Energy Harvesting with Piezotransducer using a Rectifier-free circuit for low voltage application

Under the Guidance of

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***Abstract*— In this generation of microworld, energy requirement for micro devices in critical working environment is always been a complex process for deciding the power source. By harvesting small amount of energies from the environmental sources (such as ambient Temperature, vibrations or light sources) the process is made simple. In this paper/ report, the energy harvesting circuit for low voltage input (piezo quartz transducer) with the help of rectifier free circuit (using switching components i.e., MOSFET; minimum Energy loss) for powering low powered sensors and actuators.**

Keywords— ***ac/dc conversion; rectifier free; energy harvesting; low voltage, low power***

I. Introduction

The energy harvesting from piezo transducer is vastly used nowadays in all kinds of application. The piezo quartz crystal when subjected to mechanical load (vibration; load; thermal stress) provides electrical energy (piezoelectric effect). But the voltage obtained is an Ac signal and it requires a conversion to DC for application purpose.

Figure 1: Block diagram of Energy harvesting system

Generally, conversion of ac/dc is done by bridge rectifier in a converter circuit, but this rectifier circuit has a major limitation when it is used for lower power conversion (below 0.7V) because the diode present in the rectifier needs a threshold voltage which is above 0.7V for its operation and when converting very small voltages the rectifier has more loses because of the diodes used. To overcome this problem, the rectifier in the converter circuit is replaced with switching component such as P-MOSFET and N-MOSFET for the ac/dc conversion with a minimum loss.

Power MOSFET is most probably a switch, which can control the voltage and current flow between the source and drain. It consists of source, drain, gate and a body diode. A body diode is connected between source and drain, whose function is to allow the current in unidirectional. Further a Schottky Diode is used in the circuit for allowing current from the MOFET (I_{mos}) in one direction and then followed by an Inductor which is used to control the current (i.e., it permits only steady state current to pass through it, if detected any variation in current, it resists the current flowing through it).

Finally, at the end, a capacitor is used to accumulate dc voltage and later a steady power supply can be utilized from the capacitor for a desired application.

Using these above-mentioned components, a theoretical simulation of the circuit is done on Lt spice analysis software and the results and the inferences are further discussed in the upcoming section. The simulation results illustrate that the circuit delivers a steady state low dc output voltage with a minimum energy loss. A prototype of this circuit is also done and explained.

II. Working Principle of the Circuit

A. Energy Harvesting from Piezo transducer

The response to change in the dimension of the piezo crystal by an external load is the electric charge known as piezoelectric effect and the internal generation of a mechanical strain resulting from an applied electrical field. For example, lead zirconate titanate crystals will generate measurable piezoelectricity when their static structure is deformed by about 0.1% of the original dimension. Conversely, those same crystals will change about 0.1% of their static dimension when an external electric field is applied to the material is called as inverse piezoelectric effect. [3]

B. AC/DC conversion using rectifier

The traditional way of ac/dc conversion is done by using bridge rectifier circuit but as said before it has its limitations since it needs a threshold voltage of 0.7V and losses are also high at this range of operating voltages due to its diode currents. The bridge rectifier mainly consists of four diodes (device which allows only unidirectional current) in a form of Wheatstone bridge and during the alternate cycles of ac input signals the diodes which are only parallel to each other allows current to pass through it such that the output is a dc current. During the positive cycle of ac input signal, the diodes d1 and d2 will be forward biased and during the negative half cycle the diodes d3 and d4 are reverse biased so that the output is always a positive half cycle (DC current) [4]. Since there are four diodes they draw some voltage from the input voltage for its own operation i.e., Diode current but in case of very low voltage below 1 volt the diode does not operate. Thus, a usage of bridge rectifier in low voltage converter circuit is not appreciated.

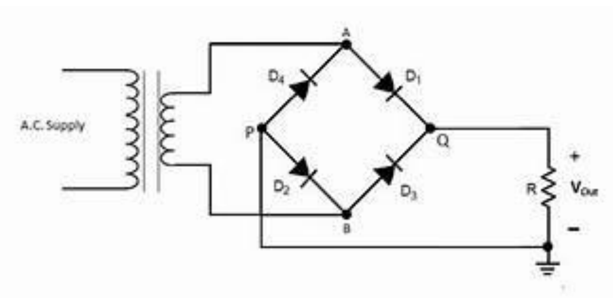

Figure 2 [5] : Universal Bridge Rectifier

III. AC-DC CONVERSION WITHOUT RECTIFIER

Due to the limitation of the bridge rectifier, we decided to use switches using P & N Power MOSFETs for the converter because the switching doesn't require any input voltage and it is automated by the body diode of the power MOSFET and loss is very low when compared to bridge rectifier circuit.

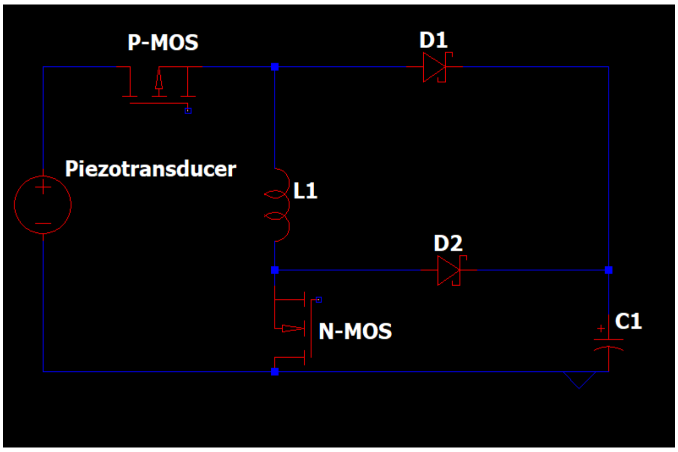

Figure 3: Circuit Design

A. Abbreviations and Acronyms

- MOSFET – Metal Oxide Semiconductor Field Effect Transistor.
- P-MOS – P doped Metal Oxide Semiconductor.
- N-MOS – N doped Metal Oxide Semiconductor.

B. Units

- Standard SI units: current – ampere (A); voltage – volts(v); Capacitance - µF; Inductance – Henry.
- Symbols: Diode current (i_D); Inductor current (i_L); capacitor.

C. Components decription

MOSFETs works in two types of mode: [5]

1. Depletion mode
2. Enhancement mode.

- Depletion mode: In this mode the MOSFET acts as "Normally opened switch".
- Enhancement mode: In this mode the MOSFET acts as "Normally closed switch".

P–MOS:

It is a four terminal device containing gate, source, drain and internal diode where source and the drain are p doped and the body is n doped. It regulates the input load current with almost negligible power consumption.

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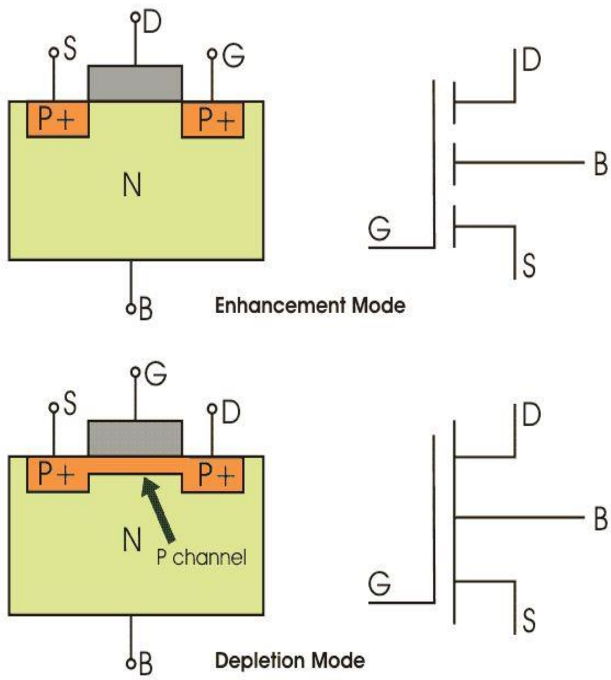

Figure 4 [6]: P- MOSFET

N–MOS:

It is a four terminal device containing gate, source, drain and internal diode where source and the drain are n doped and the body is p doped. It regulates the input load current with almost negligible power consumption.

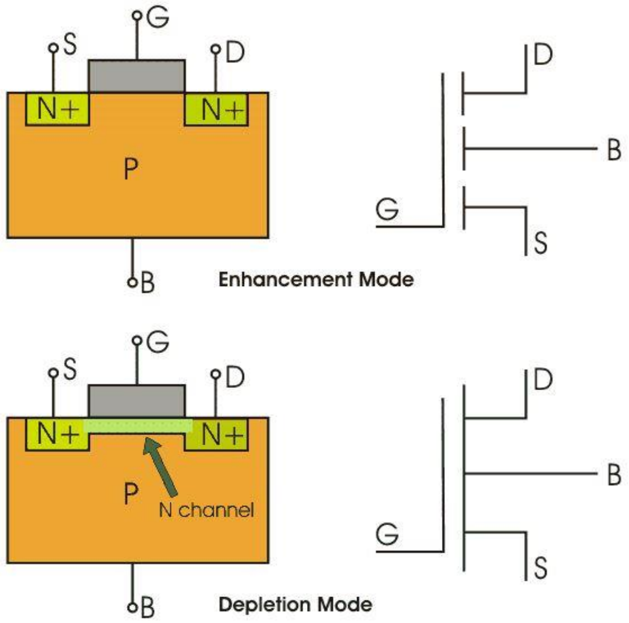

Figure 5 [6]: N-MOSFET

Diode:

A diode allows the flow of current only in one direction (i.e., Forward bias) and it blocks the current flowing in reverse direction (i.e., Reverse bias). It can also be used to convert the Alternating current to a Direct current.

A Schottky diode have less Forward voltage drop compared to normal diodes and it has very fast switching action. [9]

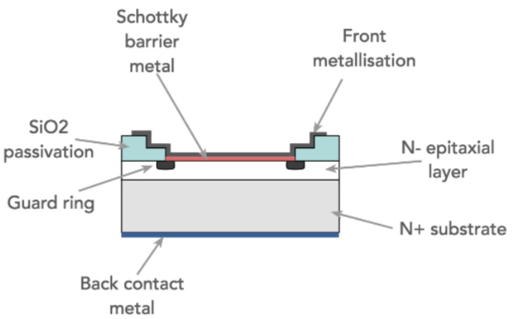

Figure 6 [7]: Diode

Capacitor:

A capacitor is used as a storage device which stores energy in the form of Electrostatic field in between the two plates.

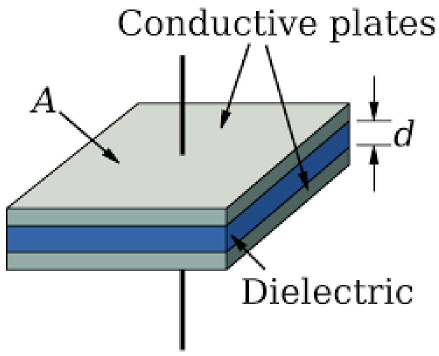

Figure 7 [8]: Capacitor

Table of Description

COMPONENTS	SPECIFICATIONS
P-MOS	12v, 4.3A
N-MOS	20v, 4.2A
Schottky diode D1, D2	20v
Capacitor	47 µF

Figure 8

D. Modes of operation

The P-mos and N-mos in the circuit acts as switches using the body diode which is internally connected from source to drain. The energy produced is stored using a capacitor for the application. As the transducer produces AC voltage it should be converted into DC voltage which is done by the circuit in two different cycles based on the received positive and negative cycle from the transducer.

Cycle I: Inverting cycle

In this cycle, the negative signal from the Piezo transducer is converted into positive DC signal and is stored in the Capacitor C1. This is done in the marked part of the figure [9].

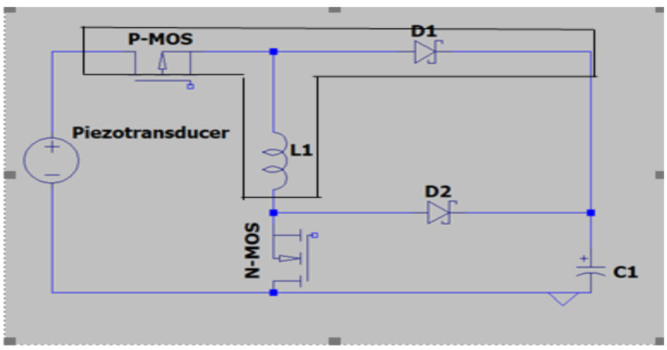

Figure 9: Cycle I

Cycle II: Non-inverting cycle

In this cycle the positive signal from the piezo transducer is converted into positive DC signal and is stored in the capacitor C1. This is done in the market part of the fig [10].

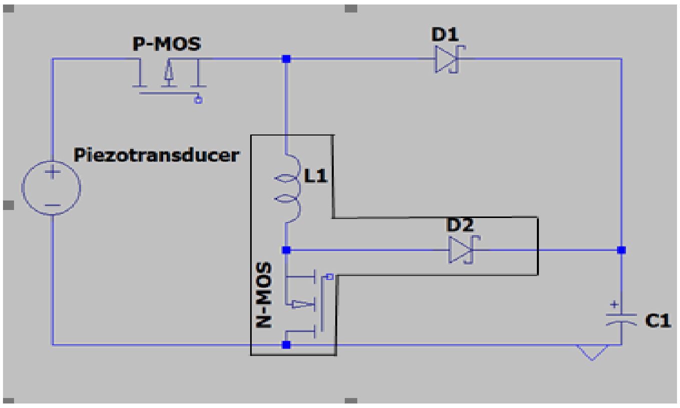

Figure 10: Cycle II

IV. SIMULATION

The simulation of the circuit was done in LT-spice and the following results of output voltage was seen for an input AC voltage of amplitude 0.4 V, frequency 50Hz and the components specifications as listed in the table. Here we can see that the converted signal is about 0.2V DC.

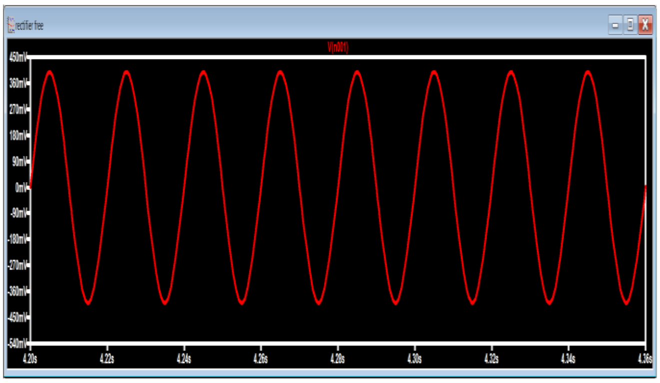

Figure 11: Input AC- Voltage

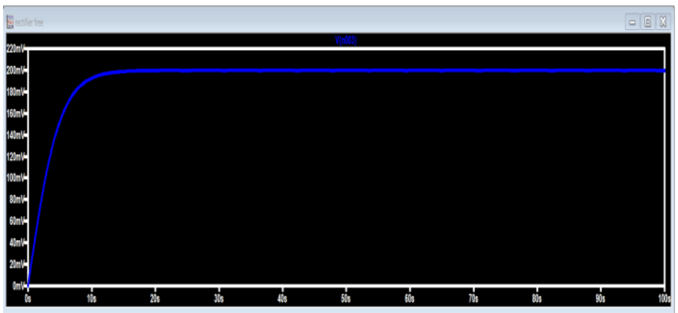

Figure 12: Output DC- Voltage

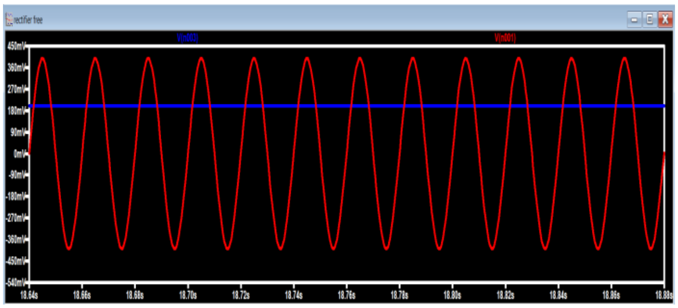

Figure 13: Output Rectified Dc- Signal

V. PRACTICAL WORK

The Piezo transducers are connected in series and kept in a tube-shaped casing with insulation between each transducer. A mass is placed on the top of the piezo stacks to apply force in respect to vibrations. A spring is place inside the casing in contact with the mass, as a restoring force for the mass due to vibrations.

Now the Positive and negative terminal of the piezo transducer is connected as a voltage source to the circuit. When the casing is subjected to mechanical vibration, the mass exerts the force on the piezo transducers, which converts the force into an electrical energy. The components are connected according to the circuit model. Now the output DC voltage produced by the converting circuit for 7 piezo transducers in series is around 2V (peak).

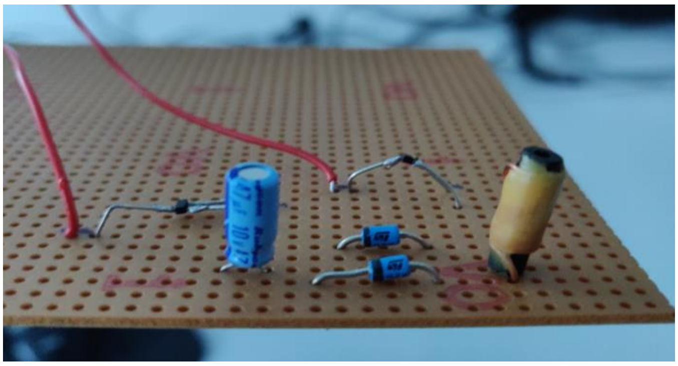

Figure 14: Realtime circuit

Figure 15: Voltage Reading

APPLICATIONS

According to the obtained output we propose that the harvested energy may be further utilized for powering up low powered devices such as Active sensors (e.g.: Accelerometer, Tilt, TPMS etc.,). Also, it can be independently used as passive sensor like Solar cell. It can also be used in wrist watches, Mobile keypads, keyboards etc.,

Other major application that we like to propose is by using the same harvesting circuit by harnessing rain drops (kinetic energy of raindrop which is directly let to hit the surface of piezo inducer).

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