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Industrial Waste Heat Management: A study of Thermoelectric Module

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Abstract: In today's world Heat Energy is the main issue and concern for all living and non-living organisms. Heating of electronics devices is of major concern. Also, heating of any surface could lead to a better advantage sometimes and may also be not of a bad impact otherwise. The heat trapping, heat extraction and other such criteria are taken into consideration and worked upon in today's fast moving technology. This paper presents a study of heat extraction from various parts of a normal day to day routine of human beings. Also the paper focuses on waste heat management in larger industries and how a Thermoelectric Power generating module (TEG) could work. The devices used here are TEG which extract heat and convert to an equivalent voltage. Thus more the amount of heat larger will be the voltage gained. This could other way be very useful and one of the efficient ways in Waste Heat Management (WHM) systems.
Keywords: Thermoelectric modules (TEM), Electronic Devices, Heat Energy, waste heat management systems.

I. INTRODUCTION

Heat is a natural phenomenon. Heat energy is the result of the movement of tiny particles called atoms, molecules or ions in solids, liquids and gases. In thermodynamics, heat means energy which is moved between two things when one of them is hotter than the other.[1] The heat that is produced and the one that is given out is basically of two different concepts. Producing heat sometimes is of great advantage and sometimes a disadvantage too. Heat means a temperature or a temperature difference between two surfaces.
This temperature difference could be extracted and given out to produce and equivalent voltage to be used in power concepts. The waste heat management system is the one that uses waste heat and converts it into a specified reusable energy. This concepts are mainly found in huge industries. Earlier heat was sent back via exhaust fans to the air where it followed the normal natural cycle. Until later it was studied that the same wasted heat could be trapped and used for some more and other different concepts in the industries. [2],[3] Thermoelectric energy harvesting is one of the interesting and fast growing technology in today's scenario. Like piezoelectric, thermoelectric modules extract a temperature difference [8] and give out an equivalent voltage that can be used in varied applications. Doing this the size, the types, and the cost of such modules should also be taken into consideration. Many discussions of how heat is produced in solids, in liquids, and in gases is of a great interest. Thus heat energy is a never ending and interesting concept as far as the electronics technology is considered.

II. WASTE HEAT MANAGEMENT

Many industries uses this concept since most of the heat production and heat dissipation happens in such huge industries that work with huge machineries. The old practised methods of using Chimneys were then replaced with large exhaust fans that dissipated the heat out from the industries which is even today a critical issue in many such industries.
Waste Heat management in many industries can be done by waste Heat recovery units are mainly used in cogeneration or also called as combined heat and power. Waste Heat management can be done in a domestic [4] or on a large sale purpose. The above discussed are the industrial criteria of managing a wasted heat energy. Further discussing about the domestic concepts. Many electronics devices like Televisions, mobile phones, laptops, refrigerators, grinders, electric gas stoves generate heat. Though they have tiny exhaust fans , the heat is actually felt by human beings. How about using the waste heat management concept here?. Yes, doing this would pay a par excellence and advantage in the field of electronics engineering.

III.DOMESTIC AND INDUSTRIAL HEAT

As mentioned above, the electronic devices specially like laptops, refrigerators, electric gas stoves many more give out large amount of heat which goes wasted. This wasted heat could be trapped my modules like TEGs and this wasted energy could be converted into a useful form or generally electricity. Also electronic devices that use batteries specially laptops could be used to extract heat and charge their own batteries. Doing this would increase the lifetime of a device battery and the device would work for a longer time.

A. Heat from laptop

An experiment was done on extraction of a laptop heat and checked for an equivalent voltage output. A laptop was continuously used and the heat at two surfaces (above and near the exhaust fan) was calculated. The thermoelectric module placed on top of the laptop with one side hot (laptop heat) and other side ambient air gave an input voltage of 0.02V and when placed under the laptop gave around 0.2V-0.5V respectively. Thus more the amount of heat the more will be the voltage output.

B. Heat from Mobile Phones.

Though mobile phones today come with great features , [5] most of the manufacturers fail to maintain their heating capacity low as a result of which many users stop using the respective mobile phones. An equivalent voltage measurement was done using a teg module simply placed on the backside of the mobile phone that gave an output voltage of 0.01V -0.02V maximum. Thus it can be concluded that domestic devices can be also be very useful in waste heat recovery concepts.

The industries everyday give out large amount of waste energy; some through waterways, some through air, through heat etc. The water management systems are also in to practise but at limited possibilities. The air or the gases given out are through chimneys which cannot be controlled but can be stopped by a greenhouse storage management. The third one being the most common one is the heat that dissipates through exhaust fans in many large and small industries. This heat given out can be trapped and extracted and can be used to charge various industrials contents.

As we know there are industries that use heavy machineries , big boilers, large manufacturing and design units that give away large amount of heat. Also the same industries can have their other functioning units where a large amount of domestic electronics like computers and thus large batteries in storage. The heat that is dissipated can be collected by the thermoelectric generators and give away a sufficient voltage and current that can charge this huge series of batteries.

Doing this would increase the domestic electronics usability and also the could save the wasted energy.

IV. PROPOSED METHOD

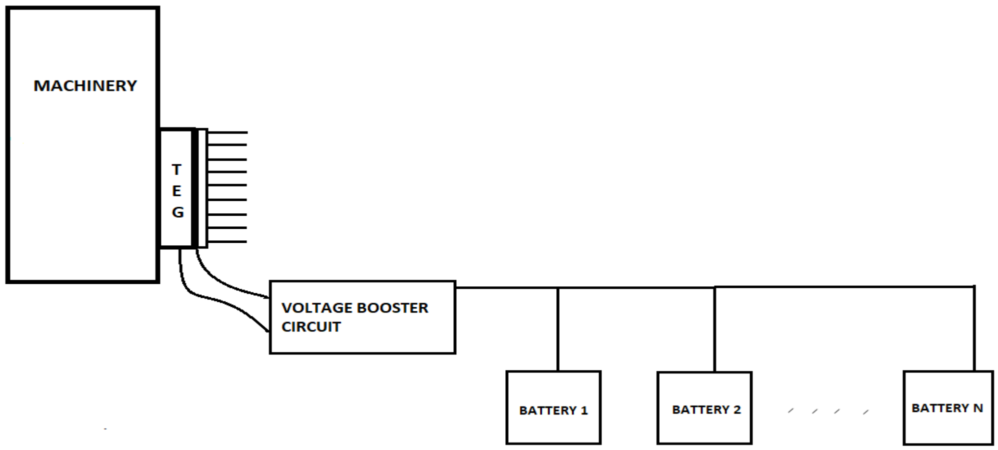

Fig. 1 Block diagram of the proposed method

From the block diagram; a TEG is shown attached to a machinery. One side of the TEG is the hot furnace heat and the other side connected is a heat sink. Heat sink is a device that absorbs waste heat. Heat sink can also be in substance form like that of pastes. The moment at which TEG senses a temperature difference it will produce a large amount of Voltage which could be either fed directly to the batteries or if low then fed through a booster circuit’s boosted voltage. This voltage can thus charge a large number of batteries concatenated in large industries

V. THERMOELECTRIC POWER GENERATING MODULES

The thermoelectric power generating modules work on the Seebeck Effect and Peltier effect. The Seebeck and Peltier effects are different manifestations of the same physical process. Both these effects are a phenomenon in which a temperature difference between two dissimilar electrical conductors or semiconductors produces a voltage difference between the two substances; though the only difference is that the Seebeck effect is the conversion of heat directly into electricity and the Peltier effect is the presence of heating or cooling at an electrified junction thus both working at an electrified junction of two different conductors or wires respectively.

The thermoelectric generator converts heat into electricity using Seebeck Effect. The Seebeck effect is a phenomenon in which a temperature difference between two dissimilar electrical conductors or semiconductors produces a voltage difference between the two substances. The generator works at 330 ˚C (626 ˚F) heat source continuously and up to 400 ˚C (752 ˚F) intermittently. Many modules have been designed to work even at 800-900 ˚C like that of big boilers in industries.

A. Selection of different Teg Modules

Modules are available on the basis of their current, voltage readings and physical parameters like length width and height.

Functioning of such modules depends on the number of thermocouples present in them. The more number of thermocouples, the more efficient is the module. But only disadvantage to be considered is its size that will increase respectively with the number of thermocouples. Size matters will only be of major concern when mini electronics comes into picture.

Thus a varied range of minimum and maximum are in the range of 0.8A to 30A for current, 0.5V to 48v for voltage, 3.4mm to 400mm for length, 3.25mm to 180mm for width, 0.095mm to 160mm for height respectively. [mouser]

B. Working of TEG

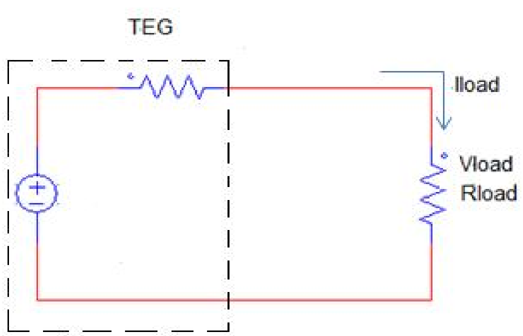

Fig. 2 Circuit equivalent of a TEG

The reason of varied output voltages and currents lies in the environmental criteria or as said the differential temperature (ΔT) which is of utmost importance when energy scavenging concepts are discussed. The differential temperature is thus given by

$$\Delta T = T_H - T_C \quad (1)$$

Where TH and TC are the Hot Side and Cold Side temperatures respectively [9]. Another experiment that was done to clarify the above concept. The Hot Side Temperature TH was taken as 50^{o}C and the Cold Side temperature Tc was taken as 25 ^{o}c (room temperature). The output voltage measured was 120mV and thus the output power calculated using the equation

$$P = V^2/R \quad (2)$$

Thermoelectric power generation requires 3 major pieces of technology: thermoelectric materials, thermoelectric modules and systems & interface with the heat source. Thus there are many materials used in the making of such modules. These materials have high electrical conductivity and low thermal conductivity [10],[11]. Only semiconductor known to have low thermal conductivity & high power factor are bismuth telluride, lead telluride and silicon germanium. The table I shows the comparison of all above mentioned materials.

TABLE I

COMPARISON OF MATERIALS USED IN TEG MODULES

Name	Bismuth Telluride	Lead Telluride	Silicon Germanium
Chemical Formula	Bi2Te3	PbTe	SiGe
Figure of Merit	1	.8 - 1	2.47 – 4.7
Molecular Weight	800.76	334.8	100.72
Electron Mobility	1140 cm2/Vs	1600 cm2/Vs	~ 4400 cm2/Vs
Hole Mobility	680 cm2/Vs	600cm2/Vs	~ 870cm2/Vs

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TABLE III
SPECIFICATIONS OF DIFFERENT TEG MODULES

Part no.	Length (mm)	Width (mm)	Current (A)	Voltage (V)
CP39255074H-2	26.25 mm	50 mm	3.9 A	12.8 V
CP502550665-2	26.25 mm	50 mm	5 A	12.8 V
CP60404567H-2	41.25 mm	45 mm	6 A	14.2 V
CP68475H-2	40 mm	40 mm	6.8 A	16 V
SDA-195-24-22-00	300 mm	150 mm	6.9 A	24 V

The table II gives the specification of different Thermoelectric Power Generating modules available. Some good and efficient modules were selected and tabled. The first 4 modules are from CUI Inc. Distributors with a cost in the range of 21USD- 50USD. The last module is from Laird Technologies. The comparison is based on the amount of voltage required. Thus it be specified that the larger the value of voltages and current the large efficiency of any proposed application.

C. Simulation of TEG

The following simulations are done using Liard Technology's AZTEC Evaluation Simulator. Figure 1 shows the general area where thermal conditions, and other requirements are to be , the centre of the area shows the equivalent circuit of a TEG with desirable component values. The Display options has a variety of graphs mentioned some of which are shown below. Such software are used in the industrial and manufacturing units of TEGs, to select a specific TEG by their own mentioned part numbers.

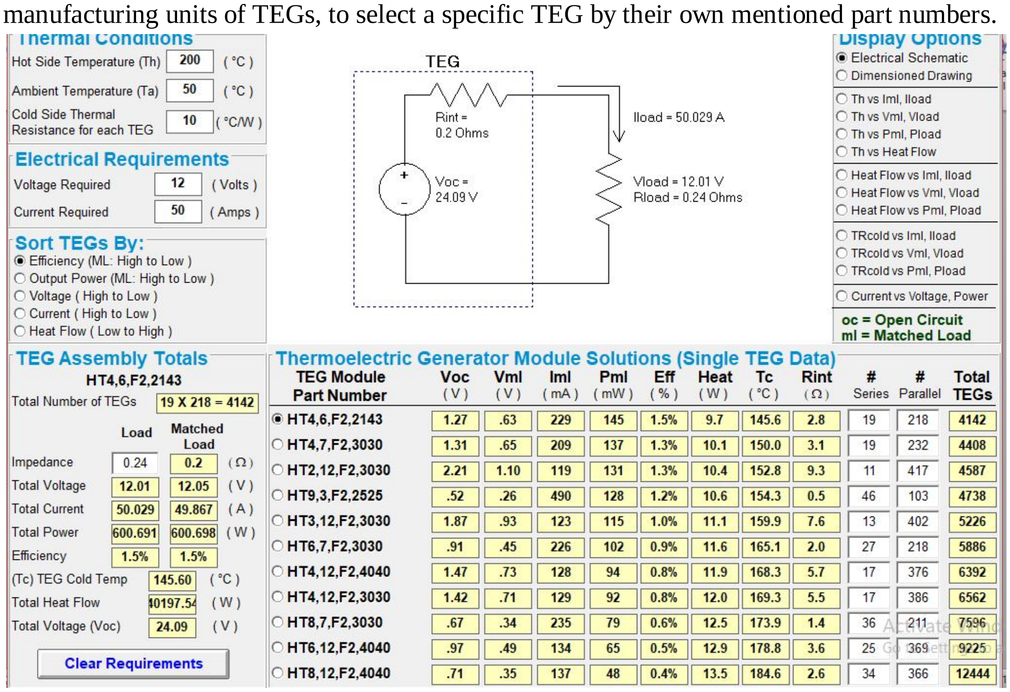

Fig. 3 Requirements of number of TEGs with equivalent circuit

From figure 1 it can be seen that a thermal (hot) temperature of 200°C can produce a 12V using 4142 number of TEGs of size approximately 40mm*4mm*22mm.. The module highlighted is a HT4,6,F2,2143 and has an efficiency of 1.5%. The rest resultant values can be seen in the respective figure. If 200°C is taken into consideration the the heat flow versus voltage produced and heat flow versus current produced is shown in figure 2 and figure 3 respectively.

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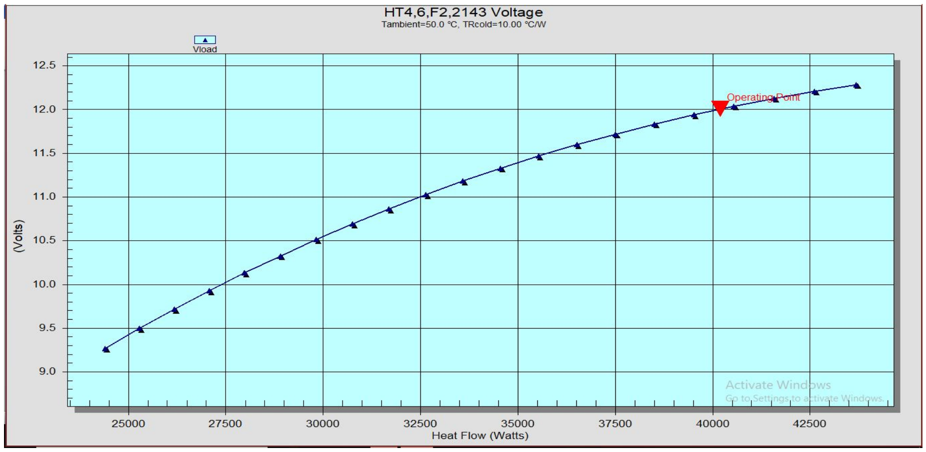

Fig. 4 Graph of Heat Flow versus Voltage produced at the load

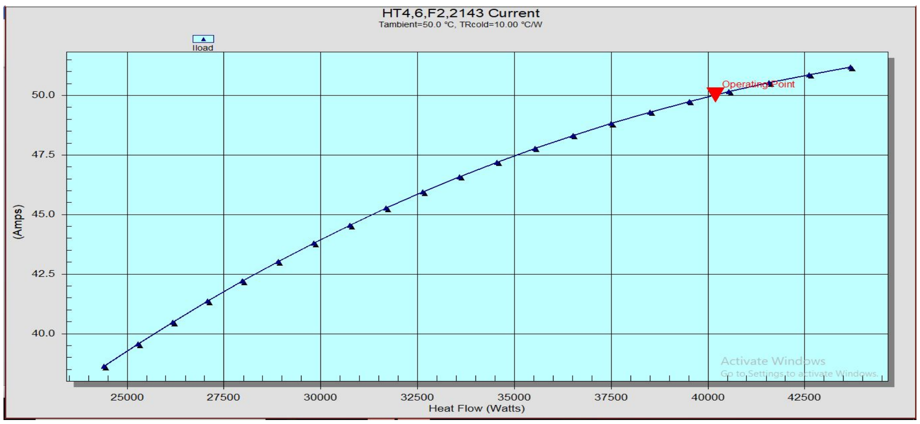

Fig. 5 Graph of Heat Flow versus Current produced at the load

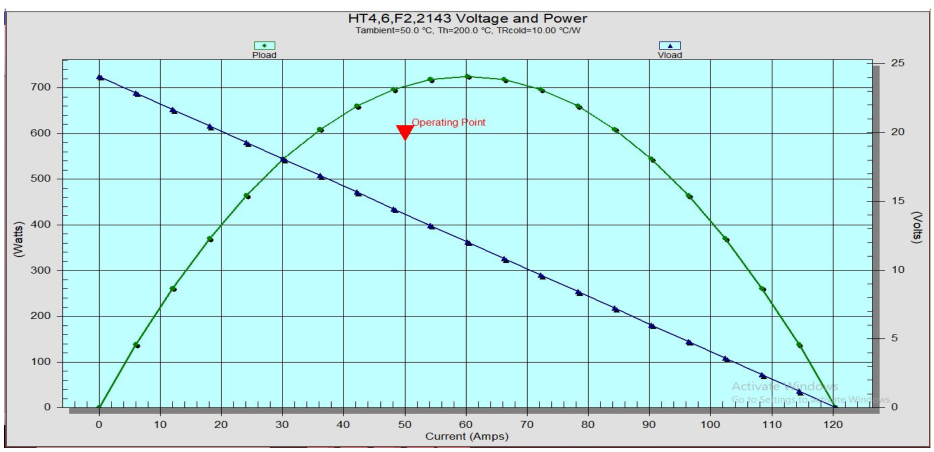

Fig. 6 Graph of Current versus voltage and Power

Figure 4 represents the graph of Heat Flow versus the Voltage produced. The Heat flow is measured in Watts. It is desirable that for a 12V output voltage a minimum of 40000Watts of heat flow should happen. In figure 5 a 40000Watts of heat flow can produce a 50A current which is sufficient to charge up large 12V batteries. The final figure 6 shows represents the Current, Voltage and Power graph. Thus it can be concluded that at a peak voltage of ~ 22.6V a 60A current can be produced with a power of 700Watts.

The simulation of TEG module was done using AZTEC software. The figure 4 describes that at 20 Volts desired output a 50Amp of current will be produced with a power of 600Watts which is enough to charge a 12V battery. Though the simulation results don't give tan accurate measurement on using the number of TEGs, a series combination of TEGs can be used which would be enough to charge up large 12V batteries in Industries.

VI. DISCUSSION

The proposed idea can work in an efficient way if implemented in real time scenario. A number of series connected TEGs can be replaced with a TEG case or a kit that has a sufficient number of TEGs connected internally and electrically in series and thermally in parallel. Only two point i.e the negative and the positive can be kept. One side (hot side) of the TEG can be fixed to the machinery and other can be exposed using a heat sink. The output from the TEGs if is low then a booster circuit could be used to increase the voltage and thus fed the current to the battery. This can work also with a large number if series connected batteries in Industries.

VII. CONCLUSION

Waste heat management is a trending concept in today's discussions. Various ideas and conclusions and implementation have been made with regards to saving a largely wasted heat. Also heat energy concept could be widely used in many domestic and specially in many industrial purposes. taking the help of waste heat management systems a large amount of heat can be extracted and converted to electricity like that of solar energy conversion into electricity. Also the Thermoelectric power generating TEG modules can be used variously and in variety of ways. A sufficient number of TEGs can be concatenated like that of solar panels to trap, extract and convert one form of energy into another. Thus with a fast pacing technology of solar energy, this renewable energy could work at par excellence.

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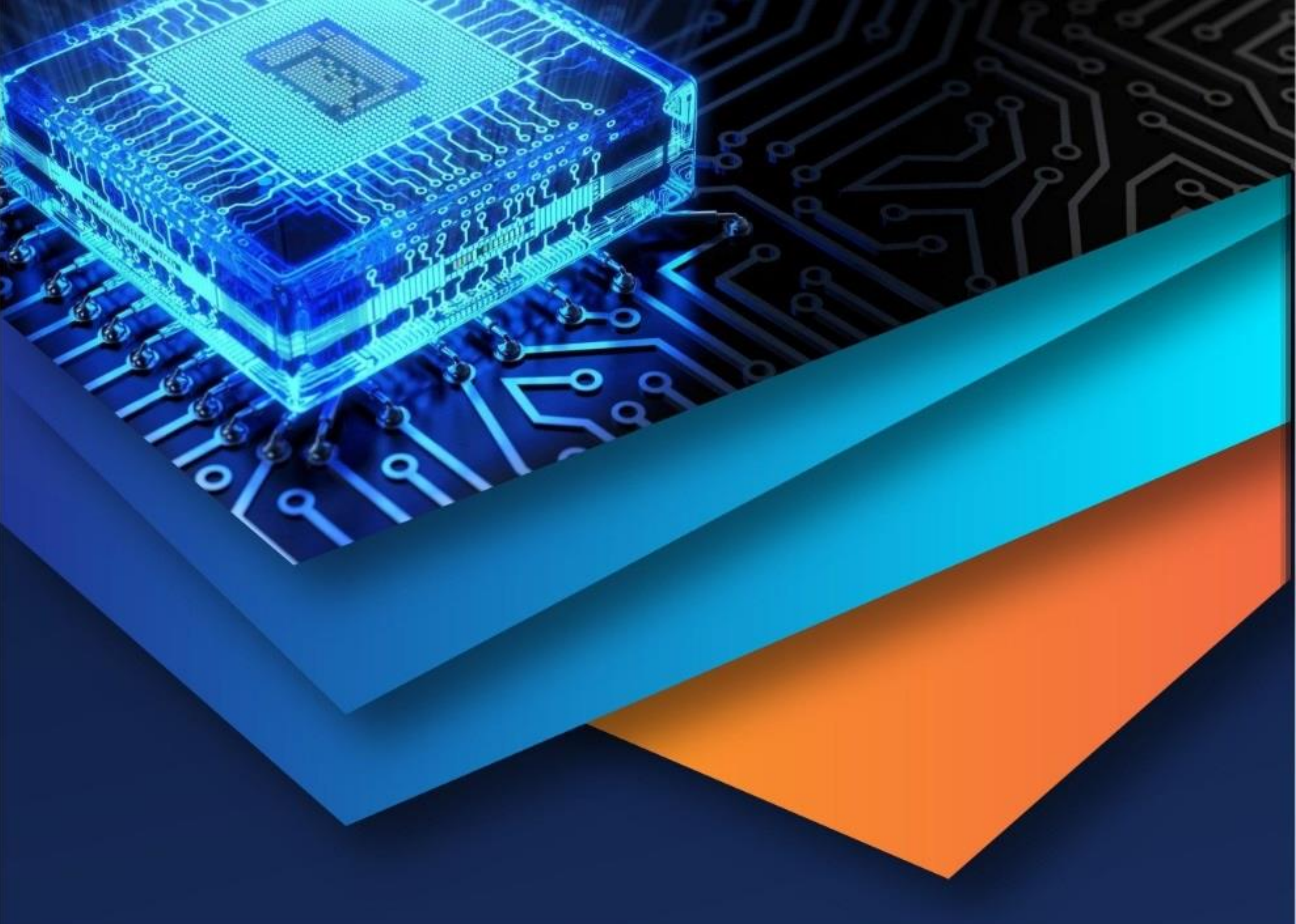

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