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Modelling and Simulation of Piezoelectric Energy Harvester for Electronic Devices

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Abstract: Piezoelectric materials are capable to respond for mechanical stress and generates an electric charge, also responds to electric charge and it will generates mechanical strain both are possible. The power generated from the piezoelectric material is not sufficient to directly supply the electronic devices. To meet the above issue, energy is stored and that energy is used to supply the electronic devices. Generally there are three mechanisms to harvest the energy from the vibration. They are piezoelectric, electrostatic and electromagnetic. Piezoelectric materials have the superior performance for the energy harvesting i.e. it will convert efficiently from mechanical strain to electric charge without any additional power and also simple structure. Here explains the modelling and simulation of piezoelectric energy harvester for lower power rating electronic devices.

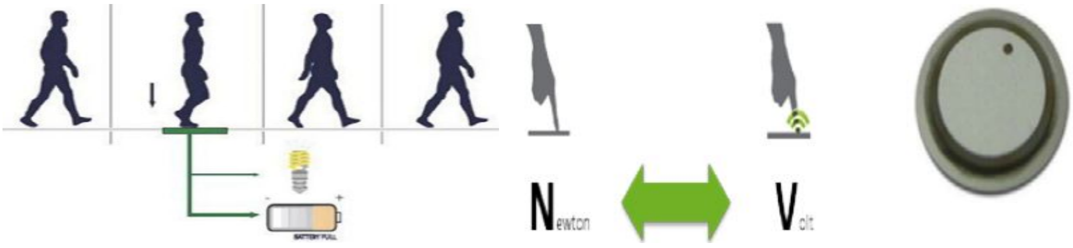
Keywords: Piezoelectric element, piezoelectric transducer, Bridge rectifier, Gate driver.

I. INTRODUCTION

In the recent papers, the improvements in reliability and output, along with the convergence of developments of associated technologies on piezo materials, MEMS etc. have led to an interest in the market for piezoelectric energy harvesting that is spurring further research and commercial opportunities. Commonly occurring vibration sources like industrial drives, generators and systems, air conditioning ducts, engine of an automobile etc. have been the driving forces for vibration based energy harvesting. Vibration-based energy harvesting has been investigated by several researchers for self-powering wireless sensors over the past several years. The ultimate objective is to power low power electronic systems (such as wireless sensors) efficiently by using the vibration energy available in the respective ambient environments. In energy harvesting system maximum power can be extracted if the impedance of the transducer, converter and the load is matched. Impedance mismatch between subsystems causes significant loss of power.This paper addresses simulation of piezotransducer, hysteretic converter simulation. Typically, there will be four subsystems in piezoelectric energy harvesting system, viz. piezoelectric transducer, rectifier, power converter and the load. Piezoelectric transducer converts the vibrational energy into electrical energy which is harvested by the power converter to source the load appropriately. The load may be a continuous or dis-continuous with very low duty cycle.

II. LITERATURE SURVEY

To generate electricity, there are number of methods in that by using piezo material electricity generation also one of the method. Foot step energy generation will be one of the operative method to generate electricity. Walking is the communal activity in human life, whenever person walks, person losses energy to the road surfaces in the form of impact, vibration, sound etc. so if we once walk on the piezo sensor, piezo sensor will converts mechanical energy to the electrical energy that is fed to the filter, filter will eliminates the ripples in AC. The filter output is fed to the bridge rectifier that will converts AC to DC. Output of the rectifier is stored in the battery. So it will be used for AC & DC loads. Generally this type of power generation can be used in the rural areas, where power is not present. Footstep energy harvesting and working of piezoelectric sensors are shown in fig.1 (a) and (b) respectively. The block diagram for the footstep power generation is shown in fig. 2.



(a) (b)

Fig.1 (a) Footstep energy harvesting (b) Working of piezoelectric sensor

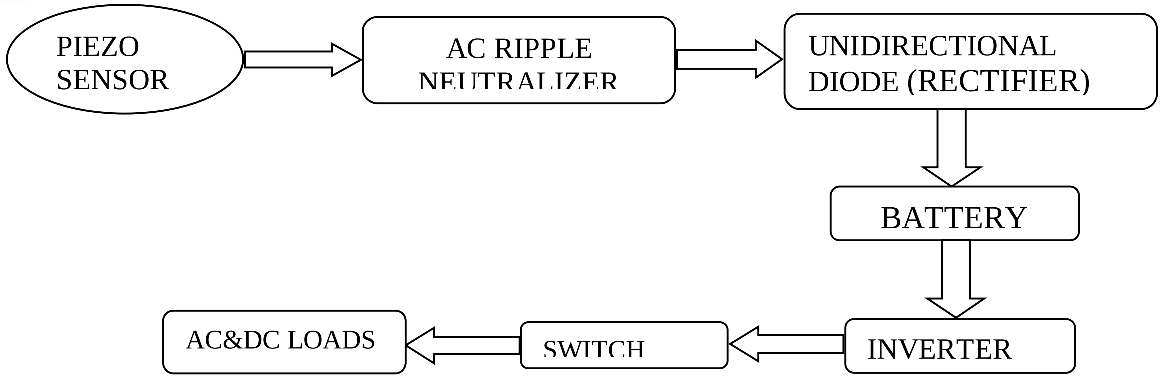


Fig.2 Block Diagram for footstep power generation

In this paper described herein was to develop an approach that maximizes the power transferred from a vibrating piezoelectric sensor to a chargeable battery, initially presents a simple model of a piezoelectric transducer. An AC-DC rectifier is added and the model is used to determine the point of optimal power flow for the piezoelectric element and then introduces an adaptive approach to achieving the optimal power flow through the use of a switch-mode dc–dc converter.

The power generated from piezoelectric transducer is estimated and checked the possibility of storage device to store the power that is generated from the PZT. Once if the power storage meets the required specifications than that power will be used for the electronic applications. The table.1 shows the literature review i.e. it explains the amount of power generated by using different software tools, or different piezoelectric materials used and also with different load resistance.

Table.1 Energy harvesting comparison

Author	Power generated	Natural frequency	Load resistance	Software or Piezo used
Shashikiran 2015	10mW	23HZ	191KΩ	LTspice
AndrezaTangerinoMineto 2010	2.6mW	13.4 Hz	149kΩ	PZT-PIC 255
Shun-Chiu Lin and Wen-Jong Wu - 2013	200.28μW 241.60μW	112.4Hz 104.4Hz	100kΩ 150kΩ	HCQ9-type PZT
Salem Saadon 2011	10pW	-	1GΩ	ANSYS11 and Coventorwar 2008
Wahied G. Ali 2012	2380μW	94Hz	50kΩ	Volture V21BL
Geffrey K. Ottman 2002	18mW	53.8Hz	24kΩ	QP20W
Ahmed Telba 2012	12 voltage	120Hz	-	-
Wahied G. Ali 2012	250μW	18Hz	50kΩ	Micro Fiber Composite material M-8528-P2
Keyur B Joshi and Shashank 2013	318μW	-	100kΩ	PZT-5H
Luigi Pinnab 2009	380μW	120Hz	120kΩ	PSpice PZT-5H
Kuok H.Mak 2011	0.129 V	157Hz	8kΩ	PSI-5A4E

III.PROPOSED METHODOLOGY AND DISCUSSIONS

A. Transducer impedance modelling

If the piezoelectric material is not stressed or at the rest, the dipoles formed by the positive and negative ions will be cancel each other due to the symmetry of the crystal structure, and an electric field is not observed at that moment. When it is stressed, the crystal deforms, symmetry is lost, and a net dipole moment is formed. This dipole moment will form an electric field across the crystal. So, the materials generated electric charge will proportional to the stress applied. If a reciprocating force is applied, an AC voltage is seen across the terminals of the device. The Relation between applied force and the resultant response will depends on piezoelectric properties of the size and shape of the piezoelectric device, and the direction of the mechanical excitation and the piezoelectric material (ceramic etc.).

Piezoelectric transducers can be modelled as a voltage source with a series capacitor and resistor or as a charge source with a shunt capacitor and resistor. These models are shown in Fig. 3. The charge produced will depends on piezoelectric constant of the device. The capacitance is determined by the area, the width, and the dielectric constant of the material. The resistance of piezoelectric transducer accounts for the dissipation of static charges/losses.

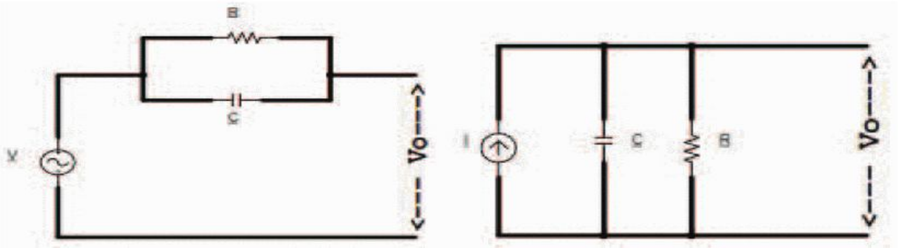


Fig.3 Piezo element - voltage source model (left). Piezo element - current source model (right).

The open circuit voltage of the piezoelectric ceramic is proportional to the applied mechanical stress. Under the given atmospheric conditions mechanical stress due to bending is given by

$\sigma_{max}=K\rho C V_{n,max}$ (1)

Values for constant K or typical solid and rectangular cross-sections are 2 and √3 respectively. V_n is the natural velocity of the beam, ρ is piezo element mass per volume and C is the wave speed in material.

The applied force F=σA, here A is area of the transducer. The relationship between Electric Potential and Electric Field is given by

$E = -\frac{\partial V}{\partial x}$ (2)

The voltage constant which is given as follows

$V = E.t = -g\sigma t = \frac{-gFt}{A}$ (3)

Here, E is the electric field, g is the piezo voltage coefficient and t is the ceramic thickness, given as:

$g = \frac{d}{\varepsilon_0 \varepsilon^x}$ (4)

Where, ϵ is the dielectric constant and d is the charge coefficient.

The voltage coefficients are related to the charge coefficients by the dielectric constant of the piezo capacitor, the voltage V is related to the charge Q by the capacitance C.

$D = \frac{Q}{A} = \frac{V.\varepsilon_0 \varepsilon^x}{t}$ (5)

$\frac{Q}{V} = \frac{\varepsilon_0 \varepsilon^x}{t} = C$ (6)

Where, C is the capacitance of the material. The above relation shows that low frequency piezoelectric plate behaves as a parallel plate capacitor.

The impedance of the piezoelectric energy source is given in terms of the capacitance and the vibration frequency of the PZT element as:

$Z = \frac{R}{1+j2\pi fRC}$ (7)

Resistor R value depends on the resistivity of the piezoelectric ceramic used in transducer and the dimension of the transducer.

$R = \rho\frac{l}{A}$ (8)

Where ρ is the resistivity of the ceramic material, A is the area of the transducer and l is the length of the transducer. The above equations have been used to derive the voltage/current source model and impedance of piezoelement for simulation of the system.

IV. SIMULATION RESULTS

Piezoelectric energy harvesting circuit was modelled with various sub circuits viz., piezoelectric transducer, AC to DC convertor (bridge rectifier), hysteretic buck convertor, high side gate driver, and the load as shown in Fig. 2.

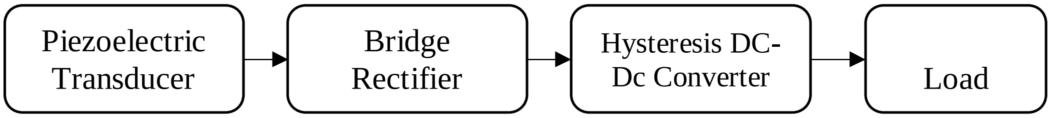


Fig.4 Piezoelectric harvester using hysteretic converter

Fig. 4 shows the piezoelectric energy harvester circuit used for simulation. The choice of input capacitor for the hysteresis convertor is based on the energy consumed by the load ($P_{load}*T_{load}$). With the required load voltage, the peak and average current consumed by the load influences $P_{load.}$ The energy loss in the capacitor during energy transfer to the load has to be replenished periodically from the harvesting source (energy gain or charging of capacitor). The charging of the capacitor is influenced by the ESR of the capacitor. The ability of replenishing the energy in the capacitor from the harvested energy periodically helps to derive the possible interval between the peak current consumption by the load.

$$Discharge\ time\ t_{dis} = (ESR + R_{load})C_{IN} \times l\,n\frac{V_{in}}{V_{min}} \qquad (9)$$

Where, is the minimum voltage that the convertor requires to operate and the charge is transferred from the input capacitor to the output capacitor during is the load resistance i.e., $V_{0/}$ I_{load}.

A. *Charging Time*

$$t_{charge} = (ESR + R_{source})C_{IN} \times l\,n\left(\frac{V_{in}-V_{min}}{0.2V_{in}}\right) \qquad (10)$$

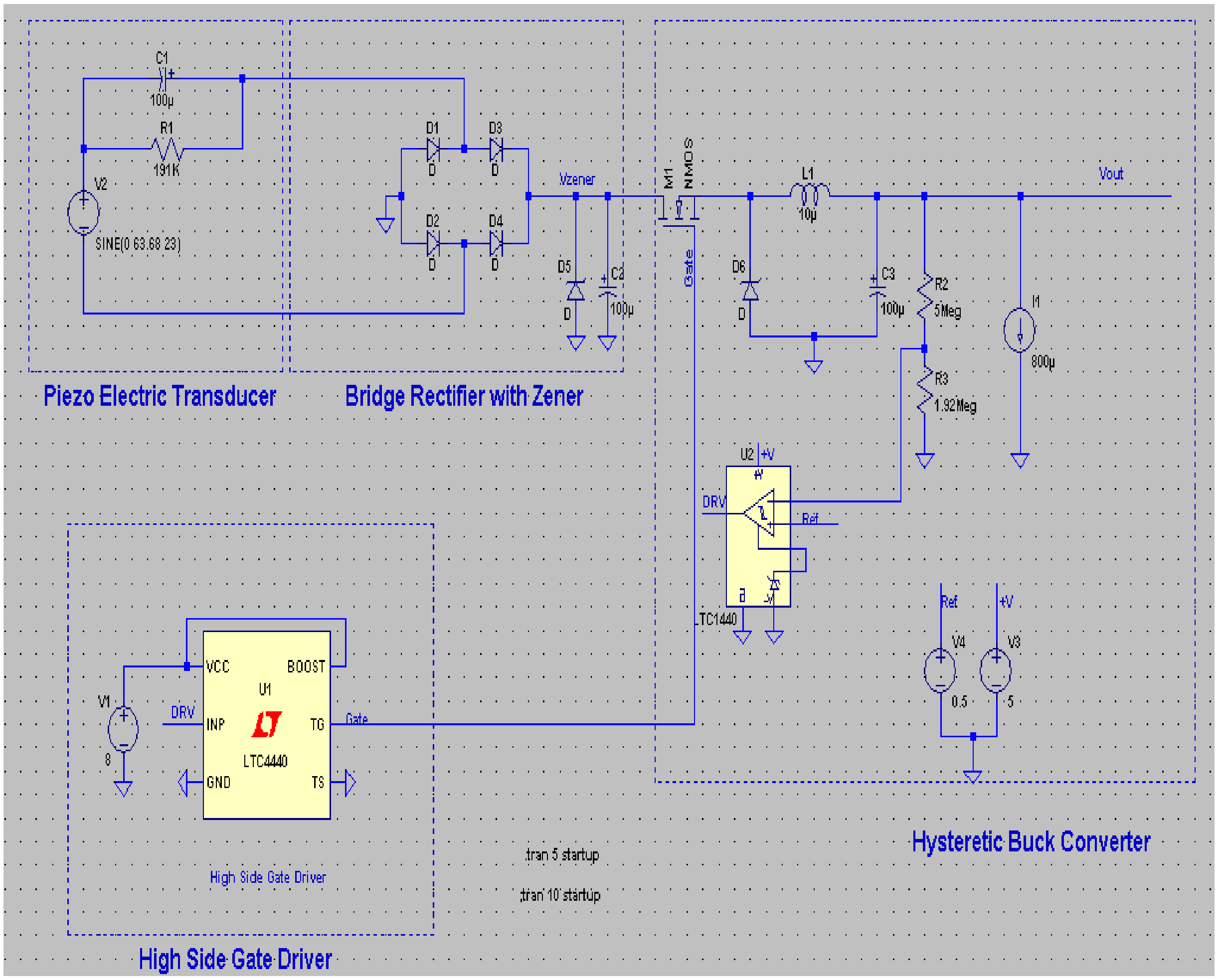
The duration between two peak load intervals should be more than the sum of charging and discharging time. Besides the energy required during sleep mode / non-active state also need to be fulfilled from the harvested energy.

The energy equation enables choice of input capacitor as,

$$P_{load}t_{load} = \frac{1}{2}C_{IN}\eta\left({V_{in}}^2 - {V_{min}}^2\right) \qquad (11)$$

Where, C_{in} is the input capacitor and η is the efficiency of the converter. V_{in} is the voltage at which the convertor begins to switch. The selection of output capacitor is based on the regulator sleep time and the load current requirement. 24mV is peak-to-peak hysteresis window.

$$t_{sleep} = C_{out}\left(\frac{24mv}{Iload}\right) \qquad (12)$$



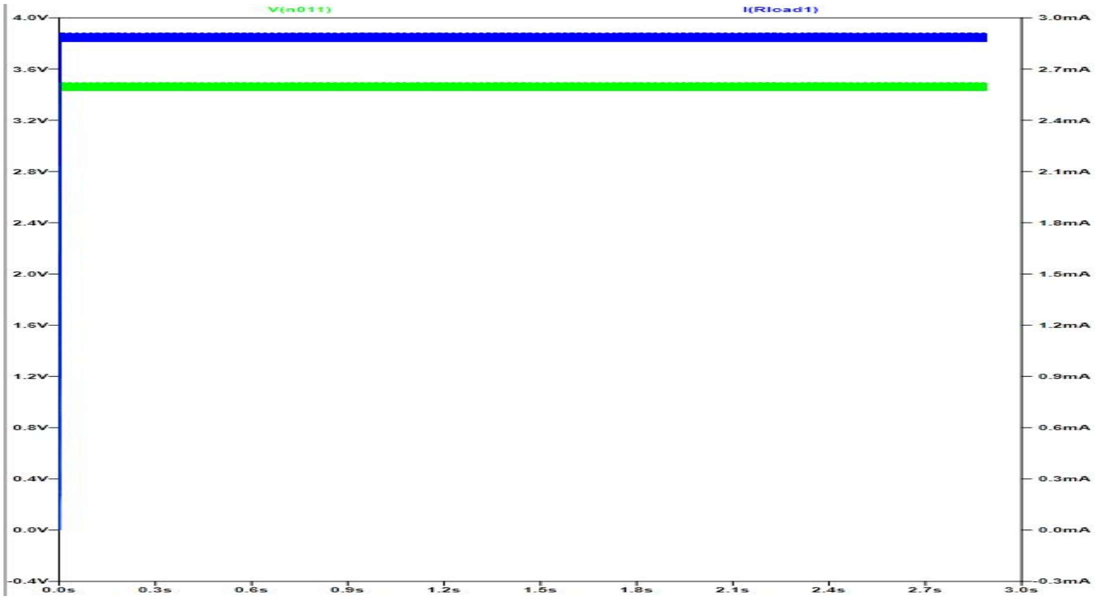


Fig.6 Piezoelectric energy harvester with continuous load current of 3ma and voltage is constant at 3.3V

V. CONCLUSIONS

This paper presents the simulation of piezoelectric energy harvester for lower power electronic systems by using LTSpice simulation tool. This will generates lower power ratings. That will be used only for lower power electronic applications and also now a day's scientists are trying to use these in space sector. Piezoelectric energy is the one of the most efficient mechanism to convert from mechanical stress to electric charge and vice versa.

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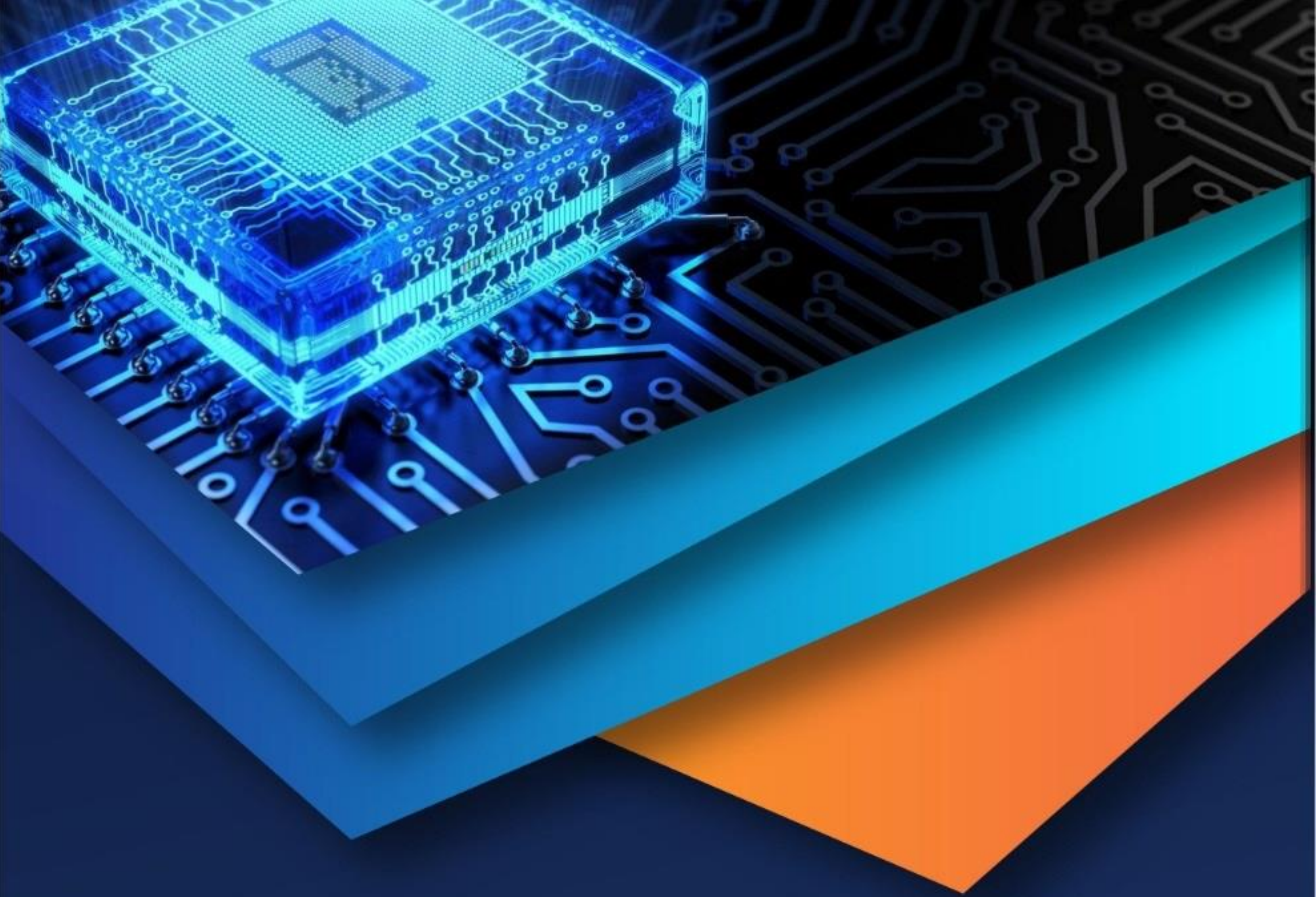

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