MEMS-Based Energy Harvesters for IoT Applications

Mohammad Taj, N V R Vikram G

ABSTRACT--- ***This paper reviews the various MEMS (Micro Electro Mechanical Systems) based energy harvesting techniques for IoT (Internet of Things) applications. The significant part of IoT is sensor network which requires wireless power sources. Based on requirement, the IoT has been implementing the autonomous powers harvesting technology. The MEMS-based vibrating devices are useful for harvesting energy with environmental effects likes Thermal, Vibrating, and Electromagnetic waves. Various methods of energy harvesting and vibrating sources are discussed.***

Keywords— MEMS, IoT, Harvesting, Thermal, Vibrating, Electromagnetic waves.

I. INTRODUCTION

IoT is a giant network in which devices are interacted with each other and make a decision without a human source. IoT can be any device with various sensors and the collection of data is done by automatically. The energy harvesting is the main demand from IoT because thousands of sensors have required power. The vibrating based MEMS device plays a major role in harvesting energy. The basic working principle of vibrating energy harvesting is to converting the environmental vibrations into electrical energy. The generated electrical energy is depending on device size, shape, and working principle. The power generated by this energy harvester is very low (as in nW). The various energy harvesting methods are employed for IoT are listed as below.

Three types of vibrating energy harvesters are:

- Machinery Energy harvesters.
- Electromagnetic Energy harvesters
- Piezoelectric Energy harvesters

The machinery energy harvesters work with the principle of mass-damping effect. These energy harvesters are also called linear harvesters. Because the energy generation depends on the fixed mass and damping. In this method. the energy generation is depending on the displacement when inertial mass applied on the device along with the change of displacement observed according to transduction principle. In electromagnetic energy harvesters, “Electromagnetic induction is based on the Faraday's Law which states that an electrical current will be induced in any closed circuit when the magnetic flux through a surface bounded by the conductor changes “. This applies whether the magnetic field changes in strength or the conductor is moved through it. The generated energy is depending on the permanent magnet and coils. The fixed coils and magnetic momentum generate electrical energy. There are two types of electromagnetic energy harvesters presented according to displacement. One is lateral movement between coil and magnet and second is two-dimensional momentum between magnet and coil. The piezoelectric energy harvester works on the basic principle of mechanical stress/strain energy is converted into electrical energy. These energy harvesters have high output potential and low current value. Commonly used materials for piezoelectric energy harvesting are BaTiO3, PZT5A, PZT-5H, polyvinylidene fluoride (PVDF) (Anton & Sodano, 2007). [1]

II. ENERGY HARVESTING FROM MACHINERY VIBRATIONS

Machinery energy harvesters work on the principle of change of displacement with applied mechanical force. The resultant potential is generated with a change of displacement and this type of harvester works as a transducer. Strain gauges are works as a mechanical energy harvester. The change length or area is decided the change of resistance and further, it decides the value of output generating potential.

Electrostatic energy harvesters are one of the mechanical energy harvesters. This harvester consists of two sets of electrodes. One is fixed and second is moveable. The capacitance value has been changed according to mechanical vibrations. The energy has harvested with a change of capacitance. The capacitance changes from minimum to maximum then the harvesting energy id depending on mechanical vibrations. Electrostatic energy harvesters are three types (Figure 1) [1]. “In-Plane Overlap which varies the overlap area between electrodes, In-Plane Gap Closing which varies the gap between electrodes and Out-of-Plane Gap which varies the gap between two large electrode plates”. These harvesters producing high potential and low current due to its capacitance effect.

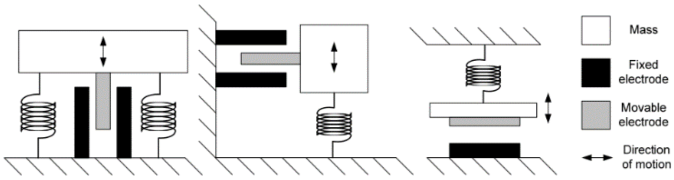

Figure 1: Types of Machinery Energy Harvesters

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The other type of mechanical harvesters is resistive and inductive harvesters. The resistive and inductive transducers also come under the machinery vibrating harvesters. For resistive harvesters, change of resistance has been observed with external vibrating force. The inductive harvesters also work with the same principle but inductance will change with external vibrating force. This type of harvesters needed an external source for harvesting the energy.

III. ELECTROMAGNETIC VIBRATION ENERGY HARVESTER

The electromagnetic energy harvesting is a common practice. The change of the magnetic field produces the required energy. This type of harvester is mainly consisting of fixed magnets and movable magnet. The movable magnet having a coil. When any environmental vibrations are occurring like the movement of the object along with human body movements. The energy harvesting process as shown in Figure 2. [2] This design consists of two fixed magnets and one movable magnet which is surrounded by the coil. The movable magnet has been fixed in between two permanent magnets. If any environmental vibrations have occurred on the device. The distance from both magnets are various and the variable potential is observed at the movable magnet coil [2].

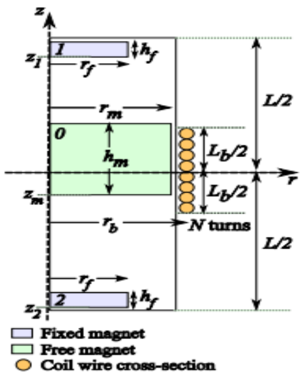

Figure 2: Architecture of Electromagnetic Energy Harvester

From Faraday's law of the potential generation is directly proportional to the rate of change of magnetic flux. The equation (1) represents the generating potential with a change of the magnetic field.

$$V = -\frac{d\Phi}{dt} \quad (1)$$

where V is the generated potential and φ is the flux linkage. In generally the magnetic flux density is depending upon a number of turns of a coil. The generated potential is varying along with the number of turns N. hence the harvested energy is represented in equation (2).

$$V = -N\frac{d\Phi}{dt} \quad (2)$$

Where N is the number of coils. These harvesters are useful to provide energy for rechargeable batteries and sensors. The energy converted from microamperes to milliamperes.

Another application of electromagnetic energy harvester is wireless power transmission to mobile phones and space applications. This topology is also useful for IoT applications. The architecture of electromagnetic energy harvester as shown in Figure 3[3]. This structure consists of an antenna, matching circuit, rectifier and low pass filter. The Antenna that converts the electromagnetic wave into radio wave or microwave signal and the matching circuit avoids the back-scattering effect of the antenna. The rectifier converts the radio frequency signal into the Direct current (DC). The low pass filter regulated the power to load. [3] This energy harvester is mostly useful for wireless power transfer for the various sensor network. The IoT is mainly concentrated on wireless power energy harvesters.

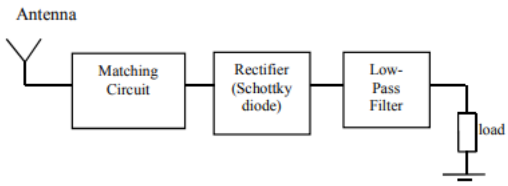

Figure 3: Wireless Electromagnetic Energy Harvester

The next electromagnetic energy harvester is to be designed as micro level. This harvester design is a conventional level as shown in Figure 4. [4] This harvester consist of a cantilever beam with a copper coil has fixed in a permanent magnet. The harvested potential is produced as Faraday's law. When displacement occurs due to cantilever bean then the potential has been induced. The magnetic flux changes with the vibrating cantilever beam. The generated potential is depended on vibrations. As per vibrations, the resultant potential has been noticed. This microstructure supports for IoT applications for harvesting the energy. [4] The generated power is in terms of microwatts.

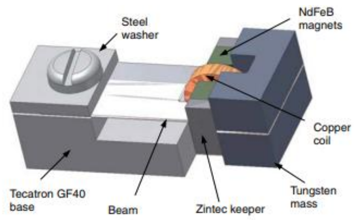

Figure 4: Micro Size Electromagnetic Energy Harvester

IV. PIEZOELECTRIC VIBRATING ENERGY HARVESTER

The piezoelectric effect is the production of electric potential with applied mechanical stress. This type of harvester is directly adapted to individual systems without an external source. The piezoelectric harvesters are consisting of crystalline materials like $BaTiO_3$, PZT5A, PZT-5H, polyvinylidene fluoride (PVDF) (Anton & Sodano, 2007). The nature of the material is to produce the electric signal with applied force. This harvester also converts the environmental vibrations into electric energy. The energy generated from this harvester is depended upon applied force. The range of generated potential is microvolts to millivolts. Piezoelectric energy harvesters are used in many applications like Bio-medical, Wireless sensors, mobiles, and many more applications. These harvesters also more useful in IoT applications to drive the sensor networks.

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Midé's Volture™ Piezoelectric Energy Harvesters is one of the piezoelectric harvesters as shown in Figure 5 [5]. The purpose of this harvester is to convert various mechanical vibrations into electric energy. Hence this system is adapted to converting wasted energy like motor bearing vibrations, aircraft wings vibrations, and other various vehicle vibrations into electric potential. This consisting of a piezoelectric transducer, rectifier, Filter, Charge management unit and various output loads. When force or stress is observed the piezoelectric sensor from environmental mechanical vibrations, then it will be converted as electric potential. This potential further is given to rectifier circuit which will convert an alternating current signal into a direct current signal. The output of the rectifier is given to filter to produce steady-state potential. The charge management circuit is used for distributing the power for various loads. Most of the applications this energy harvester has been used: Condition Based Maintenance Sensors, Mobile Asset Tracking, Industrial Health Monitoring Network Sensors, Wireless HVAC Sensors, Tire Pressure Sensors, Oil and Gas Sensors and All Air Land and Sea Vehicle Sensors. [5]

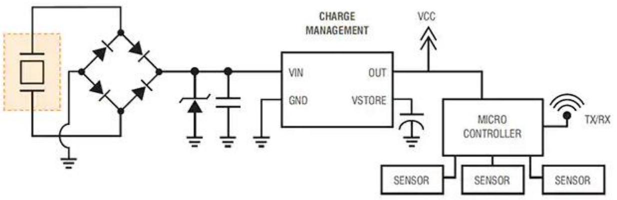

Figure 4: Piezoelectric EH

The second type of piezoelectric energy harvester is Toggle-Type MEMS Vibration Energy Harvester. This harvester works on the principle of toggle mechanical principle. This harvester consists of a rectangular membrane oh 20µm thickness and is fixed with the base frame. Two proof masses are attached to this membrane as shown in Figure 5. This whole arrangement is to be connected with a piezoelectric crystal. When any environmental vibrations are generated on the anchor. It will be toggled continuously and pressure has been observing on the piezoelectric crystal. This pressure further converted into electrical energy. This harvested energy from this device is in nano-watt. This design is suitable for a device operated with very less power like Nanosensors. [6]

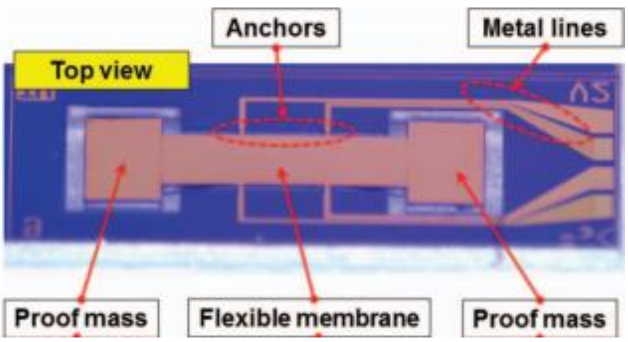

Figure 5: Toggle type Piezoelectric Energy Harvester

Another piezoelectric energy harvester is a spiral type MEMS energy harvester. This size of the device is in a micrometer. The construction of this sensor is in the spiral structure. This sensor is more sensitive due to its structure. This device obtaining energy in term of nano-watt. This sensor is useful for Nanosensor network. This will be more suitable for IoT applications. This power is sufficient for sensor network in IoT. This sensor consists of one spiral vibrating module along with piezo crystal as shown in Figure 6. When any environmental vibration has occurred on the spiral beam then it will be passed to the piezo crystal and energy is coveted from vibrations to electrical. This harvester is more sensitive because of its construction. This device senses the vibrating energy from all direction. This device also suitable for many IoT applications.

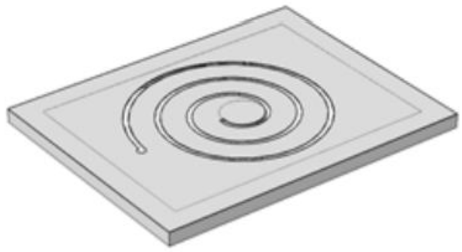

Figure 5: Spiral type Piezoelectric Energy Harvester

V. VIBRATING SOURCES AND DEVICE CAPABILITY & RESULTS

A. Vibrating Sources

Vibrating sources are the main requirement for energy harvesting. In the environment, many types of vibrating sources like a Car engine, airplane wings, mechanical machines, human body organs, and airflow. The value of acceleration is depending on the type of vibrating source. The various environmental vibrating sources are listed in Table 1.

Table 1Various vibrating sources

Vibration Source	Acceleration (g)
Consumer Appliances	
laundry Machine	0.03
standard Fan	0.611
Hoover	0.158
Cooking canopy	0.060
Microwave Oven	0.114
Kitchen Blender	0.644
Treadmill	0.006
Notebook computer	0.010
Machinery	
Air distribution unit	0.100
Industrial Grinder	0.358
Computer controlled cutting machine	0.022
Industrial Miller	0.018
Industrial Lathe machine	0.033
Moving automotive at 20-30km/hr	
Angular surface	0.027
In line road	0.013
Obstacles on road	0.057
Edges	0.011

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B. Device Capability

The energy consumption is varying along with device type. Some devices consume more energy and some consume the very less. Table 2 listed various devices and power rating. The devices consume the power up to 1μW those devices are named as microscale devices.

Table 2 Device power capability

Name of the Device	Required Power to work
32kHz Oscillator	100nW
Electronic Watch	1μW
RFID Tag	10μW
Hearing Aid	100μW
Miniature FM Radio	1mW

The power harvesting from various sources is listed in Table 3. Various vibrating harvesters are discussed in this paper. The machinery harvester is depending on the external source, electromagnetic energy harvester produces the energy in a rage of 100nW to 1μW and the piezoelectric harvester produces the energy in the range of 1μW to 10μW.

Table 3 Harvesting energy from various harvesters

Type of Energy Harvester	Harvesting range
Machinery energy Harvester	Required external source
Electromagnetic Energy Harvester	100nW - 1μW
Piezoelectric Energy Harvester	1μW - 10μW

VI. CONCLUSION

This paper has reviewed various MEMS-based vibrating energy harvesting techniques for IoT applications. The machinery vibrating harvester is a basic harvester and it requires an external energy source for energy harvesting. Electromagnetic energy harvesters are generating the power in the range of 100nW - 1μW. The piezoelectric energy harvester is the most sensitive type harvester and high-power efficiency has been observed. The harvesting range is 1μW - 10μW. This energy is sufficient to drive the various sensor networks in IoT.

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