Visvesvaraya Technological University

Belgaum, Karnataka-590 018

A Project Report on

"DESIGN OF FOOTSTEP POWER GENERATION USING PIEZOELECTRIC SENSOR"

Project Report submitted in partial fulfillment of the requirement for the award of the degree of

Bachelor of Engineering
In
Electrical & Electronics Engineering

Submitted by

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Certificate

Certified that the project work entitled **“DESIGN OF FOOTSTEP POWER GENERATION USING PIEZOELECTRIC SENSOR”** carried out by Mr. ABHISHEK D 1CR16EE400; Mr. ARUN BABU M, 1CR14EE017; Mr. GAUTHAM VINOD 1CR15EE030; Mr. NARENDRA BABU B M, 1CR17EE406 are bonafied students of CMR Institute of Technology, Bengaluru, in partial fulfillment for the award of Bachelor of Engineering in Electrical & Electronics Engineering of the Visvesvaraya Technological University, Belgaum, during the year 2019-2020. It is certified that all corrections/suggestions indicated for Internal Assessment have been incorporated in the Report deposited in the departmental library.

The project report has been approved as it satisfies the academic requirements in respect of Project work prescribed for the said Degree.

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DECLARATION

We, [**Mr. ABHISHEK D (1CR16EE400); Mr. ARUN BABU M, (1CR14EE017); Mr. GAUTHAM VINOD (1CR15EE030); Mr. NARENDRA BABU B M ,(1CR17EE406)],** hereby declare that the report entitled **"DESIGN OF FOOTSTEP POWER GENERATION USING PIEZOELECTRIC SENSOR"** has been carried out by us under the guidance of **PARVATHY T,** Assistant Professor, Department of Electrical & Electronics Engineering, CMR Institute of Technology, Bengaluru, in partial fulfillment of the requirement for the degree of **BACHELOR OF ENGINEERING in ELECTRICAL & ELECTRONICS ENGINEERING**, of Visveswaraya Technological University, Belagaum during the academic year 2019-20.The work done in this report is original and it has not been submitted for any other degree in any university.

Place: Bangalore

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Abstract

Energy harvesting is fascinating area of research now when the whole world is looking for green energy as an alternative source. This report describes the design of energy harvester prototype and the power conditioning circuit.

The optimization of extracted power out of the piezoelectric tile has been presented. The generation of electric energy when some loads applied on the sensors either in the form of direct strain or ambient vibration depends upon various factors such as number of piezoelectric transducers, electromechanical coupling coefficient of the piezoelectric sensors, amount of load applied, and also on the scheme of arrangement.

Energy harvester floor tile has been designed with piezoelectric diaphragms .An efficient way has been presented to capture the generated energy via dedicated IC and boost it by a converter to get regulated output for charging the battery. The complete charge cycle has been studied for the developed system.

The simulation and experimental studies have been successfully carried out. The model design and testing was purely for studying the energy generation and capturing phenomenon in an efficient manner. It can be implemented to generate large power by suitably considering the several factors mentioned above and implementing it on the large scale.

Acknowledgement

The satisfaction and euphoria that accompany the successful completion of any task would be incomplete without the mention of people, who are responsible for the completion of the project and who made it possible, because success is outcome of hard work and perseverance, but stead fast of all is encouraging guidance. So with gratitude we acknowledge all those whose guidance and encouragement served us to motivate towards the success of the project work.

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Finally, we acknowledge the people who mean a lot to us, our parents, for their inspiration, unconditional love, support, and faith for carrying out this work to the finishing line. We want to give special thanks to all our friends who went through hard times together, cheered us on, helped us a lot, and celebrated each accomplishment.

Lastly, to the ***Almighty****, for showering His Blessings and to many more, whom we didn't mention here.*

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LIST OF ABBREVIATIONS AND SYMBOLS

1. Alternating current (AC)
2. Direct Current (DC)
3. Micro-electromechanical systems (MEMS)
4. Integrated Circuits (IC)
5. Lead-Zirconate-Titanate (PZT)
6. Lead Magnesium Niobate-Lead Titanate (PMN-PT).
7. Under voltage lockout (UVLO)
8. Input/output (I/O)
9. Universal serial bus (USB)
10. Light emitting diode (LED)
11. Integrated Development Environment (IDE)
12. Liquid Crystal display (LCD)
13. Matrix Laboratory (MATLAB)
14. P channel MOSFET (PMOS)
15. N channel MOSFET (NMOS)
16. Reset(RST)
17. Ground (GND)
18. Clock (CLK)
19. In Circuit Serial Programming (ICSP)
20. Static Random Access Memory (SRAM)
21. Electrically Erasable Programmable Read only Memory (EEPROM)

CHAPTER 1

INTRODUCTION

1.1BRIEF BACKGROUND OF THE RESEARCH

THE SUN is the most important source of energy for the life on the earth either in direct or derivative form. Dependency on non-renewable sources decreasing these sources day by day and in near future it may get exhausted completely. Hence it is required to explore for alternative sources and shift our dependency on renewable sources. This will conserve non-renewable sources and produce clean energy. These renewable sources include solar cells (Solar energy), wind mills (Wind energy), geothermal power plants (Geothermal energy), tidal turbine (Tidal energy) etc. Solar power provides a considerable amount of energy per area and volume, but unfortunately is limited to applications that are actually sunlit. We utilize a large part of our muscular energy for moving from one place to other and also the infrastructure like roads, railways, runway bears a large amount of mechanical strain energy. This energy i.e. muscular or mechanical strain on various infrastructures gets wasted. But it is possible to convert this mechanical energy in to electrical pulse form with the help of piezoelectric transducers. These electrical pulses, which are alternating in nature, can be directly utilized or may be captured by a storage device for further utilization. Efforts have been put in this work to harvest energy from mechanical stress using the principle of piezoelectric energy conversion. For a harvesting system of constant thickness, the generated power increases with increase in applied force. The output power of harvester depends on increase in the thickness. The output power obtained from piezoelectric generators depends on various factors like which piezoelectric sensor has been used, it’s packing density, type of strain applied to it, electronic circuitry to process the pulse generated, storage device, and load connected to it. When a simple rectifier is used the output power generated greatly depends upon the load connected. The important criteria for maximizing the output power are to match the optimal load of the harvester to that of converter circuit. Several techniques are available for converting mechanical vibration energy to electrical energy. The most prevalent methods among them are electrostatic, electromagnetic and piezoelectric conversion. A majority of current research has been done on piezoelectric conversion due to low complexity of its analysis and fabrication. Most of research however has targeted a specific device scale. The latest advancement in the micro-electromechanical systems (MEMS) and wireless technology, the portable electronics and wireless sensors are in great demand. These portable devices must have their own power supply. If this supply is a conventional battery, then using this type of power supply will be problematic as their life span is finite. Importable electronics, replacing the battery may destroy the electronics any time. For sensors which are planted in the remote locations or in the host body, if battery has been discharged the sensor must be retrieved and the battery should be replaced. Because of remote location of the mobile host body, it is quite difficult to retrieve the sensor and replacing the battery. If a sensor is embedded inside a civil infrastructure then it is not possible to replace the battery. If the adequate energy in the surrounding medium could be obtained, then it can prove as the substitute of the battery. One method is to use the piezoelectric material to obtain the energy lost due to vibration of the host structure. This captured energy can be processed and could be used to prolong the life of the power supply or to provide the endless energy to a device. The host structure may be a mobile floor, roadway, pedestals, rail, runway etc. where a continuous strain is experienced and this strain or vibration energy which was wasted earlier may be transformed in to usable electrical energy to power up the low power electronic and electrical devices. Piezoelectric energy harvesters are device which convert the mechanical strain in to electrical form. They are the perfect solution for extended life micro power generator as they generate enough power to drive low power electronic devices such as smart wireless sensor which dissipates less than few milli watts. A vibrating piezoelectric element electrically behaves as a capacitive ac source which is rectified at later stage at a desired dc voltage level to be useful for powering electronic devices. A boost converter to get regulated output of 12 Volts for load utilization. This boosted DC output is then used to charge the battery. Energy harvester firstly designed with Diode Bridge and electrolyte capacitor as the storage and then the diode bridge was replaced by energy harvesting IC and electrolyte capacitor was replaced by ultra-capacitor. It is found that piezoelectric energy harvester faces low drop with dedicated IC than Diode Bridge and also the ultra-capacitor response to store energy is quite fast. The generated power can be scaled by designing a robust piezoelectric load bearing mechanical structure comprising very strong piezoelectric discs arranged in multilayer stack.

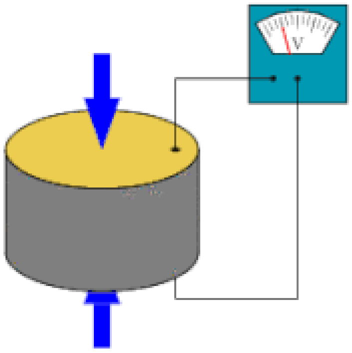
1.2 OBJECTIVE OF THE THESIS

The main aim of this project is to develop much cleaner cost effective way of power generation method, which in turns helps to bring down the global warming as well as reduce the power shortages and dependency on non-renewable .In this project the conversion of the force energy i.e., the daily walking of human is converted into electrical energy. The control mechanism carries the piezo electric sensor, n number of piezoelectric sensors are connected in parallel to increase current and A.C ripples neutralizer, unidirectional current controller and 12V lead acid dc rechargeable battery and an inverter is used to drive AC/DC loads. The battery is connected to the inverter. This inverter is used to convert the 12 Volt D.C. This A.C voltage is used to activate the loads. We are using conventional battery charging unit also forgiving supply to the circuitry. As well as we are displaying the health condition of battery and number of steps on the sensors, charging current from converter circuit. For this purpose we are using Arduino Uno microcontroller .

The main objective of this project is to charge the 12V battery and to use dc lamp load to light the street.

CHAPTER 2

PIEZOELECTRIC TRANSDUCER



A piezoelectric sensor is a device that uses the piezoelectric effect to measure changes in pressure, acceleration, temperature, strain, or force by converting them to an electrical charge.

Piezoelectric sensors are versatile tools for the measurement of various processes. They are used for quality assurance, process control, and for research and development in many industries. Pierre Curie discovered the piezoelectric effect in 1880, but only in the 1950s did manufacturers begin to use the piezoelectric effect in industrial sensing applications. Since then, this measuring principle has been increasingly used, and has become a mature technology with excellent inherent reliability.

They have been successfully used in various applications, such as in medical, aerospace, nuclear instrumentation, and as a tilt sensor in consumer electronics or a pressure sensor in the touch pads of mobile phones. In the automotive industry, piezoelectric elements are used to monitor combustion when developing internal combustion engines. The sensors are either directly mounted into additional holes into the cylinder head or the spark/glow plug is equipped with a built-in miniature piezoelectric sensor.

The rise of piezoelectric technology is directly related to a set of inherent advantages. The high modulus of elasticity of many piezoelectric materials is comparable to that of many metals and goes up to 10^6 N/m^2.Even though piezoelectric sensors are electromechanical systems that react to compression, the sensing elements show almost zero deflection. This gives piezoelectric sensors ruggedness, an extremely high natural frequency and an excellent linearity over a wide amplitude range. Additionally, piezoelectric technology is insensitive to electromagnetic fields and radiation, enabling measurements under harsh conditions. Some materials used (especially gallium phosphate or tourmaline) are extremely stable at high temperatures, enabling sensors to have a working range of up to 1000 °C. Tourmaline shows pyro electricity in addition to the piezoelectric effect; this is the ability to generate an electrical signal when the temperature of the crystal changes. This effect is also common to piezo ceramic materials. Gautschi in Piezoelectric Sensorics (2002) offers this comparison table of characteristics of piezo sensor materials vs other types

One disadvantage of piezoelectric sensors is that they cannot be used for truly static measurements. A static force results in a fixed amount of charge on the piezoelectric material. In conventional readout electronics, imperfect insulating materials and reduction in internal sensor resistance causes a constant loss of electrons and yields a decreasing signal. Elevated temperatures cause an additional drop in internal resistance and sensitivity. The main effect on the piezoelectric effect is that with increasing pressure loads and temperature, the sensitivity reduces due to twin formation. While quartz sensors must be cooled during measurements at temperatures above 300 °C, special types of crystals like $GaPO_4$ gallium phosphate show no twin formation up to the melting point of the material itself.

However, it is not true that piezoelectric sensors can only be used for very fast processes or at ambient conditions. In fact, numerous piezoelectric applications produce quasi-static measurements, and other applications work in temperatures higher than 500 °C.

Piezoelectric sensors can also be used to determine aromas in the air by simultaneously measuring resonance and capacitance. Computer controlled electronics vastly increase the range of potential applications for piezoelectric sensors.

Piezoelectric sensors are also seen in nature. The collagen in bone is piezoelectric, and is thought by some to act as a biological force sensor.

2.1 Principle of operation

The way a piezoelectric material is cut defines one of its three main operational modes:

- Transverse
- Longitudinal
- Shear.

Transverse effect

- A force applied along a neutral axis (y) displaces charges along the (x) direction, perpendicular to the line of force.
- The amount of charge (Q{x}) depends on the geometrical dimensions of the respective piezoelectric element. When dimensions {a,b,d} apply,
- Where {a} is the dimension in line with the neutral axis, {b} is in line with the charge generating axis and {d} is the corresponding piezoelectric coefficient.
- $Q_x = d_{xy} F_y b/a$

2.2 Electrical properties

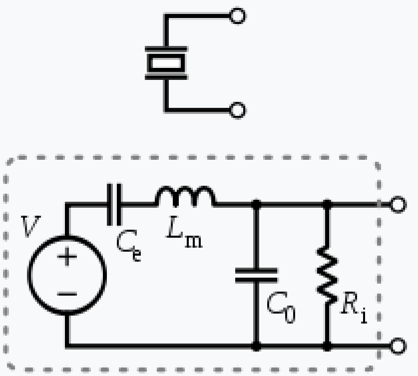


Fig2 Schematic symbol and electronic model of a piezoelectric sensor

A piezoelectric transducer has very high DC output impedance and can be modelled as a proportional voltage source and filter network. The voltage *V* at the source is directly proportional to the applied force, pressure, or strain. The output signal is then related to this mechanical force as if it had passed through the equivalent circuit.

A detailed model includes the effects of the sensor's mechanical construction and other non-idealities. The inductance L_m is due to the seismic mass and inertia of the sensor itself. C_e is inversely proportional to the mechanical elasticity of the sensor. C_0 represents the static capacitance of the transducer, resulting from an inertial mass of infinite size. R_i is the insulation leakage resistance of the transducer element. If the sensor is connected to a load resistance, this also acts in parallel with the insulation resistance, both increasing the high-pass cut-off frequency

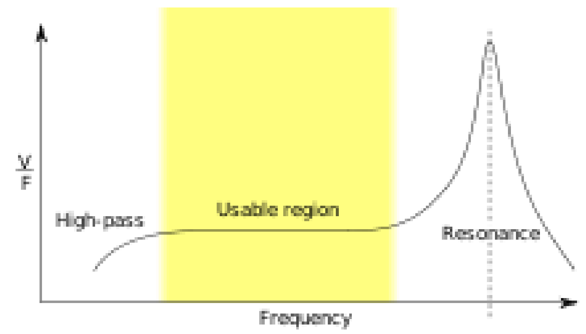
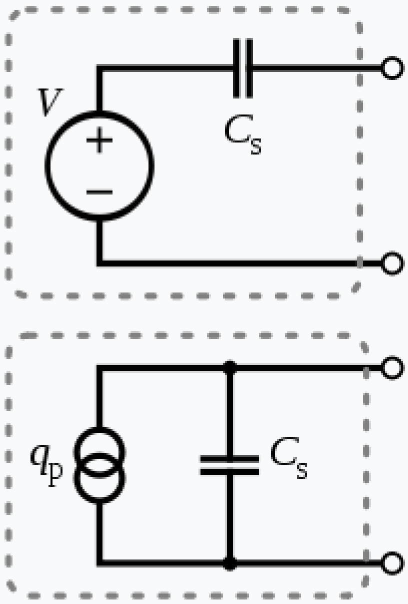


Fig3 Frequency response of a piezoelectric sensor: output voltage over applied force versus frequency.



In the flat region, the sensor can be modeled as a voltage source in series with the sensor's capacitance or a charge source in parallel with the capacitance

For use as a sensor, the flat region of the frequency response plot is typically used, between the high-pass cut-off and the resonant peak. The load and leakage resistance must be large enough that low frequencies of interest are not lost. A simplified equivalent circuit model can be used in this region, in which C_s represents the capacitance of the sensor surface itself, determined by the standard formula for capacitance of parallel plates. It can also be modelled as a charge source in parallel with the source capacitance, with the charge directly proportional to the applied force, as above.

2.3 Sensor Design

Metal disks with piezo material, used in buzzers or as contact microphones

Based on piezoelectric technology various physical quantities can be measured the most common are pressure and acceleration. For pressure sensors, a thin membrane and a massive base is used, ensuring that an applied pressure specifically loads the elements in one direction. For accelerometers, a seismic mass is attached to the crystal elements. When the accelerometer experiences a motion, the invariant seismic mass loads the elements according to Newton's second law of motion .

The main difference in working principle between these two cases is the way they apply forces to the sensing elements. In a pressure sensor, a thin membrane transfers the force to the elements, while in accelerometers an attached seismic mass applies the forces. Sensors often tend to be sensitive to more than one physical quantity. Pressure sensors show false signal when they are exposed to vibrations. Sophisticated pressure sensors therefore use acceleration compensation elements in addition to the pressure sensing elements. By carefully matching those elements, the acceleration signal (released from the compensation element) is subtracted from the combined signal of pressure and acceleration to derive the true pressure information.

Vibration sensors can also harvest otherwise wasted energy from mechanical vibrations. This is accomplished by using piezoelectric materials to convert mechanical strain into usable electrical energy.

2.4 Sensing materials

Two main groups of materials are used for piezoelectric sensors: piezoelectric ceramics and single crystal materials. The ceramic materials (such as PZT ceramic) have a piezoelectric constant/sensitivity that is roughly two orders of magnitude higher than those of the natural single crystal materials and can be produced by inexpensive sintering processes. The piezo effect in piezo ceramics is "trained", so their high sensitivity degrades over time. This degradation is highly correlated with increased temperature.

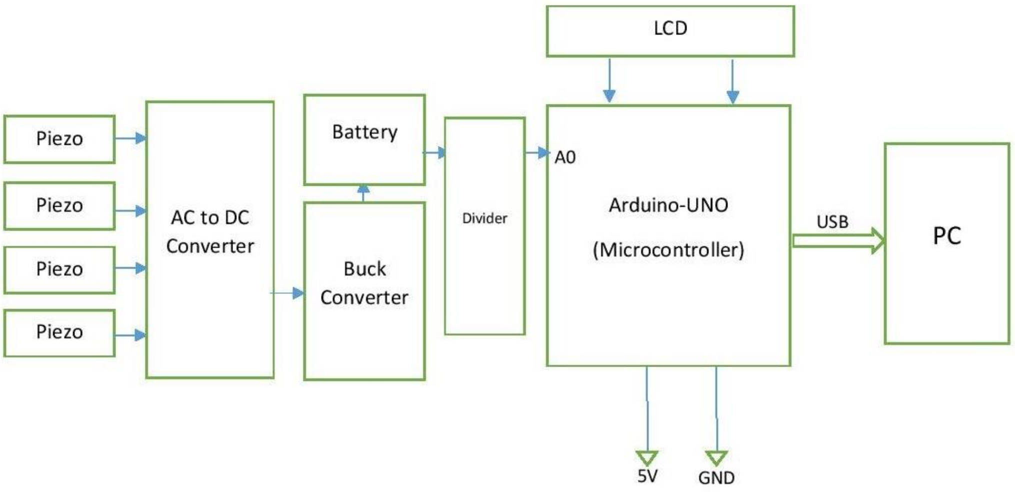
The less-sensitive, natural, single-crystal materials (gallium phosphate, quartz, tourmaline) have a higher – when carefully handled, almost unlimited – long term stability. There are also new single-crystal materials commercially available such as Lead Magnesium Niobate-Lead Titanate (PMN-PT). These materials offer improved sensitivity over PZT but have a lower maximum operating temperature and are currently more expensive to manufacture

Natural Piezoelectric Material	**Synthetic Piezoelectric Material**
Quartz (most used)	Lead zirconate titanate (PZT)
Rochelle Salt	Zinc Oxide (ZnO)
Topaz	Barium Titanate ($BaTiO_3$)
TB-1	Piezoelectric ceramics Barium titanate
TBK-3	Calcium barium titanate
Sucrose	Gallium orthophosohate ($GaPO_4$)

CHAPTER 3

PROPOSED MODEL

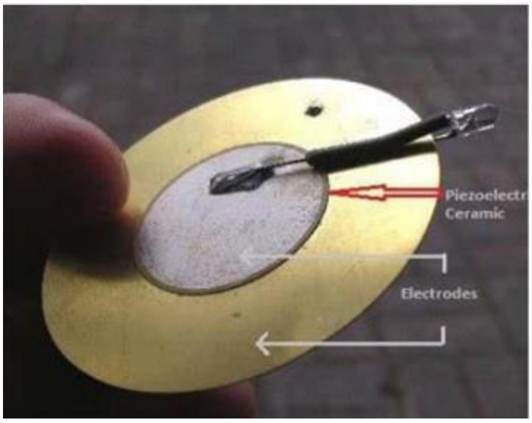
Block Diagram:



- The piezoelectric material converts the pressure applied to it into electrical energy. The source of pressure can be either from the weight of the moving vehicles or from the weight of the people walking over it.
- The output of the piezoelectric material is not a steady one. So a bridge circuit is used to convert this variable voltage into a linear one.
- Again a ripple filter is used to filter out any further fluctuations in the output.
- The output dc voltage is then stored in a rechargeable battery.
- As the power output from a single piezo-sensor was extremely low, combination of few Piezo sensors was investigated. Two possible connections were tested - parallel and series connections.
- The parallel connection did not show significant increase in the voltage output. With series connection, additional piezo-film results in increased of voltage output but not in linear proportion.
- From battery provisions are provided to connect DC load.
- An inverter is connected to battery to provide provision to connect AC load.
- The voltage produced can be seen in a LCD. For this purpose Arduino is used.

3.1 Piezoelectric sensor

Piezoelectric ceramics belong to the group of ferroelectric materials. Ferroelectric materials are crystals which are polar without an electric field being applied. The main component we are using is the piezoelectric material. The proper choice of the piezo material is of prime importance. Next, to check the connection that gives considerable voltage and current necessary, for that piezo transducer are connected in series.



The process for selection was better output voltage for various pressures applied. In order to understand the output corresponding to the various forces applied, the VI characteristics of each material namely, Piezo transducer were plotted. For this the Piezo transducer material under test is placed on a wooden base. Voltmeters are connected across both of them for measuring voltages and an ammeter is connected to measure the current. As various forces are applied on the Piezo material, different voltage readings corresponding to the force is displayed. For each such voltage reading across the force sensor, various voltage and current readings of the Piezo test material are noted.

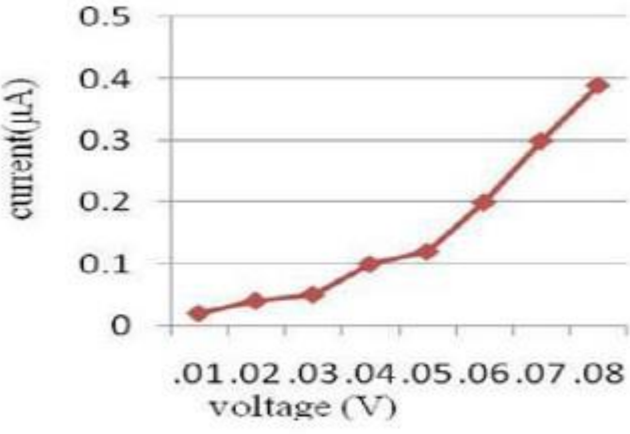
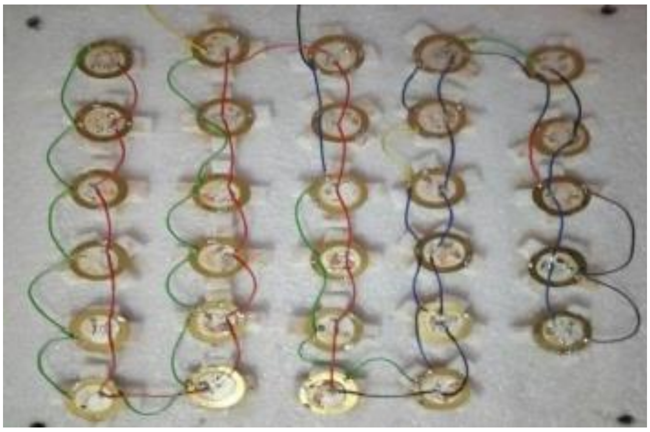


Fig 2: V-I graph of PZT material

3.2 STUDY OF CONNECTIONS

Next, to check the connection that gives considerable voltage and current necessary, for that piezo transducer are connected in series.



A voltmeter is connected to this series combination. As various forces are applied on tiles connection, different voltages are noted. Also the voltage produced across the series connection and the current is measured. Similarly the connections of 29 PZT are done for parallel and series-parallel connections are done and the graphs are as in figures 2 and 3.
It can be seen from the graph that the output voltage from a series connection is good but the current obtained is poor, whereas the current from a parallel connection is good but the voltage is poor. But this problem is rectified in a series parallel connection where a good voltage, as well as the current, can be obtained.

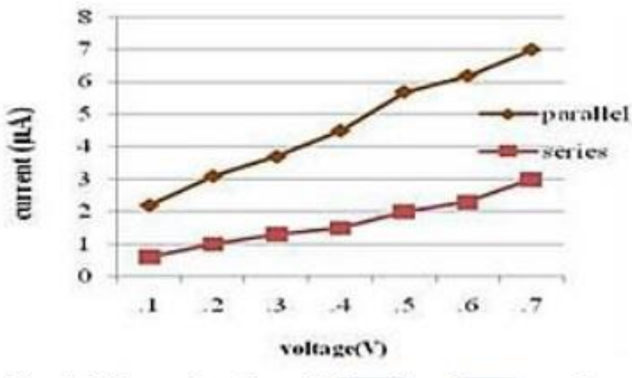


Fig 4: V-I graph of parallel and series connection

So we are going to connect the piezoelectric sensors in parallel combination inorder to increase the current.

3.3 RECTIFIER (AC TO DC CONVERTER)

In electronics, Rectifier circuit is the most used circuit because almost every electronic appliance operates on DC (Direct Current) but the availability of the DC Sources are limited such as electrical outlets in our homes provide AC **(**Alternating current**)**. The rectifier is the perfect candidate for this job in industries & Home to convert AC into DC. Even our cell phone chargers use rectifiers to convert the AC from our home outlets to DC**.** Different types of Rectifiers are used for specific applications.

We mainly have two types of voltage types present that are widely used these days. They are alternating and direct voltage types. These voltage types can be converted from one type to another using special circuits designed for that particular conversion. These conversions happen everywhere.

Our main supply which we get from power grids are alternating in nature and the appliances we use in our homes generally require a small DC voltage. This process of converting alternating current into direct current is given the name rectification. Converting AC to DC is preceded by further process which can involve filtering, DC-DC conversion and so on. One of the most common part of an electronic power supply is a bridge rectifier.

Many electronic circuits require rectified DC power supply for powering various electronic basic components from available AC mains supply. The simple bridge rectifier is used in a variety of electronic AC based power devices.

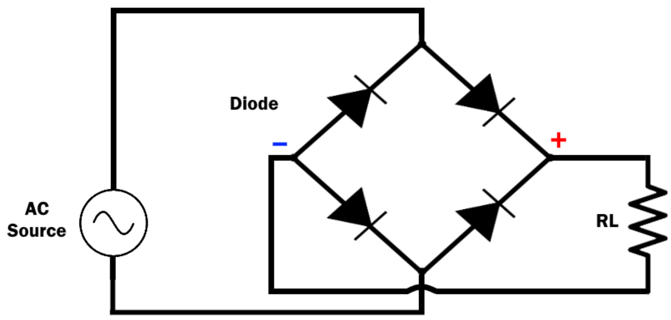
Another way to look at the rectifier circuit is that, it can be said to convert currents instead of voltages. This makes more intuitive sense, because we are more accustomed to using current to define a component's nature. Concisely, a rectifier take a current which has both negative and positive components and rectifies it such that only the positive component of the current remains.

Bridge rectifiers are widely used in power supplies that provide necessary DC voltage for the electronic component or devices. The most efficient switching devices whose characteristics are known fully are diodes. In theory any solid-state switch which can be controlled or cannot be controlled can be used instead of the diodes.

Bridge Rectifier

A bridge rectifier uses four diodes to convert both half cycle of the input AC into DC output.

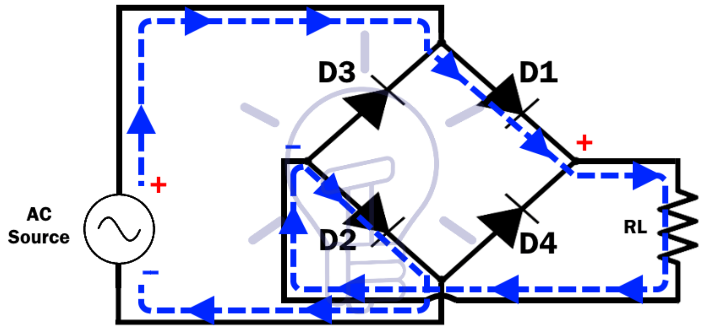
In this type of rectifier, the diodes are connected in a specific form as given below.



Bridge Rectifier

POSITIVE HALF CYCLE

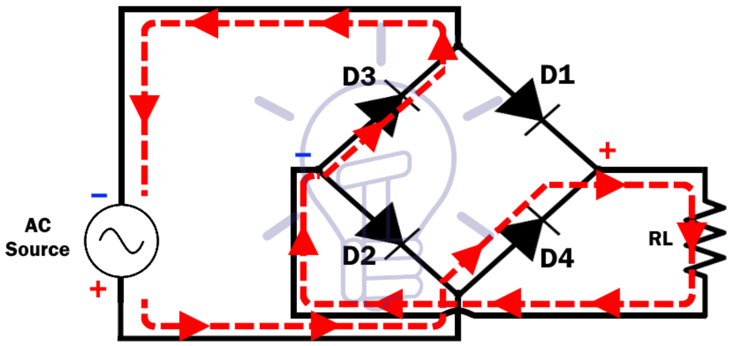
During input positive half cycle, the diode **D1 & D2** becomes forward bias while **D3 & D4** becomes reverse bias. The diode **D1 & D2** form a closed loop that provides a positive output voltage across the load resistor **RL**.



Bridge Rectifier During Positive Cycle

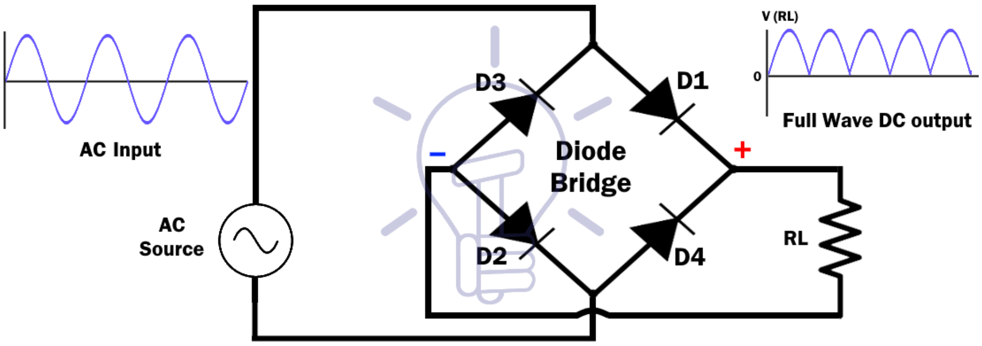
NEGATIVE HALF CYCLE

During the negative half cycle, the diode **D3 & D4** becomes forward bias while **D1 & D2** becomes reverse bias. But the polarity across the load resistor **RL** remains the same and provides a positive output across the load.



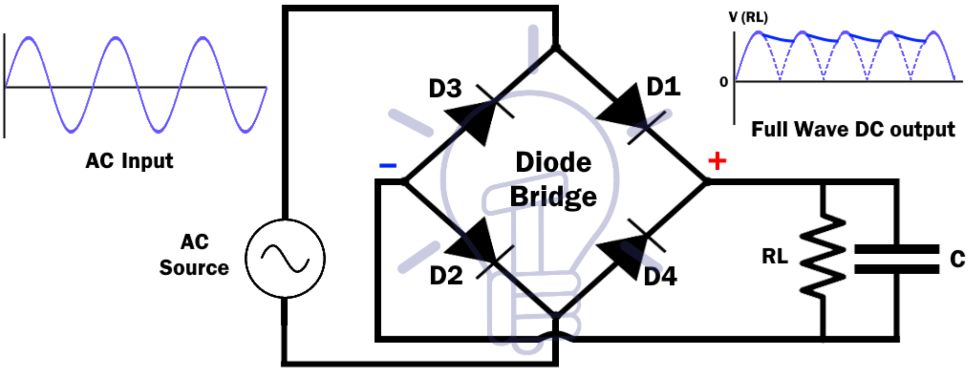
Bridge Rectifier During Negative Cycle

The output of full wave rectifier has low ripples compared to half-wave rectifier but still, it's not smooth and steady.



Bridge Rectifier Output

In order to make the output voltage smooth & steady, a **capacitor** is placed at the output as shown in the figure below.



Bridge Rectifier Output With Capacitor

The capacitor charge & discharges which make smooth transitions between the half cycles.

Working of Bridge Rectifier Circuit

From the circuit diagram it is apparent that the diodes are connected in a particular fashion. This unique arrangement gives the converter its name. In bridge rectifier, voltage that is given as the input can be from any source. It can be from a transformer that is used to step up or down the voltage or it can be from the mains of our domestic power supply. In this article, we are using a 6-0-6 centre tapped transformer for providing AC voltage.

In the first phase of working of the rectifier, during the positive half cycle, diodes D3-D2 get forward biased and conducts. Diodes D1-D4 gets reversed biased and do not conduct in this half cycle, acting as open switches. Thus, we get a positive half cycle at the output. Conversely, in the negative half cycle, diodes D1-D4 get forward biased, and start conducting whereas diodes D3-D2 gets reversed biased and do not conduct in this half cycle.

Again, we get a positive half cycle at the output. At the end of the rectification process, the negative part of the AC current is converted into a positive cycle. The output from the rectifier is two half-positive pulses with the same frequency and magnitude as that of the input.

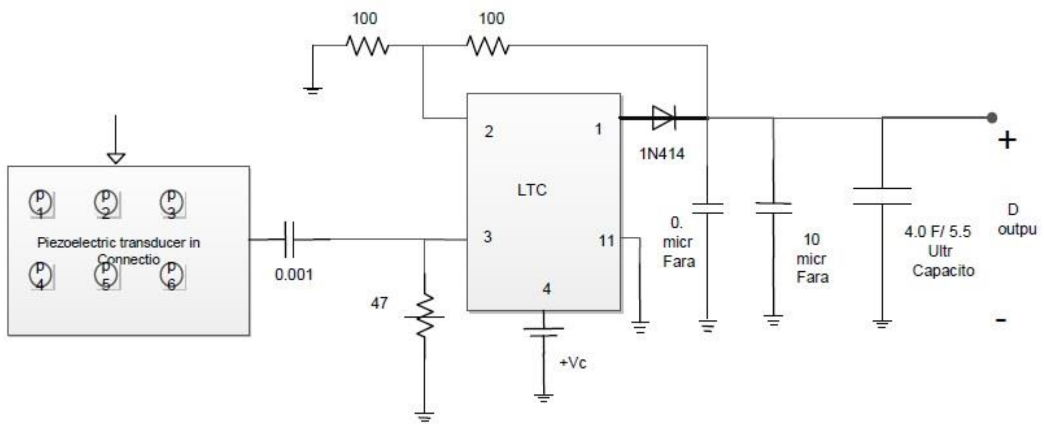
In contrast to the working of a half-wave rectifier, the full bridge rectifier has another branch which allows it to conduct for the negative half of the voltage waveform which the half-bridge rectifier had no means of doing. So the average voltage at the output of the full bridge rectifier is double than that of the half-bridge rectifier.

Although we use four individual power diodes to make a full wave bridge rectifier, pre-made bridge rectifier components are available "off-the-shelf" in a range of different voltage and current sizes that can be used directly to make a working circuit.

The output voltage waveform after the rectification is not a proper DC, so we can try to make it more into a DC waveform using a capacitor for filtering purpose. Smoothing or reservoir capacitors that are connected in parallel with the load across the output of the full wave bridge rectifier circuit increases the average DC output level to the required average DC voltage at the output because the capacitor not only acts as a filtering component, but it also periodically charges and discharges effectively increasing the output voltage.

Capacitor charge till the waveform goes to its peak and discharges uniformly into the load circuit when waveform starts going low. So when the output is going low, capacitor maintains the proper voltage supply into the load circuit, hence creating the DC.

3.4 ENERGY HARVESTER CIRCUIT



The ac output voltage when a variable strain is applied on the tile is shown in above figure. The voltage obtained without bridge rectifier is of alternating nature of frequency below 10Hz. The magnitude of ac output obtained depends on the various factors such as packing density of piezoelectric transducer, frequency of excitation, and type of strain applied on the surface. The AC voltage obtained is further processed via energy harvester circuit that consists of the rectifier IC LTC3588. Earlier the bridge rectifier has been used with electrolyte capacitor as the storage but it caused the drop of generated power across the diode and electrolyte capacitor. The electrolyte capacitor has been replaced by the ultra-capacitor but it was not charging since the frequency of the harvested power was very low. Then we have used an IC which not only rectifies with low drop but also multiplies the frequency. LTC3588 is the energy harvesting IC programmed for low power generation that integrates the bridge rectifier and the efficient energy storage hardware algorithm. The output of IC is low ripple containing DC with 51.33 % ripple factor.

3.5 LTC3588-1

The LTC®3588-1 integrates a low-loss full-wave bridge rectifier with a high efficiency buck converter to form a complete energy harvesting solution optimized for high output impedance energy sources such as piezoelectric, solar, or magnetic transducers. An ultralow quiescent current under voltage lockout (UVLO) mode with a wide hysteresis window allows charge to accumulate on an input capacitor until the buck converter can efficiently transfer a portion of the stored charge to the output. In regulation, the LTC3588-1 enters a sleep state in which both input and output quiescent currents are minimal. The buck converter turns on and off as needed to maintain regulation.

Four output voltages, 1.8V, 2.5V, 3.3V and 3.6V, are pin selectable with up to 100mA of continuous output current; however, the output capacitor may be sized to service a higher output current burst. An input protective shunt set at 20V enables greater energy storage for a given amount of input capacitance.

FEATURES

950nA Input Quiescent Current (Output in Regulation – No Load)

450nA Input Quiescent Current in UVLO

2.7V to 20V Input Operating Range

Integrated Low-Loss Full-Wave Bridge Rectifier

Up to 100mA of Output Current

Selectable Output Voltages of 1.8V, 2.5V, 3.3V, 3.6V

High Efficiency Integrated Hysteretic Buck DC/DC

Input Protective Shunt – Up to 25mA Pull-Down at VIN ≥ 20V

Wide Input Under voltage Lockout (UVLO) Range

Available in 10-Lead MSE and 3mm × 3mm DFN Packages

APPLICATIONS

Piezoelectric Energy Harvesting

Electro-Mechanical Energy Harvesting

Wireless HVAC Sensors

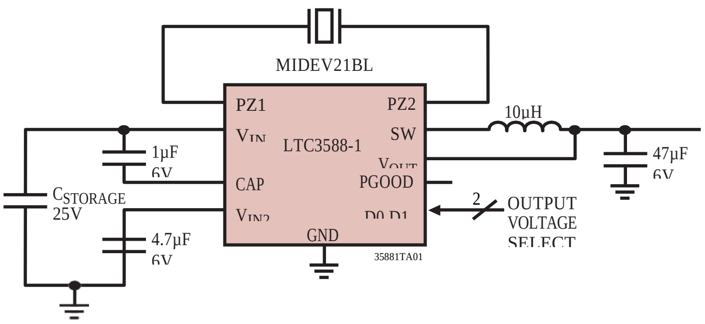
Mobile Asset Tracking

Tire Pressure Sensors

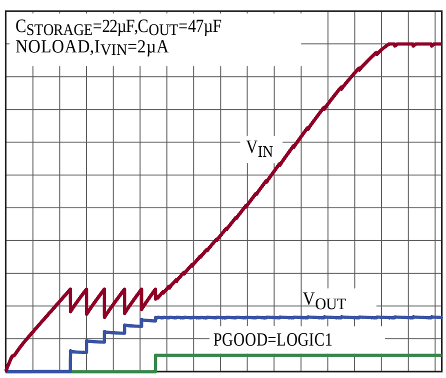
Battery Replacement for Industrial Sensors

Remote Light Switches

Standalone Nano power Buck Regulator



Piezoelectric Energy Harvesting Power Supply



LTC3588-1 3.3V Regulator Start-Up Profile

ABSOLUTE MAXIMUM RATINGS

VIN

Low Impedance Source =0.3V to 18V*

Current Fed, ISW = 0A   25mA†

PZ1, PZ2=0V to VIN

D0, D1=0.3V to [Lesser of (VIN2 + 0.3V) or 6V]

CAP=[Higher of –0.3V or (VIN – 6V)] to VIN

VIN2=0.3V to [Lesser of (VIN + 0.3V) or 6V]

* VIN has an internal 20V clamp

† For t < 1ms and Duty Cycle < 1%,

Absolute Maximum Continuous Current = 5mA

VOUT V to Lesser of (VIN2 + 0.3V) or 6V

PGOOD=V to Lesser of (VOUT + 0.3V) or 6V

IPZ1, IPZ2±50mA

ISW =350mA

Operating Junction Temperature Range 40 to 125°C

Storage Temperature Range 65 to 150°C

Lead Temperature (Soldering, 10 sec)

MSE Only 300°C

PIN CONFIGURATION

PIN FUNCTIONS

PZ1 (Pin 1): Input connection for piezoelectric element or other AC source (used in conjunction with PZ2).

PZ2 (Pin 2): Input connection for piezoelectric element or other AC source (used in conjunction with PZ1).

CAP (Pin 3): Internal rail referenced to VIN to serve as gate drive for buck PMOS switch. A 1µF capacitor should be connected between CAP and VIN. This pin is not intended for use as an external system rail.

VIN (Pin 4): Rectified Input Voltage. A capacitor on this pin serves as an energy reservoir and input supply for the buck regulator. The VIN voltage is internally clamped to a maximum of 20V (typical).

SW (Pin 5): Switch Pin for the Buck Switching Regulator. A 10µH or larger inductor should be connected from SW to VOUT.

VOUT (Pin 6): Sense pin used to monitor the output volt- age and adjust it through internal feedback.

VIN2 (Pin 7): Internal low voltage rail to serve as gate drive for buck NMOS switch. Also serves as a logic high rail for output voltage select bits D0 and D1. A 4.7µF capacitor should be connected from VIN2 to GND. This pin is not intended for use as an external system rail.

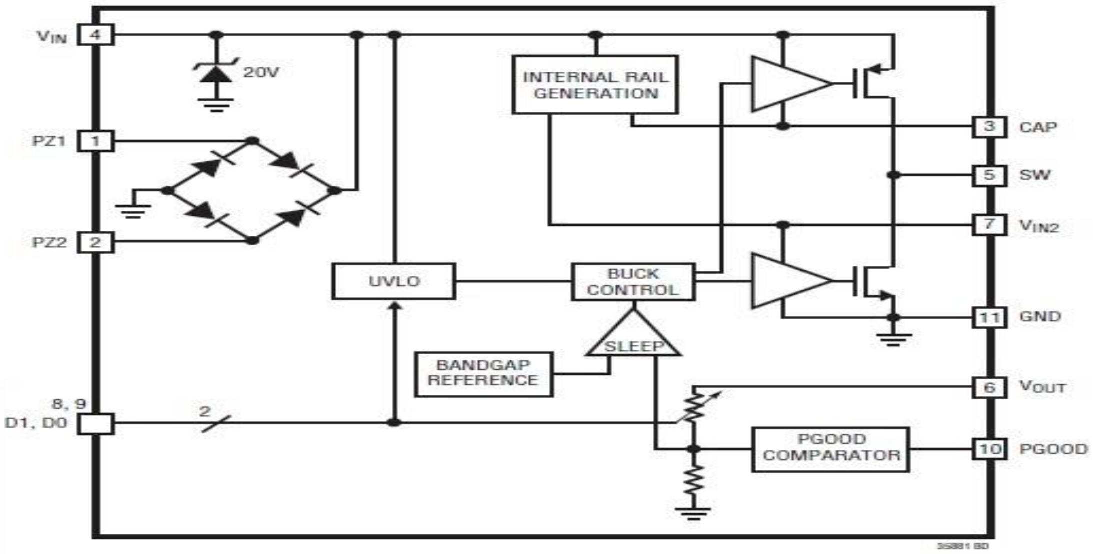
D1 (Pin 8): Output Voltage Select Bit. D1 should be tied high to VIN2 or low to GND to select desired VOUT (see Table 1).

D0 (Pin 9): Output Voltage Select Bit. D0 should be tied high to VIN2 or low to GND to select desired VOUT (see Table 1).

PGOOD (Pin 10): Power good output is logic high when VOUT is above 92% of the target value. The logic high is referenced to the VOUT rail.

GND (Exposed Pad Pin 11): Ground. The Exposed Pad should be connected to a continuous ground plane on the second layer of the printed circuit board by several vias directly under the LTC3588-1.

BLOCK DIAGRAM



OPERATION

The LTC3588-1 is an ultralow quiescent current power supply designed specifically for energy harvesting and/or low current step-down applications. The part is designed to interface directly to a piezoelectric or alternative A/C power source, rectify a voltage waveform and store harvested energy on an external capacitor, bleed off any excess power via an internal shunt regulator, and maintain a regulated output voltage by means of a nanopower high efficiency synchronous buck regulator.

Internal Bridge Rectifier

The LTC3588-1 has an internal full-wave bridge rectifier accessible via the differential PZ1 and PZ2 inputs that rectifies AC inputs such as those from a piezoelectric element. The rectified output is stored on a capacitor at the VIN pin and can be used as an energy reservoir for the buck converter. The low-loss bridge rectifier has a total drop of about 400mV with typical piezo generated currents (~10µA). The bridge is capable of carrying up to 50mA. One side of the bridge can be operated as a single-ended DC input. PZ1 and PZ2 should never be shorted together when the bridge is in use.

Internal Rail Generation

Two internal rails, CAP and VIN2, are generated from VIN and are used to drive the high side PMOS and low side NMOS of the buck converter, respectively. Additionally the VIN2 rail serves as logic high for output voltage select bits D0 and D1. The VIN2 rail is regulated at 4.8V above GND while the CAP rail is regulated at 4.8V below VIN. These are not intended to be used as external rails. Bypass capacitors are connected to the CAP and VIN2 pins to serve as energy reservoirs for driving the buck switches. When VIN is below 4.8V, VIN2 is equal to VIN and CAP is held at GND. Figure 1 shows the ideal VIN, VIN2 and CAP relationship.

Under voltage Lockout (UVLO)

When the voltage on VIN rises above the UVLO rising threshold the buck converter is enabled and charge is transferred from the input capacitor to the output capacitor. A wide (~1V) UVLO hysteresis window is employed with a lower threshold approximately 300mV above the selected regulated output voltage to prevent short cycling during buck power-up. When the input capacitor voltage is depleted below the UVLO falling threshold the buck converter is disabled. Extremely low quiescent current (450nA typical) in UVLO allows energy to accumulate on the input capacitor in situations where energy must be harvested from low power sources.

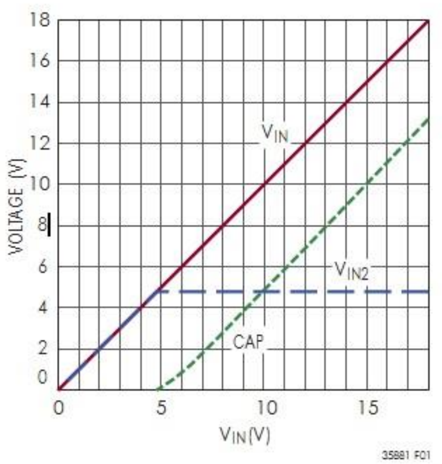


Figure 1. Ideal V_{IN}, V_{IN2} and CAP Relationship

Buck Operation

The buck regulator uses a hysteretic voltage algorithm to control the output through internal feedback from the VOUT sense pin. The buck converter charges an output capacitor through an inductor to a value slightly higher than the regulation point. It does this by ramping the inductor current up to 260mA through an internal PMOS switch and then ramping it down to 0mA through an internal NMOS switch. This efficiently delivers energy to the output capacitor. The ramp rate is determined by VIN, VOUT, and the inductor value. If the input voltage falls below the UVLO falling threshold

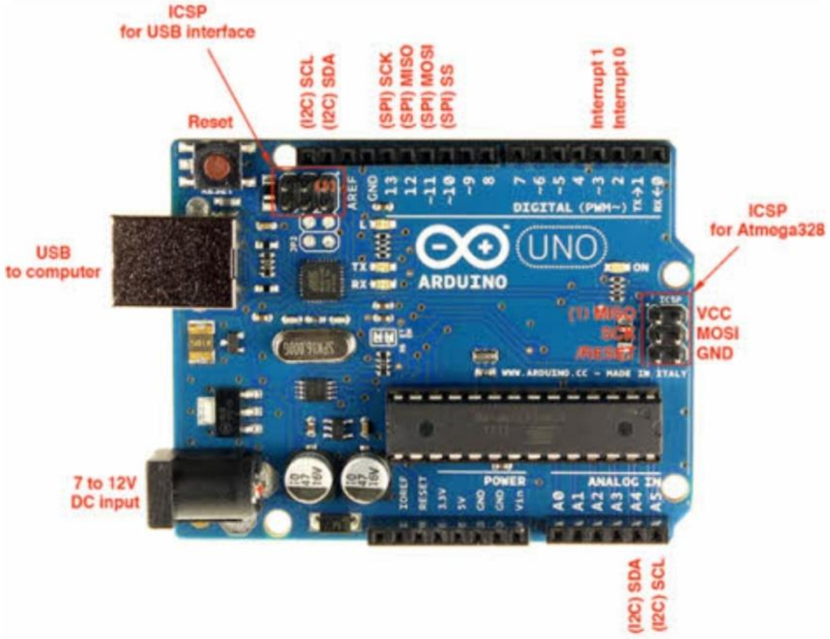
3.6 ARDUINO UNO

The Arduino Uno is one kind of microcontroller board based on ATmega328, and Uno is an Italian term which means one. Arduino Uno is named for marking the upcoming release of microcontroller board namely Arduino Uno Board 1.0. This board includes digital I/O pins-14, a power jack, analog i/ps-6, ceramic resonator-A16 MHz, a USB connection, an RST button, and an ICSP header. All these can support the microcontroller for further operation by connecting this board to the computer. The power supply of this board can be done with the help of an AC to DC adapter, a USB cable, otherwise a battery. This article discusses what is an Arduino Uno microcontroller, pin configuration, Arduino Uno specifications or features, and applications.

Features of Arduino Uno Board

The feature of Arduino Uno ATmega328 includes the following.

- The operating voltage is 5V
- The recommended input voltage will range from 7v to 12V
- The input voltage ranges from 6v to 20V
- Digital input/output pins are 14
- Analog i/p pins are 6
- DC Current for each input/output pin is 40 mA
- DC Current for 3.3V Pin is 50 mA
- Flash Memory is 32 KB
- SRAM is 2 KB
- EEPROM is 1 KB
- CLK Speed is 16 MHz



Arduino Uno Board Pin Configuration

Arduino Uno Pin Diagram

The Arduino Uno board can be built with power pins, analog pins, ATmegs328, ICSP header, Reset button, power LED, digital pins, test led 13, TX/RX pins, USB interface, an external power supply. The Arduino UNO board description is discussed below.

The Arduino Uno power supply can be done with the help of a USB cable or an external power supply. The external power supplies mainly include AC to DC adapter otherwise a battery. The adapter can be connected to the Arduino Uno by plugging into the power jack of the Arduino board. Similarly, the battery leads can be connected to the Vin pin and the GND pin of the POWER connector. The suggested voltage range will be 7 volts to 12 volts.

Input & Output

The 14 digital pins on the Arduino Uno can be used as input & output with the help of the functions like pinMode(), digitalWrite(), & Digital Read().

Pin1 (TX) & Pin0 (RX) (Serial): This pin is used to transmit & receive TTL serial data, and these are connected to the ATmega8U2 USB to TTL Serial chip equivalent pins.

Pin 2 & Pin 3 (External Interrupts): External pins can be connected to activate an interrupt over a low value, change in value.

Pins 3, 5, 6, 9, 10, & 11 (PWM): This pin gives 8-bit PWM o/p by the function of analog Write().

SPI Pins (Pin-10 (SS), Pin-11 (MOSI), Pin-12 (MISO), Pin-13 (SCK): These pins maintain SPI-communication, even though offered by the fundamental hardware, is not presently included within the Arduino language.

Pin-13(LED): The inbuilt LED can be connected to pin-13 (digital pin). As the HIGH-value pin, the light emitting diode is activated, whenever the pin is LOW.

Pin-4 (SDA) & Pin-5 (SCL) (I2C): It supports TWI-communication with the help of the Wire library.

AREF (Reference Voltage): The reference voltage is for the analogi/ps with analog Reference().

Reset Pin: This pin is used for reset (RST) the microcontroller.

Memory

The memory of this Atmega328 Arduino microcontroller includes flash memory-32 KB for storing code, SRAM-2 KB EEPROM-1 KB.

Communication

The Arduino Uno ATmega328 offers UART TTL-serial communication**,** and it is accessible on digital pins like TX (1) and RX (0). The software of an Arduino has a serial monitor that permits easy data. There are two LEDs on the board like RX & TX which will blink whenever data is being broadcasted through the USB.

A Software Serial library permits for serial communication on Arduino Uno digital pins and the ATmega328P supports TWI (I2C) as well as SPI-communication. The Arduino software contains a wired library for simplifying the utilization of the I2C bus.

How to Use an Arduino Uno?

Arduino Uno can detect the surroundings from the input. Here the input is a variety of sensors and these can affect its surroundings through controlling motors, lights, other actuators, etc. The ATmega328 microcontroller on the Arduino board can be programmed with the help of an Arduino programming language and the IDE (Integrated Development Environment). Arduino projects can communicate by software while running on a PC.

Arduino Programming

Once the Arduino IDE tool is installed in the PC, attach the Arduino board to the computer with the help of USB cable. Open the Arduino IDE & select the right board by choosing Tools–>Board>Arduino Uno, and select the right Port by choosing Tools–>Port. This board can be programmed with the help of an Arduino programming language depends on Wiring.

To activate the Arduino board & flash the LED on the board, dump the program code with the selection of Files–>Examples>Basics>Flash. When the programming codes are dumped into the IDE, and then click the button 'upload' on the top bar. Once this process is completed, check the LED flash on the board.

High Voltage Protection of USB

The Arduino Uno board has a rearrange able poly fuse that defends the USB port of the PC from the over-voltage. Though most of the PCs have their own inner protection, the fuse gives an additional coating of safety. If above 500mA is given to the USB port, then the fuse will routinely crack the connection until the over-voltage is removed.

Physical Characteristics

The physical characteristics of an Arduino board mainly include length and width. The printed circuit board of the Arduino Uno length and width are 2.7 X 2.1 inches, but the power jack and the USB connector will extend beyond the previous measurement. The board can be attached on the surface otherwise case with the screw holes.

Applications of Arduino Uno

The applications of Arduino Uno include the following.

- Arduino Uno is used in Do-it-Yourself projects prototyping.
- In developing projects based on code-based control
- Development of Automation System
- Designing of basic circuit designs.

3.7 BATTERY

A battery is a device consisting of one or more electrochemical cells with external connections for powering electrical devices such as flashlights, mobile phones, and electric cars. When a battery is supplying electric power, its positive terminal is the cathode and its negative terminal is the anode. The terminal marked negative is the source of electrons that will flow through an external electric circuit to the positive terminal. When a battery is connected to an external electric load, a redox reaction converts high-energy reactants to lower-energy products, and the free-energy difference is delivered to the external circuit as electrical energy. Historically the term "battery" specifically referred to a device composed of multiple cells, however the usage has evolved to include devices composed of a single cell.

Primary (single-use or "disposable") batteries are used once and discarded, as the electrode materials are irreversibly changed during discharge; a common example is the alkaline battery used for flashlights and a multitude of portable electronic devices. Secondary (rechargeable) batteries can be discharged and recharged multiple times using an applied electric current; the original composition of the electrodes can be restored by reverse current. Examples include the lead-acid batteries used in vehicles and lithium-ion batteries used for portable electronics such as laptops and mobile phones.

Batteries come in many shapes and sizes, from miniature cells used to power hearing aids and wristwatches to small, thin cells used in smartphones, to large lead acid batteries or lithium-ion batteries in vehicles, and at the largest extreme, huge battery banks the size of rooms that provide standby or emergency power for telephone exchanges and computer data centers.

Batteries have much lower specific energy (energy per unit mass) than common fuels such as gasoline. In automobiles, this is somewhat offset by the higher efficiency of electric motors in converting chemical energy to mechanical work, compared to combustion engines.

12VOLTS BATTERY

3.8LIQUID CRYSTAL DISPLAY (LCD)

►Character LCD 16x2

►5x8 dots includes cursor

►Built-in controller (ST7066 or Equivalent)

►+5V power supply (Also available for +3V)

►Negative voltage optional for +3V power supply

►1/16 duty cycle

►LED can be driver by PIN1, PIN2, PIN15, PIN16 or A and K

►Interface : 6800, option SPI/I2C (RW1063 IC)

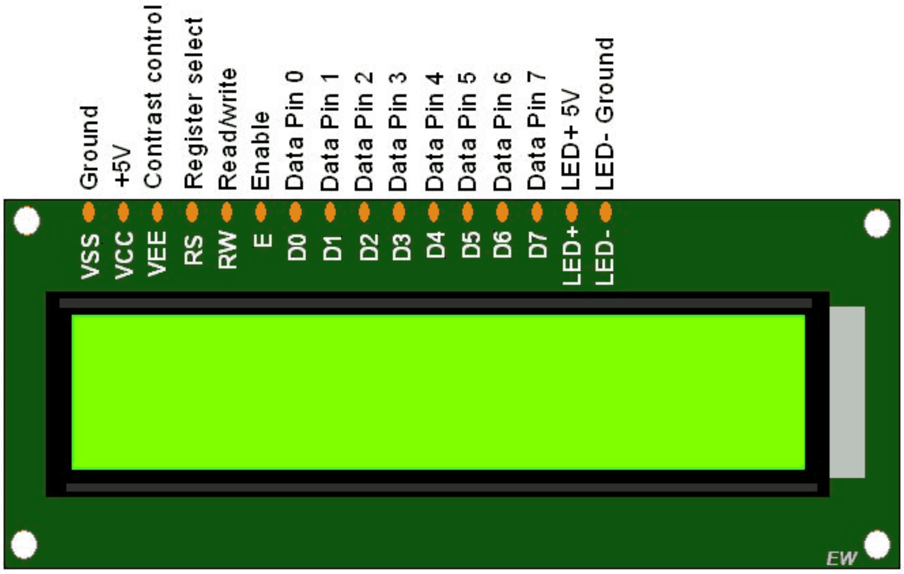
LCDs (Liquid Crystal Displays) are used in embedded system applications for displaying various parameters and status of the system.

LCD 16x2 is a 16-pin device that has 2 rows that can accommodate 16 characters each.

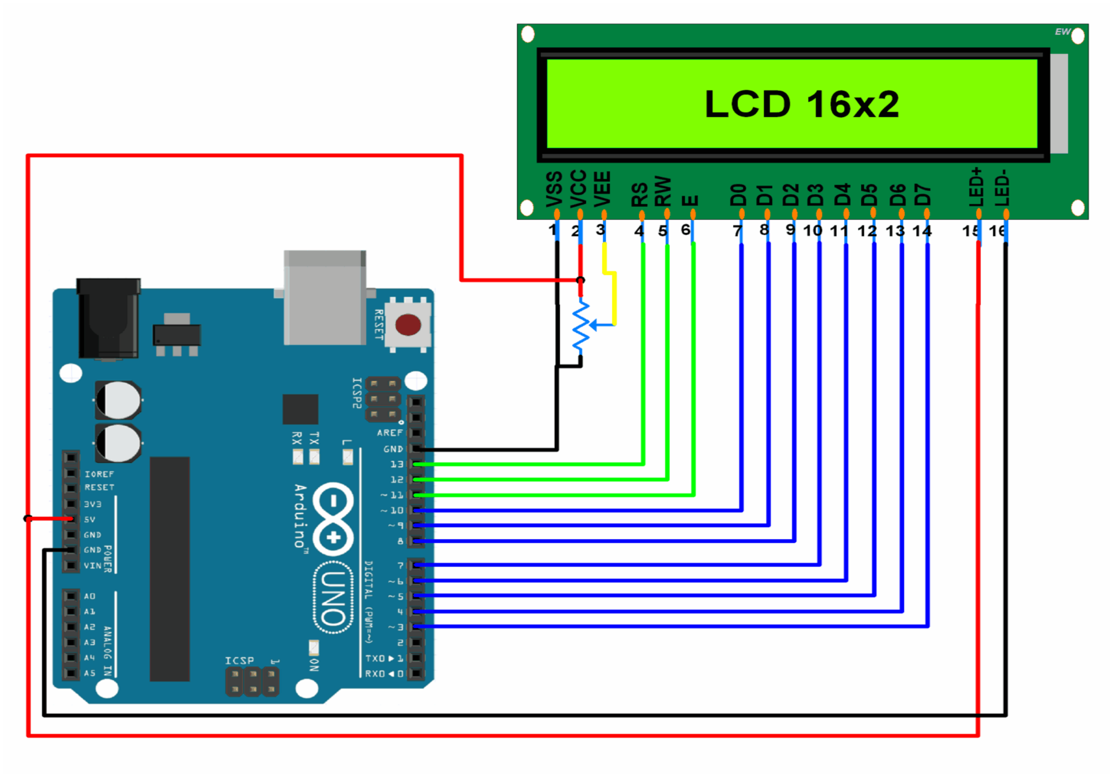
LCD 16x2 can be used in 4-bit mode or 8-bit mode.

It is also possible to create custom characters.

It has 8 data lines and 3 control lines that can be used for control purposes.



Lcd interfacing diagram

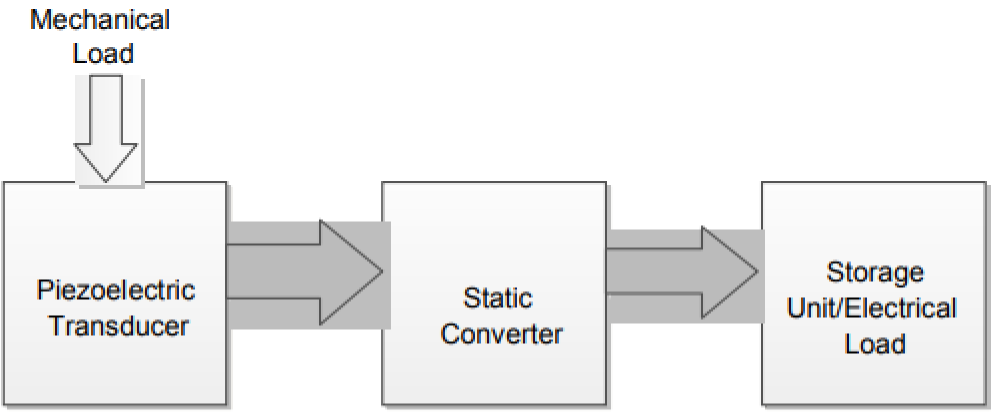


CHAPTER 4

SIMULATION

4.1Harvester Mechanical to Electrical Modeling

The harvesting principle of electrical energy from mechanical energy is shown in Fig. 4. The piezoelectric transducer remains in direct contact with the source of vibration. When the vibration occurs, the piezoelectric transducer induces the electric charge. The rate of change of these induced charges with respect to time gives the alternating current pulses. A static converter is used before feeding the storage unit or the electrical load.



Schematic diagram of a vibrating piezoelectric Harvester model

The transducer used in this model are piezoelectric diaphragms or bender plate that consists of a piezoelectric ceramic plate (PZT), with electrodes on both sides, attached to a metal with conductive adhesive shown in Fig. 2. The resonant frequency of these diaphragms is given by Helmholtz's equation

$$f_0 = \frac{C}{2\pi}\sqrt{\frac{4a^2}{d^2h(t+ka)}}$$

Where f_0 is the resonant frequency (Hz), C is the velocity of energy wave, a is the radius of ceramic diaphragm (cm), d is the diameter of the support, t is the thickness of support and k is the material constant. It is considered that piezoelectric transducers are operated under self-resonant frequency so that maximum charge can be induced.

4.2 Simulation model and Results for Harvester Circuit

An approximated model of piezoelectric harvester has been drawn in MATLAB by considering the electrical equivalent model of piezoelectric transducer assuming the suitable constants. The output of a piezoelectric transducer is an AC signal. It must be converted to DC for load or storage cell utilization. A full bridge rectifier is used to convert the AC voltage produced by piezoelectric diaphragm to DC voltage. It is observed that during each load impact on the piezoelectric tile at least six piezoelectric transducers are simultaneously actuated. Therefore, a parallel grid of six units of the transducer has been used at the input of rectifying units and primary storage unit (C_r). Firstly a rectifier circuit without the filter capacitor (C_r)and with purely resistive load is considered, secondly the filter capacitor is applied and output is measured across load resistor. The simulation circuit diagram and corresponding output waveforms are shown in figure 5 and figure 6, respectively.

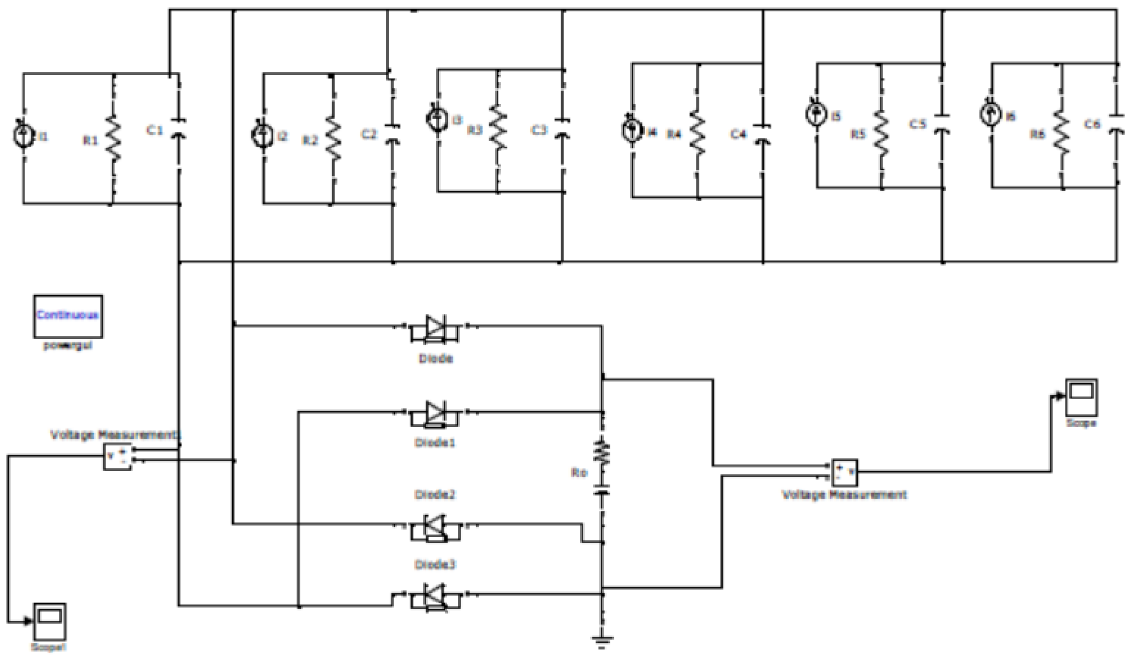


Fig. 5 Simulation model for equivalent piezoelectric energy harvester circuit with bridge rectifier and output capacitor

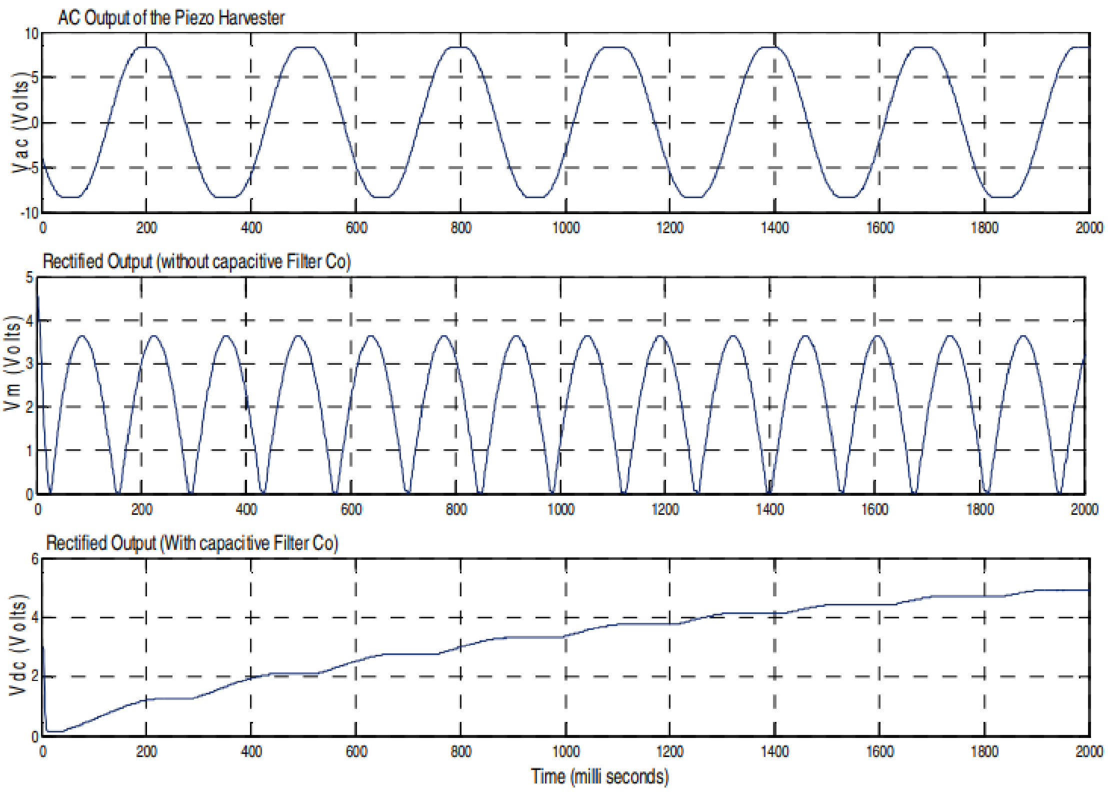


Fig. 6 AC output waveform of Piezo equivalent model (Top), Rectified output without C_r (Middle) & Output with a rectifying capacitor $C_r$of $100\mu f$ (Bottom)

The harvester circuit output power can be represented as the sum of the output power generated by each individual PZT (Piezoelectric Diaphragm-Lead-Zirconium-Titanate). As the PZT are connected in parallel, Kirchhoff's law can be applied to find the equivalent circuit. Here the source (I) can be taken as the sum of the individual current source of PZT and is given by equation (4).

$$I = i_1 + i_2 + i_3 + i_4 + i_5 + i_6$$

The total resistance (R) of the PZT is taken as the parallel combination of individual units given by equation (5).

$$R = R_1||R_2||R_3||R_4||R_5||R_6$$

Also the total capacitance of the piezoelectric grid can be represented by (6)

$$C = C_1 + C_2 + C_3 + C_4 + C_5 + C_6$$

The power output of a full bridge rectifier with a single transducer is given in equation (7) [8].

$$P_R = C_i * V_R * f_i * (V_i - V_R - 2V_{di})$$

Here, P_R is the total power output of the bridge rectifier unit with one piezoelectric diaphragm, C_i is the plate capacitance of the piezoelectric transducer, V_R is the voltage at rectifier output, f_i is the excitation frequency of the transducer, V_i is the open circuit voltage at the output of PZT unit and the $V_{di}$is the diode voltage drop. The grid equivalent of the six transducers has the frequency of excitation to be half of actual excited frequency and is given by equation (8).

$$f_i = \frac{f_0}{2}$$

Thus, the total output power P_T of the harvester with the transducer grid can be given as

$$P_T = C * V_{RT} * (V_{iT} - V_{RT} - 2V_{Di}) * f_0/2$$

Here V_{RT} represents the total voltage at rectifier output, V_{iT} is the total open circuit voltage at the output of PZT grid connected in parallel.

CHAPTER 5

ADVANTAGES AND APPLICATION OF PROJECT

Advantages of project

- Everyday wasted energy can be put to good use
- Peizo electric sensor is cheap and easily available
- It is a clean source of energy which does not pollute the environment
- No fossil fuels needed
- Battery is used to store generated power
- Low maintenance
- No moving parts
- Self-generating , no external power required

Applications of project

- Can be implemented in populated metropolitan cities with a lot of footfall
- Can be installed in Railway stations ,populated streets, School and College corridors.
- Power generated can be used for Street lighting.
- Footstep power generated can be used in emergency power failure situations
- Generated power can be used for AC/DC loads

Drawbacks

- Only applicable in high density areas
- Power generated from piezoelectric sensor very less
- Power generated is dependent on the pressure exerted on the sensor
- Can not be used for heavy loads

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

A piezoelectric energy harvester has been simulated and designed experimentally. A constantly increasing impulse strain is applied every time to the entire unit. It has been a great experience to harvest the electrical energy from mechanical strain. The equivalent circuit model is developed in MATLAB and the expected result is obtained. The developed energy harvester can be applied to supply low powered electronics like wireless sensors, bugging devices, weather monitoring devices, aircraft power supply and many more low powered MEMS (Micro electromechanical Systems) devices. There is a wide scope of improvement of this type of harvesting technique because of increased demand of portable micro powered electronics. The all round development of self powered electronics depends upon the highly efficient energy harvesting systems. Some improvements have been done in this model to reduce the voltage drop at rectifier stage using dedicated IC. Further improvements may be done to minimize the loss and to accumulate the optimum power.

REFERENCES

1. Li Tianze, Zhang Xia, Jiang Chuan, &Hou Luan.(2009). Analysis of the characteristics of piezoelectric sensor and research of its application.2009 18th IEEE International Symposium on the Applications of Ferroelectrics.

2. Kumar, D., Chaturvedi, P., &Jejurikar, N. (2014). Piezoelectric energy harvester design and power conditioning.2014 IEEE Students' Conference on Electrical, Electronics and Computer Science.

3. Songsukthawan, P., &Jettanasen, C. (2017). Generation and storage of electrical energy from piezoelectric materials. 2017 IEEE 3rd International Future Energy Electronics Conference and ECCE Asia (IFEEC 2017 - ECCE Asia)

4. sandeep kale, nehalnawkhare ,utkarshajamodhkar, aniketbayanat, niketbhole, nishantade. implementation of piezoelectric tile to generate electricity. international journal of engineering research in electrical and electronic engineering Vol 4 issue 3 march 2018