. NVC is cascaded with an active diode structure that is composed of reverse current detector (RCD) and transistor MP . This reduces the forward voltage drop on charging path, compared to full and half bridge rectifiers, down to a few tens of millivolts. Start-up circuit monitors VSTOR voltage during colds startup operation where CSTOR is charged through NVC and DS. When there exists enough charge on CSTOR, signal ENTRIG is generated to activate SSHCI. Optimum time intervals to transfer energy between CPZ and CEXT are autonomously detected using charge flipping detectors (CFDs) in phases III and V. CFDs communicate with switch control block utilizing CFD1 (generated at the end of phase III) and CFD2 (generated at the end of phase V) signals. Sign Detector (SD) informs SSHCI circuit about polarization of PEH terminals (VPOS>VNEG or VPOS<VNEG). This is important for SSHCI operation since SD output determines which CFD will be active in phases III and V.It is possible to adjust generated pulse width using RD and CD. Inductor oscillation cancellation (IOC) and residual charge elimination (RCE) blocks are high voltage transistors which remove any leftover charge on LEXT and CEXT after charge flipping phases finish. IOC shorts LEXT terminals in phases I, II, and IV whereas RCE connects CEXT terminals to each other during phases I and II. An internal reference circuit provides various voltage levels to bias SSHCI-MPPT. Biasing voltage levels can be tuned externally via RBIAS.

3. SOFTWARE IMPLEMENTATION

GENERAL -MATLAB 17a

MATLAB (matrix laboratory) is a numerical computing environment and fourth-generation programming language. Developed by Math Works, MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, including C,C++,Java, and Fortran. Although MATLAB is intended primarily for numerical computing, an optional toolbox uses the MuPAD symbolic engine, allowing access to symbolic computing capabilities.

An additional package, Simulink, adds graphical multi- domain simulation and Model-Based Design for dynamic and embedded systems. In 2004, MATLAB had around one million users across industry and academia. MATLAB users come from various backgrounds of engineering, science, and economics. MATLAB is widely used in academic and research institutions as well as industrial enterprises. MATLAB was first adopted by researchers and practitioners in control engineering, Little's specialty, but quickly spread to many other domains. It is now also used in education, in particular the teaching of linear algebra and numerical analysis, and is popular amongst scientists involved in image processing.

The MATLAB application is built around the MATLAB language. The simplest way to execute MATLAB code is to type it in the Command Window, which is one of the elements of the MATLAB Desktop. When code is entered in the Command Window, MATLAB can be used as an interactive mathematical shell. Sequences of commands can be saved in a text file, typically using the MATLAB Editor, as a script or encapsulated into a function, extending the commands available.

Functions for integrating MATLAB based algorithms with external applications and languages, such as C, C++, Fortran, Java™, COM, and Microsoft Excel. MATLAB is used in vast area, including signal and image processing, communications, control design, test and measurement, financial modeling and analysis, and computational. Add-on toolboxes (collections of special-purpose MATLAB functions) extend the MATLAB environment to solve particular classes of problems in these application areas. MATLAB can be used on personal computers and powerful server by stems, including the Cheaha compute cluster. With the addition of the Parallel Computing Toolbox, the language can be extended with parallel implementation for common computational functions, including for-loop unrolling. Additional this toolbox supports offloading computationally intensive workloads. MATLAB is one of a few languages in which each variable is a matrix (broadly construed) and "knows" how big it is. Moreover, the fundamental operators (e.g. addition, multiplication) are programmed to deal with matrices when required. And the MATLAB environment handles much of the bothersome housekeeping that makes all this possible. Since so many of the procedures required for Macro-Investment Analysis involves matrices, MATLAB proves to be an extremely efficient language for both communication and implementation.

THE MATLAB LANGUAGE

The MATLAB language supports the vector and matrix operations that are fundamental to engineering and scientific problems. It enables fast development and execution. With the MATLAB language, you can program and develop algorithms faster than with traditional languages because you do not need to perform low-level administrative tasks, such as declaring variables, specifying data types, and allocating memory. In many cases, MATLAB eliminates the need for „for" loops. As a result, one line of MATLAB code can often replace several lines of C or C++ code. At the same time, MATLAB provides all the features of a traditional programming language, including arithmetic operators, flow control, data structures, data types, object-oriented programming (OOP), and debugging features. MATLAB lets you execute commands or groups of commands one at a time, without compiling and linking, enabling you to quickly iterate to the optimal solution. For fast execution of heavy matrix and vector computations, MATLAB uses processor-optimized libraries. For general-purpose scalar computations, MATLAB generates machine-code instructions using its JIT (Just-In-Time) compilation technology. This technology, which is available on most platforms, provides execution speeds that rival those of traditional programming languages.

DESIGNING GRAPHICAL USER INTERFACES

By using the interactive tool GUIDE (Graphical User Interface Development Environment) to layout, design, and edit user interfaces. GUIDE lets you include list boxes, pull-down menus, push buttons, radio buttons, and sliders, as well as MATLAB plots and Microsoft ActiveX controls. Alternatively, you can create GUIs programmatically using MATLAB functionsDATA ANALYSIS

MATLAB provides interactive tools and command-line functions for data analysis operations, including:

- Interpolating and decimating
- Extracting sections of data, scaling
- Thresholding and smoothing
- Correlation, Fourier analysis, and filtering
- 1-D peak, valley, and zero finding
- Basic statistics and curve fitting
- Matrix analysis

4. HARDWARE DESCRIPTION CIRCUIT DIAGRAM OF PROPOSED HARDWARE

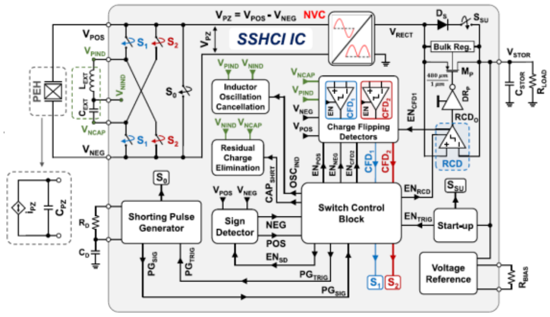


Figure 4

Harvesting system is able to charge C_{STOR} from completely discharged condition (0 V) by means of NVC, on-chip diode D_S and switch S_{SU} as shown above. When adequate amount of charge is accumulated on C_{STOR}, R_{CD} and SR latches in switching control block are enabled to sequence SSHCI phases. As C_{STOR} charges from zero voltage with ambient motion, reference voltage levels are generated first for biasing. Then, as the supply voltage V_{DD} develops, the bias current increases, leading to charge accumulation on the node where gates of M6, M8, and M9 transistors are connected. Voltage at this node activates the inverter made up of M8 and M9, and the generated signal EN_{TRIG} triggers SSHCI system. Start-up trigger circuit is disabled completely after the generation of EN_{TRIG} signal. The bias voltage V_{BIAS} controls the triggering voltage level.

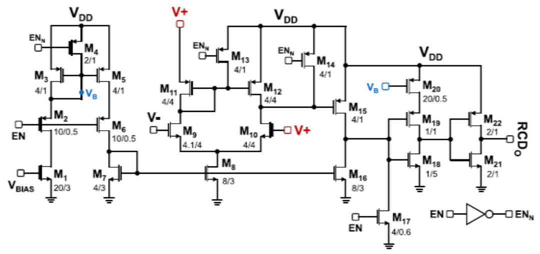


Figure 5

PEAK DETECTOR AND REFRESH UNIT

This Peak detector circuit is capable of detecting voltage peaks across a wide frequency spectrum. Since the detector works in current mode, rectified piezoelectric voltage is transformed into current through on-chip capacitor C_S. While V_{RECT} rises, node voltage V_A increases up to the threshold voltage of M_3 due to negative feedback formed by M_2 and M_3. Sensing current i_S becomes zero as V_{RECT} reaches its peak value. Then, transistor M_3 turns OFF as a result of decreased voltage at node V_A. This process disables negative feedback loop, and voltage starts to develop at node V_B due to mirrored bias current. Common source amplifier, consisting of M_{10} and M_{11}, and a buffered output stage generates the peak detection pulse.

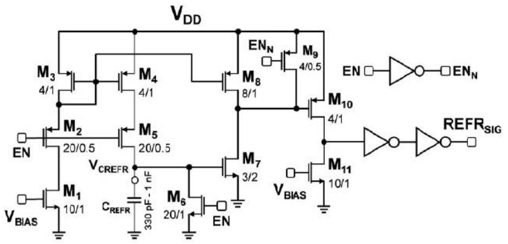


Figure 6

Voltage on resistor R_{BIAS} is created due to gate-source voltage difference between M_1 and M_2. M_3 and M_4 regulate the current passing through M_1 and M_2 to be equal at biasing current level. This supply independent current is mirrored through M_5 and M_8, and is then converted into reference voltage through saturated load MOSFETs M_6, M_7, and M_9. M_{S1}-M_{S5} and C_S serve as start-up configuration. Generated reference levels V_{REFH} and V_{REFL} can be tuned via R_{BIAS}.

MICROCONTROLLER

Microcontroller is a general purpose device, which integrates a number of the components of a microprocessor system on to single chip. It has inbuilt CPU, memory and peripherals to make it as a mini computer. A microcontroller combines on to the same microchip:

- CPU core
- Memory (both ROM and RAM)

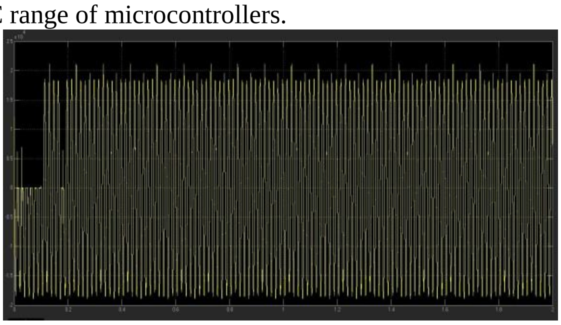
Microcontrollers will combine other devices such as:

- A timer module to allow the microcontroller to perform tasks for certain time period
- A serial I/O port to allow data to flow between the controller and other devices such as a PIC or another microcontroller.
- An ADC to allow the microcontroller to accept analogue input data for processing.

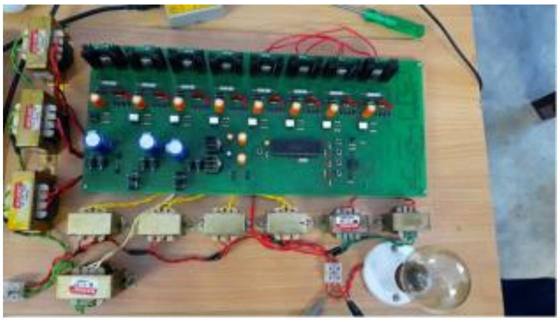
Microcontrollers are:

- Smaller in size
- Consumes less power
- Inexpensive

Microcontroller is a standalone unit, which can perform functions on its own without any requirements for additional hardware like I/O ports and external memory. The heart of the microcontroller is the CPU core. In the past, this has traditionally been based on an 8 bit microprocessor unit. For example, Motorola uses a basic 6800 microprocessor core their 6805/6808 microcontroller devices. In the recent years, microcontrollers have been developed around specifically designed CPU cores, for example the microchip PIC range of microcontrollers.



Outputwave form



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