Acoustic Energy Harvesting Using Piezoelectric Effect for Various Low Power Applications

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Abstract--- *In recent years energy consumption has been increased due to increase in many wireless networks which must require longer lifetimes. Most of sensors nodes which are operated on battery have limited storage capacity and wear out with time. Nowadays there is huge demand for substitute energy resources to overcome energy demand. Hence this paper focuses on harvesting energy from the acoustic energy already present in environment which goes wasted. This can be carried out by piezoelectric effect mechanism. Piezoelectric materials are those materials which convert ambient vibrations to electric energy that can be used for low power devices. The energy so generated can be applied for various low power networks, which can overcome the ever increasing demand for power supply and also it is an eco friendly one.*

Keywords--- *Piezoelectric Effect, Quarter Wavelength Tube Resonator, Smart Road.*

I. INTRODUCTION

THERE is an increase in self-powered electronics due to which devices that harvest power are gradually increasing. Due to advancement in wireless technology and low power wireless networks, sensors & actuators are being developed that can be found almost everywhere. Lots of research work has been going on in harvesting energy resources that are abundantly present in environment in efficient manner. For example, solar energy, wind energy, thermal energy. Even though we harvest energy in these forms some kind of energy goes wasted & unused. Therefore these form of energy must be harvested for better utilization and increasing demand.

The environmental impact of the noise guides the researchers in the field of noise reduction and noise harvest. Providing electric energy from so-called waste energy (noise), offers more possibilities to assure new renewable energy for hand devices or for different applications. The researches developed in the last decades lead to three conversion ways of

the acoustic energy: electromagnetic using the electromagnetic induction effect, electrostatic or capacitive and piezoelectric [2].

According to the law of energy "Energy can neither be created nor destroyed, it can be converted from one form of energy into any other form of energy". Electricity can be generated in numerous ways. It can be either renewable energy resources or non renewable energy resources. It can be conventional or non conventional energy resources[3].

Scientists have been doing research in this field so as to produce alternate methods to produce electricity which can be of lesser cost and then can be sustained for longer time. There is numerous numbers of applications present in technological world that use the energy produced by transducers. Here transducers may basically consist of piezoelectric materials. The proposed system converts incoming sound vibrations into AC electrical signals which is then rectified into DC signals for further usage [4].

In energy harvesting technology, extracting unused or wasted energy from our environment and then converting such energy into usable energy has received considerable research interest. Harvesting energy from thermal, solar, radio frequency, wind and mechanical vibration, which are environmental energy sources, has been investigated with regard to the use of these sources in powering low consumption electronic devices such as wireless sensor, portable electronics, and electronic communication devices. In addition, for wireless sensor networks, battery replacement is extremely challenging because of their mote locations of a large number of sensors, resulting in higher maintenance cost [5].

Energy harvesting through sound is one of the most interesting and new topics of discussion in this modern world. The world has many different sources to generate energy but still it is insufficient to power it completely. Also various different types of pollution are grasping this world. Hence, noise being one of the biggest reasons of pollution can be used as a source to generate energy. This might solve the world's ever rising energy crisis. Energy harvesting materials and systems have emerged as prominent research area and continue to grow at rapid pace [7]. The past few decades have witnessed the advancement and intensive utilization of wireless sensors and high technology electronics in human daily life, for instance, cell phone, mobile computers, sensory monitoring system, pacemakers and cardioverter-defibrillator. All these modern technologies stated above had two common characteristics: it needs battery and the battery will be depleted one day. Battery technologies have remained stagnant

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compared to computing and electronics technology where it no longer able to cope with the ever shrinking geometrical constraint and increasing power density requirements. Providing a better battery solution is achievable through new battery composition and design, but even every new battery design could deplete one day, needless to mention the cost and reliability of the new battery technology. Therefore, a more comprehensive and ultimate solution is needed i.e. battery elimination. It is possible by implementing a self-sustaining energy source where the energy originates from the ambient environment through energy harvesting [8, 9, 10, 11].

II. LITERATURE SURVEY

Piezoelectric materials are applied in many autonomous Microsystems devices that designed to convert ambient mechanical energy into useful electrical energy. Most of the designs are based on mechanical resonant device that is targeted to match the vibration spectrum of the source and based on forced, damped harmonic oscillator. A few common configurations for piezoelectric device are cantilever and diaphragm. In fact, there are too many devices available in the literature search and those, which had revelation with acoustic energy harvesting and piezoelectric, will be highlighted here. Acoustic noise is a product from pressure waves, which is a resultant of vibration.

A few examples of acoustic noise are acoustic power and acoustic pressure. Acoustic power is the total amount of sound energy radiated in a time frame and expressed in Watts. Acoustic pressure is a reference of hearing threshold of human ear, which is 20dB. A team of researcher from University of Florida fabricated two devices in millimeters scale and incorporates a Helmholtz resonator. The piezoelectric material used is PZT-based custom fabricated and operated in diaphragm mode. Their resonant frequencies measured are 12.6 kHz and 5.2 kHz. The output is connected to a linear regulator and an AC to DC fly back converter to increase the power transfer from the piezoelectric patch to the storage medium and also allows the circuit impedance to be matched with the impedance of the piezoelectric device. Results showed that the maximum power density harvested was around $0.34 \mu\text{Wcm}^{-2}$ at 149 dB, posting an efficiency of 0.0012% only.

Further investigation shows that the sources of unacceptable low efficiency are PZT material quality, poling capability and residual stress, where if all of the issues are addressed, the output power density would be in the order of $250 \mu\text{Wcm}^{-2}$ and overall efficiency would be 8.8%. Later, the device technology is improvised by adjusting the resonator acoustic impedance and additional degree of freedom added by coupling it to a passive electrical shunt network. Experiment shows that the device able to produce 20-30mW continuous power at 151dB. The device is later incorporated for the development of self-powered, wireless, active acoustic liner system in aero acoustics.

The work is continued by another team of researchers where results show approximately 30mW of output power is harvested for an incident sound pressure level of 160 dB with fly back converter. Such power is suffice whole wide range of low power electronic devices.

Researchers investigated acoustical energy harvesting using piezoelectric curved beams in the cavity of a sonic crystal. The piezoelectric beam is located in the cavity of the sonic crystal. The sonic crystal is used to localize the acoustic wave as the acoustic wave is incident into the sonic crystal at the resonant frequency. Energy harvesting is achieved as the acoustic waves are incident at the resonant frequency. The piezoelectric material used is PVDF. The resonant frequency of the sonic crystal is 4.21 kHz. Using a speaker to generate acoustic pressure, the frequency is matched with the sonic crystal resonant frequency. It is also found out that the acoustic wave is a sinusoidal function of time, which mean external force applied on the PVDF film is harmonic at frequency 4.21 kHz. The maximum measured output voltage and power is 26 mV and 37 nW respectively, both at load resistance of 16 k Ω [11].

III. IMPORTANT TERMINOLOGIES

A. *Piezoelectricity and Piezoelectric Effect*

Piezoelectricity is the electric charge that accumulates in certain solid materials (such as crystals, certain ceramics, and biological matter such as bone, DNA and various proteins) in response to applied mechanical stress. The word piezoelectricity means electricity resulting from pressure. It is derived from the Greek, which means to squeeze or press. Piezoelectricity was discovered in 1880 by French physicists Jacques and Pierre Curie [12].

The piezoelectric effect is understood as the linear electromechanical interaction between the mechanical and the electrical state in crystalline materials with no inversion symmetry. The piezoelectric effect is a reversible process in that materials exhibiting the direct piezoelectric effect (the internal generation of electrical charge resulting from an applied mechanical force) also exhibit the reverse piezoelectric effect (the internal generation of a mechanical strain resulting from an applied electrical field). For example, lead zirconatetitanate 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. The inverse piezoelectric effect is used in production of ultrasonic sound waves [13]. A transducer can be anything which converts one form of energy to another.

Piezoelectric material is one kind of transducers. We squeeze this material or we apply force or pressure on this material it converts it into electric voltage and this voltage is function of the force or pressure applied to it. The material which behaves in such a way is also known as piezoelectric sensor. The electric voltage produced by piezoelectric transducer can be easily measured by voltage measuring instruments, which can be used to measure stresses or forces. The physical quantity like mechanical stress or force cannot be measured directly. Therefore, piezoelectric transducer can be used.

The origin of the piezoelectric effect was, in general, clear from the very beginning. The displacement of ions from their

equilibrium positions caused by a mechanical stress in crystals that lack a centre of symmetry must result in the generation of an electric moment, i.e., in electric polarization as shown in Figure 1. Attempts to calculate the piezo constants of a crystal based on this model were first undertaken by the brothers Curie.

We assume that some crystals have spontaneous polarization. Thus, only some crystals like pyroelectric crystals that have a unique polar axis, along which the spontaneous polarization exists, are considered. A typical PZT plate is shown in Figure 2.

Figure 1: Effects on Piezoelectric Materials.

Figure 2: A Typical PZT Plate

B. Quarter Wavelength Tube Resonator

A resonator used most commonly on air intake systems to reduce resonance. Works over a narrow frequency range, i.e. used to attenuate a specific frequency. The quarter wave tube is open at the end that connects with the air inlet pipe and closed at the other end. The frequency at which the quarter wave tube attenuates is controlled by the length of the quarter wave tube. The maximum attenuation is achieved when the cross-section of the quarter wave tube matches that of the main duct. The quarter wave tube, as per the title, a quarter of a wavelength long. The total distance that the acoustic wave travels is half a wavelength. Therefore, in the time taken for the acoustic wave to travel down the quarter wave tube and back to the main duct the acoustic wave in the main duct has moved along half a wavelength [14]. The fabricated Quarter wavelength tube resonator can be seen in Figure 3.

The fundamental resonant frequency of a quarter wave tube, f_r is given in equation (1).

$$f_r = \frac{c}{4L_b} \quad (1)$$

where

c = speed of sound [ms^{-1}]

L_b = length of side branch [m]

The transmission loss, TL is given in equation (2).

$$TL = 10 \log_{10} \left[1 + \left(\frac{S_b}{2S} \right)^2 \tan^2 \left(\frac{\pi f}{2f_r} \right) \right] \quad (2)$$

where

f = excitation frequency [Hz]

S = cross-sectional area of main duct [m^2]

S_b = cross-sectional area of side branch [m^2]

Figure 3: (a) A Quarter-Wavelength Straight Tube Resonator with one end open and the other end closed. (b) Perspective and (c) front views of the Straight tube Resonator with PZT Piezoelectric Plates Installed.

IV. ARRANGEMENT AND WORKING OF PROPOSED SYSTEM

The proposed system involves certain procedures as shown in figure. The major sub systems involved is Energy harvesting circuit, Rectifiers, Amplifiers, Filtering, Energy Storage and various other low power networks based on applications. It can well substitute various power supplies presently in use. The blocks shown in Figure.4 can be explained as follows.

Energy Harvesting Circuit contains the piezoelectric materials like PZT plates placed orderly in Quarter wavelength tube resonator fabricated for a particular frequency. The resonant frequency is obtained by calculating it manually. The desired frequency so obtained is then practically checked. The input is nothing but the mechanical stress or acoustic noise present in environment. The external sound waves need to be amplified initially if it is not sufficient to drive the circuit.

Figure 4: Block Diagram of Proposed System

The electricity so generated is alternating in nature. Hence it is essential to convert it to direct components using rectifier. Therefore the output of harvester circuit is given to rectifier and then the dc output will be filtered using capacitor.

The energy so produced is stored in any Metal halide batteries or amplified and fed to the systems which require the power.

V. ADVANTAGES

1. With a larger focus on green energy, acoustic energy is one of the vastly available energy sources and so harvesting this energy plays an important role in research.
2. Thus, utilizing environmental energy as an alternative to electrochemical battery, which has a finite lifespan, can be a great advantage to these electronic devices.
3. Harvesting environmental energy, such as solar, thermal, wind flow, water current, and raindrops, has attracted increasing research interest in the field of energy harvesting.
4. Energy harvesting systems based on the transformation of acoustic vibrations into electrical energy are increasingly being used for niche applications due to the reduction in power consumption of modern day electronic systems [17].
5. Acoustic signals seem to be such an alternative ambient energy source.
6. Nowadays, numerous daily life applications related to wireless networks, sensors, low power electronics, biomedical applications etc. demand small amount of electrical power for their operation. These applications are rapidly increasing and bringing to the fore the need for small scale electrical power generation [18].
7. Reduces harmful effects on environment as this is pollution free and can be a best substitute for energy resources. Makes any system self reliant and self sustained for longer duration of time. So that they can be installed in most remote networks.

VI. TWO MAJOR APPLICATIONS

A. Smart Road

We aim at producing a pollution free electricity from the use piezoelectric materials and power generation by thin film MEMS, PZT, PMPG and using them in piezoelectric roads, as

congestion on roads is increasing day by day due attraction of society towards possessing of personal vehicle. Accordingly, present invention is the good method of generating electrical power that does not have any negative effect on environment..

A piezoelectric road that will produce electricity from the stress experienced by the roads due to the movement of automobiles is proposed as illustrated in Figure 5. The main principle behind this is the piezoelectric effect. The energy is produced due to mechanical stress and doesn't require any special input source [15].

For this, the piezoelectric materials that will be set up beneath the road can convert these vibrations into electrical current which isn't less then a magic. The method uses an electrical generation device installed beneath the roadbed.

The electrical generation device includes a pressure plate covered with one or more protection layers which lie beneath the surface of the road. Protection layers are very much important so that the system installed beneath roads will be protected by the excess weight of the vehicles moving over it. In this process, piezoelectric material is embedded beneath the road with the electrical generating device.

Figure 5: Pressure Applied by Wheels on Underlying Piezoelectric Materials

For a road with embedded piezoelectric generators, part of the energy the vehicle expands on roads deformation is transformed into electric energy (via direct piezoelectric effect) instead of being wasted as thermal energy (heat). This electrical generating device includes pressure plates that are covered with protection layer or asphalt as shown in following.

Power generated will be continuous on roads as they will be always equipped with huge number of vehicles on busy roads such as highways and main roads. This is pictorially shown in Figure 6. Power generated from 'Piezo-smart roads' concept is Green power and no harm to the environment. This power can be very well utilized for the street lightning and other small scale purposes. This source of electrical energy is a long term investment having merits of being a continuous source, independent and unaffected by climatic conditions [16]. Its implementation is shown in Figure 7.

Israeli engineers are about to begin testing a stretch of what may become the road of the future. The road contains piezoelectric crystals that produce electricity when squeezed, enabling them to harvest some of the energy which vehicles

lose to the environment during their journeys. As the number of vehicles are increasing day by day all over the world this system can be implemented under the roads which may help in preventing huge loss of energy to environment.

Figure 6: Real Time Application of Smart Road for Traffic Lights

The system is expected to produce up to 400 kilowatts from a 1-kilometre stretch of dual carriageway and the technology is also applicable to airport runways and rail systems. In addition to being able to produce its own power, the system can also deliver real-time data on the weight, frequency and speed of passing vehicles as well as the spacing between vehicles [6].

Figure 7: Smart Road Implemented with Help of Piezoelectric System

B. Self Powered Wireless Keyboards

This system can very efficiently be used in wireless keyboards as shown in Figure 8. Such keyboards then can be self charging which will eliminate the frequent charging requirement of such keyboards. Pressing of various keys produced some amount of mechanical stress, which can be a source for piezoelectric system [16]. Hence use of batteries can be eliminated for frequent charging. Power consumed is typically around 1.5V which can be satisfied by proposed system.

Figure 8: Wireless Keyboard Implemented using Piezoelectric System

VII. VARIOUS OTHER FUTURE SCOPES

The energy generated from concept of piezoelectric effect can be used to satisfy demands various wireless, low power, self reliant systems. This piezoelectric system can be employed under the railway tracks so as when the train passes over it, it will lead to the generation electric power. The power generated by this system will be very large as the force applied by the trains would be very high. This system can be employed under walkway, so whenever people walk on the way it will lead to the generation of power. This can be implemented wherever there is lots of mechanical stress and abundant noise which goes wasted in the environment.

VIII. CONCLUSION

Therefore the proposed system may be best substitute to the existing energy resources and an eco friendly method of energy harvesting which may be implemented in areas where noise energy is produced sufficiently and goes as a waste in the environment. It may help in reducing the ever increasing demands for the power for certain extent. It may be fed to various low power based systems which helps in making them self powered, overcoming drawbacks of batteries.

REFERENCES

- [1] V. Raghunathan, S. Ganeriwal and M. Srivastava, "Emerging techniques for long lived wireless sensor networks", IEEE Communications Magazine, Vol.44, No.4, Pp.108-114, 2006.
- [2] H.A. Sodano, D.J. Inman and G. Park, "Comparison of piezoelectric energy harvesting devices for recharging batteries", Journal of Intelligent Material Systems and Structures, Vol.16, No.10, Pp.799-807, 2005.
- [3] B. Li, J.H. You and Y.J. Kim, "Low frequency acoustic energy harvesting using PZT piezoelectric plates in a straight tube resonator", Smart Materials and Structures, Vol.22, No.5, Pp. 055013, 2013.
- [4] N. Filip, G. Fodor and L. Candale, "ESTIMATION OF ACOUSTIC ENERGY HARVESTED FROM SOUND USING ELECTROMAGNETIC TRANSDUCER", International Conference on Experimental Mechanics, New Trends and Perspectives, Porto, Portugal, Pp. 555, 2012.
- [5] S.A. Putrevu and S.K. Chaladi, "Study on Generation of Electricity using Sound", Current Trends in Technology and Science, Vol.04, No.03, 2015.
- [6] N. AHMED, "MOBILE CHARGER USING PIEZOELECTRIC EFFECT", Doctoral dissertation, University of Mumbai, 2014.
- [7] White Paper: "Zero Power Wireless Sensors Using Energy Processing", WP-72-02 Rev 4.

- [8] S. Sherrit, "The Physical Acoustics of Energy Harvesting", Digital Object Identifier: 10.1109/ULTSYM.2008.0253, pp. 1046-1055, 2008.
- [9] H.F. Hassan, S. Idris, S. Hassan and R.A. Rahim, "Acoustic Energy Harvesting Using Piezoelectric Generator for Low Frequency Sound Waves Energy Conversion", IJET, Vol.5 No.6, Pp. 4702-4708, 2014
- [10] R. Bhat, "Acoustic Energy Harvesting", International Journal of Science and Research (IJSR), 2012.
- [11] K.F. Chen, J.H. Ho and E.H. Yap, "Piezoelectric Approach on Harvesting Acoustic Energy", World Academy of Science, Engineering and Technology, International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering, Vol.9, No.8, Pp.734-740, 2015.
- [12] <https://en.wikipedia.org/wiki/Piezoelectricity>
- [13] <http://www.electrical4u.com/piezoelectrictransducer/>
- [14] http://www.diracdelta.co.uk/science/source/q/u/quarter%20wave%20tube/source.html#.V9zKE_197IU
- [15] A. Abbasi, "Application of Piezoelectric Materials in Smart Roads and MEMS, PMPG Power Generation with Transverse Mode Thin Film PZT", International Journal of Electrical and Computer Engineering (IJECE), Vol.3, No.6, Pp.857-862, 2013.
- [17] P. Kumar, "Piezo-smart roads. International Journal of Enhanced Research in Science Technology and Engineering," Electronics Engineering, Vol.2, No.6, Pp.65-70, 2013.
- [18] G. Park, T. Rosing, M.D. Todd, C.R. Farrar and W. Hodgkiss, "Energy harvesting for structural health monitoring sensor networks", Journal of Infrastructure Systems, Vol.14, No.1, Pp.64-79, 2008.
- [19] S. Sherrit, "The physical acoustics of energy harvesting", In 2008 IEEE Ultrasonics Symposium, Pp.1046-1055, 2008.

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