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Deposition of Energy using Piezoelectric Material and its Application in TPMS

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Abstract: The limited lifespan in portable, remote and implantable devices and the need to recharge or replace batteries periodically has been a consistent issue. Ambient energy can usually be found in the form of thermal energy, vibrational energy and solar energy. Among these energy sources, vibrational energy presents a constant presence in nature and artificial structures. Energy harvesting through piezoelectric materials by extracting power from ambient vibrations is a promising technology. The material is capable to harvest sufficient energy required to make autonomous and self-powered electronic systems. The characteristic of piezoelectric material is electromechanical coupling between electrical and mechanical domains. The design of a piezoelectric device for the purpose of storing the kinetic energy of random vibrations at the wheel of a vehicle is presented. The harvester is optimized to power the Tire Pressure Monitoring System (TPMS). The aim is to make of the value of power and voltage outputs for different input frequency conditions. A typical TPMS system consists of a battery operated one, in this paper bimorph is designed to powering a TPMS commercial feasibility of this option is compared to existing TPMS modules, which require batteries for operation.
Keywords: energy harvesting, tyre pressure monitoring, cantilever beam, Material selection, alternating voltage.

I. INTRODUCTION

The topic of energy harvesting from piezoelectric materials has received attention of many researcher. The energy consumption of sensors have continuously decreased with new developments in efficient circuitry such that ambient energy can be considered as feasible solution in providing power to sensors. Conventionally sensors are dependent on batteries for power. However, the chemicals used in batteries leave negative impact on environment. In many cases the cost of battery replacement become very high in system life span. It is not an easy job to replace batteries easily every time, it may be time consuming. The sensors used in remote locations for data transmission, if this need battery replacement then it is tedious job to access the device. In these situation the most accepted solution is to harvest ambient vibrational energy that may able to power the wireless sensors and periodic replacement of batteries eliminated.

A. Ambient Energy Harvesting

Every mechanical system have vibrations which are not desirable. This vibration reduce the efficiency of the system and sometimes it is dangerous for operator and system both. The waste vibrational energy is significant amount of energy which can be recovered and utilised in useful applications. It has been recognised that piezoelectric material can successfully utilised this waste vibrational energy to useful energy. Different forms of piezoelectric effects on different sets of designed structures have been studied and still attracting researchers to work in this field. With such self-powering capabilities, it can run the device for a very long time without any requirement of maintenance. Piezoelectric energy harvester uses waste vibrational energy as a source for small power production. Hence it is necessary to design a harvester for deterministic natural frequency, so that the harvester will be in resonance with ambient vibration. The environmental conditions are different system are perfectly different from one another. It is the prime reason for the design of different harvesters depending upon their applications. The individual harvester is designed for specific application for particular frequency range. Monitoring tire pressure has proven to be of the utmost importance when considering passenger safety. Correctly regulated tire pressures could save lives and drastically improve tire lifetime. In fact, 9% of traffic accidents occur from erratic tire inflation While low inflation in the range of 0.2 bar leads to a 2% increase in fuel consumption. and reduces tire life by up to 25%. Piezoelectric, electrostatic and electromagnetic transductions are the three most basic conversion mechanisms that are generally used to recover waste vibrational energy to useful electrical energy. The energy density obtained through piezoelectric mechanism is three times as compared to other means [Anton and Sodano, 2007; Priya, 2007 and Chennault et al, 2008]. Cantilever beam is best model for harvesting energy, this is because of two important reason. First reason is that cantilever beams have high flexibility, as the material deform more power production will also rise and the second reason is that this model has low natural frequency.

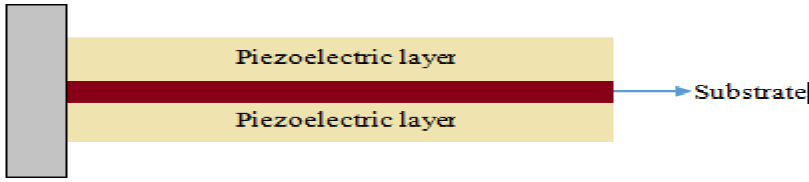


Figure 1.1: A schematic diagram of Piezoelectric Bimorph

B. Scope And Objective

The piezoelectric effect can employed in numerous applications. For example piezoelectric materials embedded in shoe may work as a mobile phone charger in remote area. A vehicle passing along roads and bridges, which have the energy potentials and this can be converted into useful energy. The components of an industry vibrate, that can be utilise to run a sensor smoothly. There are many more ideas that can recover ambient waste vibrational energyinto a useful energy.

II. ENERGY HARVESTING THROUGH BIMORPH CANTILEVER BEAM

A piezoelectric energy harvester is normally a cantilevered beam with few layers of piezoelectric material and few layers of metal. This harvester i.e. bender is located on vibrating host structure. The cantilever beam is free from one end and fixed at another end; so due to host vibration the free end of the bender deflects. The dynamic strain is produced due to this dynamic deflection of the bender, in metallic plate as well as piezoelectric layers. In half cycle of host vibration, the bender deflects in one of normal to the length of bender while for next half cycle of host vibration, the bender deflects in opposite direction from the previous deflection.

For a symmetrical bimorph i.e. a metallic layer is sandwiched between two piezoelectric layers. In first half cycle if the upper piezoelectric layer is in tension then the lower piezoelectric layer will be in compression. And similarly for next half cycle the upper piezoelectric layer is in compression and lower piezoelectric layer will be in tension. This alternation create the alternating voltage, which is main aim of this paper.

A. Uncoupled Distributed Parameter Base Excitation Model

To analyse the coupled mechanical equations and modal analysis. It is necessary to overview the governing equations related to uncoupled distributed parameter base excitation model. Based on the Euler-Bernoulli beam assumptions (neglecting shear deformation and rotary inertia) for a uniform cantilever beam. The following partial equation shows free vibration of the beam.

$$YI\frac{\partial^4 u(x,t)}{\partial x^4} + m\frac{\partial^2 u(x,t)}{\partial t^2} = 0$$

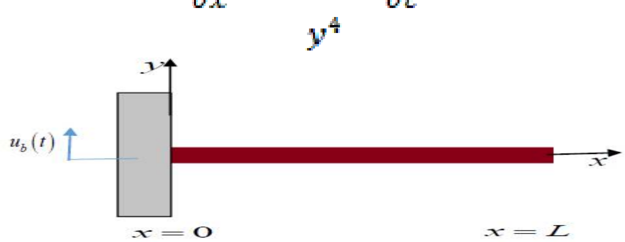


Figure 2.1: Cantilever beam excited by the motion to its base in the transverse direction

III. MATERIAL SELECTION AND DESIGN CONSIDERATIONS

In This section we will discuss about different design specification energy harvester piezo bimorphs having proof mass. The main reason behind attaching proof mass in energy harvester is reduction in natural frequency & also increment in the tip deflection of the bender ,so that we can harvest maximum considerable energy .The purpose of designing biomarph whose natural frequency is same as host structure excitation frequency , here we have to match the natural frequency of biomarph to host structure excitation frequency to at least one mode if 1st mode is unable to match or harvesting purpose .A description is given on [Dutoit et al,2005]

The another design aspect of Piezoelectric Biomarph is expulsion of energy which we can use in wireless sensor systems .Electrical systems can be optimized according toned of various applications . So In this Regard Qualitative & quantative analysis of different piezoelectric materials & substrate is necessary because off some restrictions of space & according to power requirements .

So single piezoelectric module can be applied in every applied in every applications .Normally one piezoelectric module can be applied with one application for certain range of bandwidth of frequency . So in this regard selection of appropriate material & design consideration of biomarph are important.The main aim of this paper is to design the energy harvester to power the tire pressure sensor. For different tires the lateral frequency ranges from 220 rad/s to 650 rad/s. In next chapter energy harvesters for tire 205/60R15 91V and 195/65R15 91T have been designed which have lateral frequencies 515 rad/s and 264 rad/s respectively. For this, MATLAB results are validated with previous researchers [Erturk and Inman, 2009]. The inputs are same as taken by them. Table 4.1 and 4.2 shows geometrical and material parameters taken for inputs.

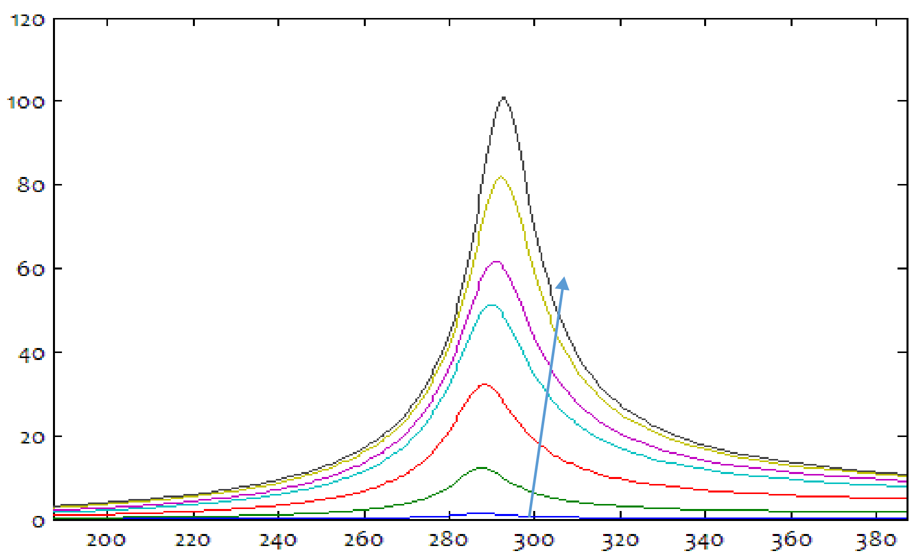
Table 3.1: Geometrical Parameters of bimorph

Geometric Parameters	Piezoelectric (PZT-5A) (mm)	Substrate (Brass) (mm)
Length, L	50.8	50.8
Width, b	31.8	31.8
Thickness, h	0.26	0.14

Table 3.2: Material Parameters of bimorph

Material Parameters	Piezoelectric (PZT-5A)	Substrate (Brass)
Mass density,	7800 kg/m^3	9000 kg/m^3
Young's modulus, Y	66 GPa	105 GPa
Piezo. Constant, d_{31}	-190 pm/V	----
Permittivity, ϵ_{33}	1500 ϵ_0 F/m	----

The voltage output calculated for 1 kΩ, 10 kΩ, 33 kΩ, 70 kΩ, 100 kΩ, 200 kΩ and 470 kΩ of load resistances as shown in figure 4.1. The direction of arrow in the figure shows direction of increment of load resistance.



A. Variation Of Natural Frequency Due To Change Of Mechanical Properties

The energy harvester bimorph is combination of two piezoelectric layers and one metallic substrate sandwiched between these two piezoelectric layers. We design our bimorph compatible to use the surrounding waste vibrational energy. Bimorph design should be such a way that its natural frequency matches with external vibration. The natural frequency of the bimorph depends on the geometric and mechanical properties of the materials.

B. Variation Of Natural Frequency Due To Change Of Substrate

For the PZT-5A ceramic change is substrate; i.e. along with brass, aluminum alloy, zinc alloy, low alloy steel and alumina have been taken to see the effect of substrate on natural frequency. Due to change of substrate, its mechanical properties density, and Young's modulus changes. Different modes of frequency calculated here using.

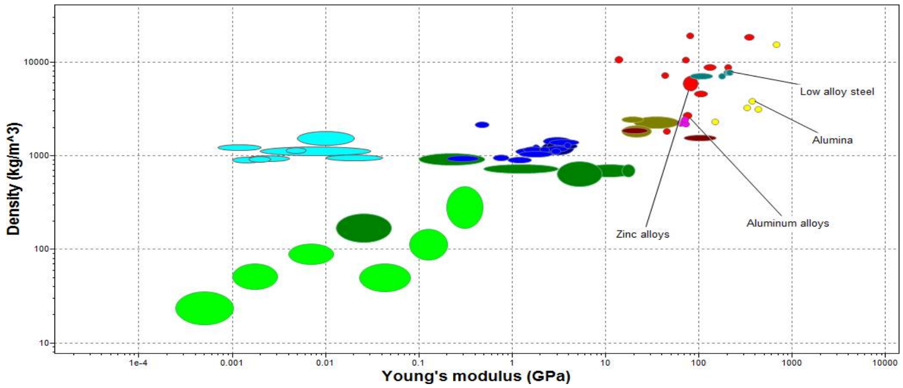


Figure 3.1: Density and Young's modulus of the different substrate (Source: CES EduPack 2016).

Table 4.5: 1st, 2nd and 3rd natural frequency of bimorph due to change of substrate

Substrate Material	Young's Modulus (GPa)	Density (kg/m^3)	1st natural frequency (rad/s)	2nd natural frequency (rad/s)	3rd natural frequency (rad/s)
Alumina	366	3890	529.7	12174.4	39204
Aluminium Alloy	74.7	2690	515.5	12085.5	38927
Low Alloy Steel	211	7850	520.7	11273.1	36271
Zinc Alloy	80.4	5890	514.8	11467.8	36913
Brass	105	9000	515.0	10973.5	35299

IV. TIRE PRESSURE MONITORING SYSTEM

In the present scenario, there are numerous applications of piezoelectricity. The prime motivation for the use of piezoelectricity is to eliminate the use of external power source. The drawback of batteries is that they need periodic replacement when discharged. In many applications replacement of batteries becomes a challenge.

Replacement of batteries is costly and time consuming in TPMS (Tire Pressure Monitoring System). In existing TPMS, Li-Ion battery is used to power the pressure sensor. This module is fixed between rim and tube of the tire. So it is tedious job to remove the module for battery replacement. The piezoelectric energy harvesters are designed for two specific tires (195/65R15 91T and 205/60R15 91V) in this chapter.

A. Need of TPMS

Most of the drivers are not experienced enough to judge whether tire pressure is correct according to specifications or not. On an average, there are ten centimetres thicker air and tire layers between rim and ground. Because of the underinflated tires, there has been significant number of accidents occurring each year. One of the common causes for accidents is failure of tire which is due to lower pressure in tube. Even if lower pressure in tube cannot cause tire failure it can still cause a fatality. In under-inflated tires, the driver does not get good control and also cause to increase stopping distance. The NHTSA (National Highway Traffic Safety Administration) estimates that tire pressure sensor system in vehicles would prevent about 120 fatalities in a year in USA.

B. Challenges in TPS Systems

TPS (Tire Pressure Sensor) systems must be designed to meet following requirements:

1) The pressure sensor must be small enough because it should be fit inside the tire.
2) A small power source to supply power to the sensor.
3) The data from the sensor should be extracted.
4) Extracted data must be displayed to drivers.

C. Design Of TPMS With PZT Bimorph Harvester

The challenge is (i) to know the natural frequency of the tire; actually it can vary very randomly due to change of load, change of speed, change of roads etc., (ii) design the bimorph which has natural frequency near to the natural frequency of the tire, (iii) design of electrical circuit which will supply undisrupted power to the sensor and required voltage to the sensor, (iv)compact and solid casing for the whole TPS.

The previous chapter describes different parameters that affect the natural frequencies of PZT bimorphs. On the basis of these trends, one can choose proper geometrical and mechanical constraints to obtain desired natural frequency. Some authors used a smooth radial 195/65R15 91T tire inflated to 220 kPa [Koizumi et al, 2010] and found that first mode natural frequency of tire as 515 rad/s. Here a PZT bimorph is designed for this natural frequency. The geometric and material parameter chosen for this design is shown in the table below.

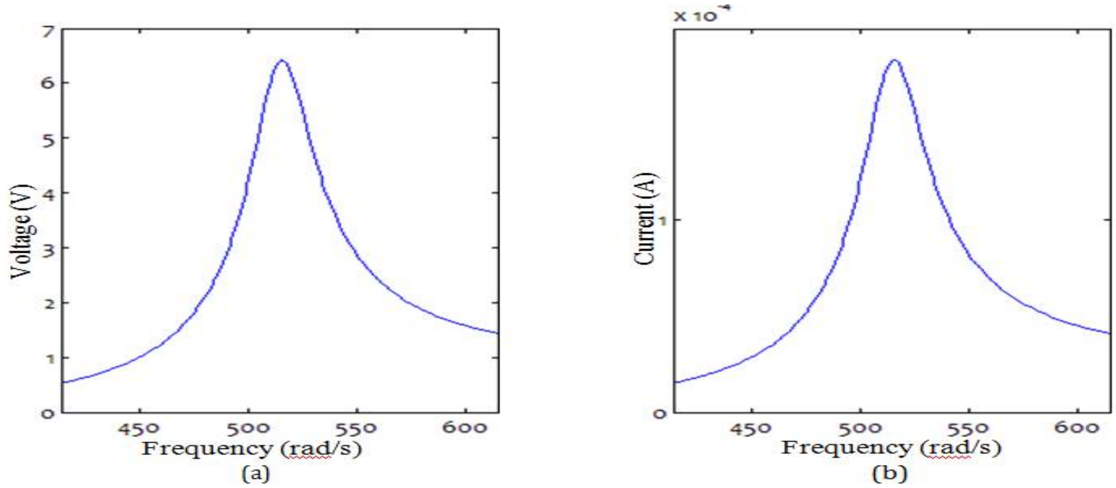


Figure 4.1: (a) Voltage and (b) current of the harvester at first mode of frequency at 35 $k\Omega$ of load resistance for 195/65R15 91T tire

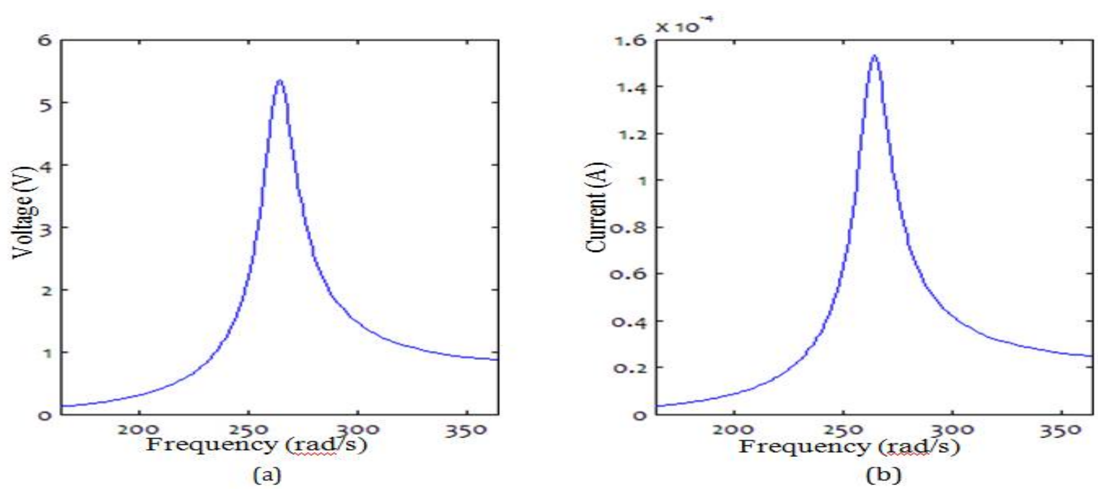


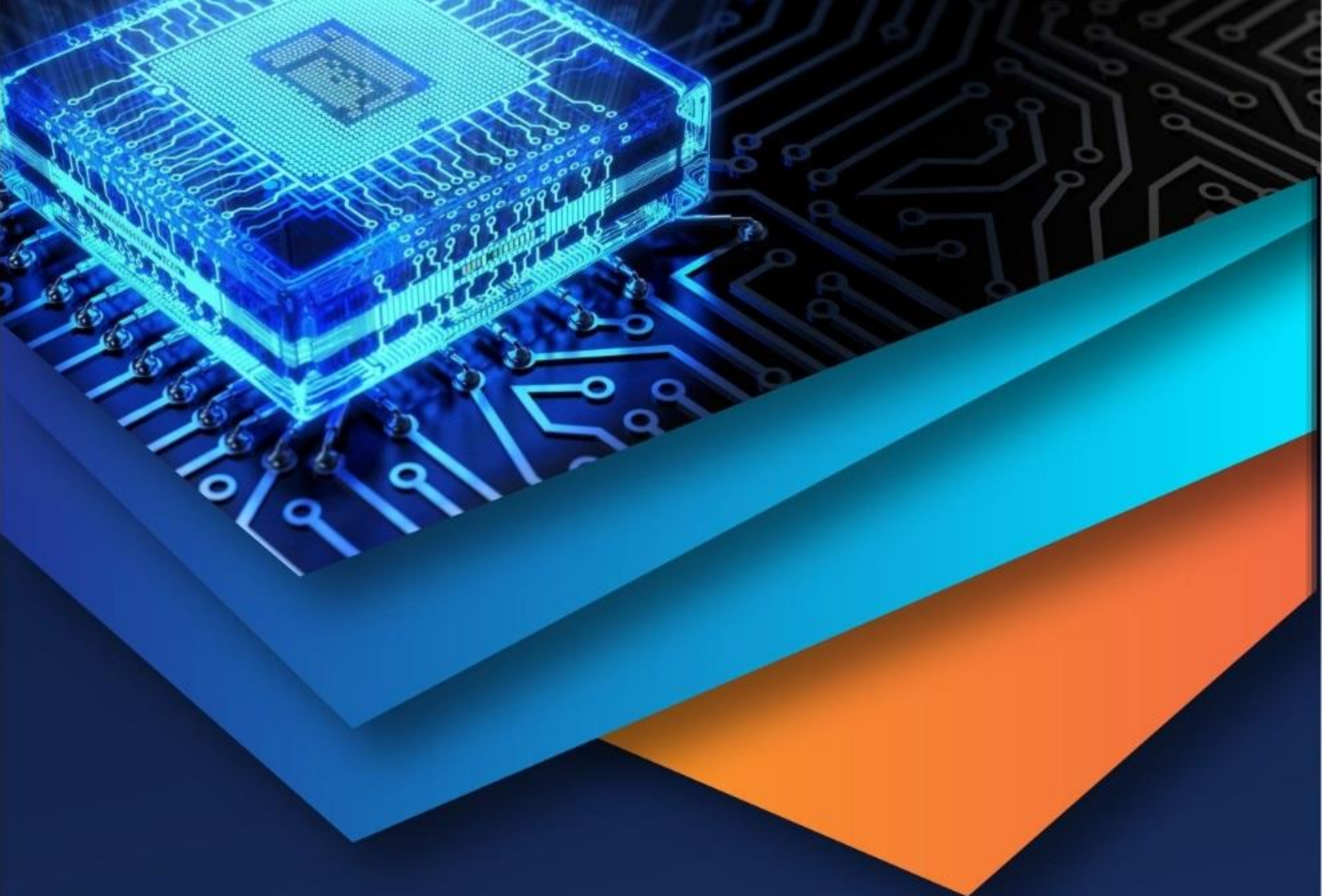
Figure 5.5: (a) Voltage and (b) current of the harvester at first mode of frequency at 35 $k\Omega$ of load resistance for 205/60R15 91V tire

V. CONCLUSIONS

Piezo-technology can harness ambient waste energy to make the system self-sustained and environmentally friendly. The ambient waste energy can be harnessed in a better way if the natural frequency of the designed bender matches with the natural frequency of the source of ambient waste energy. The work of this thesis started with a study of constitutive equations of piezoelectric materials and consequentially their application to mathematical modeling of PZT bimorphs for harnessing the electrical potential to power the sensor. Different geometrical and material parameters of a variety of piezoelectric materials and substrates have been compared in regard to finding desired natural frequency of the bender. Electrical potential for the different resistive loads at designed natural frequency has been compared. Effects of stacking in the thickness direction as well as in width direction on the frequency and electrical potential have been discussed briefly. Lastly, this thesis moves to the application part. Piezo technology is used to harness the tire vibrations, to run the TPMS without any disruption. As the modern technology is moving toward automation, self-sustaining systems, and green energy, piezoelectric materials help a lot to achieve these obstacles.

REFERENCES

[1] Alper Erturk and Denial Inman, (2008), A distributed parameter electromechanical model for cantilevered piezoelectric energy harvesters, Journal of vibration and acoustics, August 2008
[2] Alper Erturk and Denial Inman, (2009), An experimentally validated bimorph cantilever model for piezoelectric energy harvesting from cantilevered beams, Smart Mater. Struct. 18 (2009) 025009 (18pp)
[3] Alper Erturk and Denial J. Inman, Piezoelectric Energy Harvesting, John Wiley & Sons, 2011, ISBN 978-0- 470-68254-8
[4] Arash Sabet and Xavier J. Avula, (2007), Analytical and computational solutions to piezoelectric bending: A comparative study, NSTI-Nanotech 2007, ISBN 1420061844 Vol. 3, 2007
[5] Arthur L. Chait, Solving "The last milli-mile" problem in vehicle safety; The EoPlex approach to powering wireless.Tire Pressure Sensors, President & CEO EoPlex technologies
[6] Hans Pacejka, Tire and Vehicle dynamics, SAE International, Elsevier, 2012,ISBN 978-0-08-097016-5 How tire pressure affects MPG,http://procarmechanics.com/how-tire-pressure-affects-mpg/, 2015
[7] Joe Weisenfelder, Tire Pressure affects stopping distance, fuel economy, http://www.newsday.com/classifieds/cars/tire-pressue-affects-stopping-distance-fuel- economy-1.3760110, 2012



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