DESIGN OF ENERGY HARVESTING PROTOTYPES FROM WASTE HEAT OF HOME CHIMNEY USING THERMOELECTRIC GENERATORS

Project report submitted in partial fulfilment of the requirement for the degree of

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IN

ELECTRONICS AND COMMUNICATION ENGINEERING

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DECLARATION BY THE SCHOLAR

We hereby declare that the work reported in the B-Tech thesis entitled **"Design of Energy Harvesting Prototypes from Waste Heat of Home Chimney using Thermoelectric Generators"** submitted at **Jaypee University of Information Technology, Waknaghat, India,** is an authentic record of my work carried out under the supervision of **DR. SHRUTI JAIN**. We have not submitted this work elsewhere for any other degree or diploma.

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CERTIFICATE

This is to certify that the work reported in the B.tech project report entitled **"Design of Energy Harvesting Prototypes from Waste Heat of Home Chimney using Thermoelectric Generators"** which is being submitted by **Mansi Kathuria(131050), Ossein Sharma(131080) and Kaushik Raj Singh(131086)**in fulfillment for the award of Bachelor of Technology in Electronics and Communication Engineering by the Jaypee University of Information Technology, is the record of candidate's own work carried out by him/her under my supervision. This work is original and has not been submitted partially or fully anywhere else for any other degree or diploma.

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LIST OF ABBREVIATIONS AND ACRONYMS

AC	Alternating Current
DC	Direct Current
DG	Diesel Gensets
LPG	Liquefied Petroleum Gas
TEG	Thermoelectric Generators
VOC	Volatile Organic Compound
WHP	Waste Heat to Power
USD	United States Department

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ABSTRACT

In our project we are converting waste thermal energy into productive electrical energy. With an increase in the number of industries day by day, we continuously read about the thermal energy wastage and the harm it is causing to our environment. Efficiently use of energy is of paramount importance. Thus to do our bit for the environment, we chose this as our project topic. The project constitutes conversion of waste energy from smoke to useful voltage that may be used to operate a mobile charger or some other appliances. We have obtained a maximum of 491 mV using 4 thermopiles in series while the food is being cooked at the time interval of 10 minutes after which it became constant. To widen our scope, we further input our obtained voltage to DC-DC booster circuit to boost up the voltage to greater scale with negligible effect on current.

CHAPTER – 1

INTRODUCTION

All through the United States, an extensive wellspring of energy is being over looked. The source is squander warm which is a by-result of the modern operations which could revive American assembling however make employments and drop down the cost of vitality and make diminishment in complete discharges from electric era. In the event that the waste warmth is not seized and along these lines is utilized to create sustainable indistinguishable power, this waste warmth is discharged to the climate through stacks, holes and mechanical hardware.

Waste heat to power (WHP): It's a method of recuperating squander warmth and using it to make which is without ignition and outflows. WHP structures use the advancements introduced in endeavours, comprehensive of the geothermal business. In a mechanical operation, which incorporates change of crude materials into valuable items – refineries, synthetic plants and general processing plant fabricating, the warmth which is discharged in the encompassing condition is wasted as a by - item. This squandered warmth is manufactured at whichever point the procedure is running, consistently 24 hours a day and 365 days a year. On the off chance that this waste warmth is not recouped for reuse as lower temperature prepare warm or to deliver control, this warmth will be dispersed into the climate and get squandered.

WHP helps in lessening vitality costs for mechanical operations. By utilizing the waste warmth to create power, modern clients can return squander vitality to the procedure which delivered that waste warmth, coordinate the power elsewhere, or pitch it to the framework to bolster for clean vitality conveyance, generation and use.

On the off chance that the warmth is not caught and utilized as a part of a productive way, squander warmth is discharged into the environment missing a vitality effectiveness opportunity. Squander Heat Recovery is in this way a procedure of gathering of waste warmth and utilizing it to fill a coveted reason somewhere else. It is Cool Energy's innovation that catches and turns this vast measure of waste warmth to deliver power. The utilization of this innovation enables the mechanical client to put their warmth squander over into the procedure which made that waste warmth.

Establishment of Thermo. For at least one year's opportunity squander warm from the warmth motors have a payback time. From the report USD of Energy, up to 55% of the vitality of each fills consumes in the U.S. ends up being waste warmth to the air. Hence from the examination we can without much of a stretch see that recovery of the vitality squander from industrial facilities cells could satisfy up to 20% of aggregate U.S. power requests and at the same time impact of 25% abatement in ozone harming substance discharges. From the examination 12GW of energy can be delivered if incomparable quality waste warmth from business and manufacturing plants applications is caught and change to outflow free power.

Advantages from Waste Heat Recovery in Public Sector:

1. Pollution Control:

Contamination control gadgets are made to wreck particles and unstable organic components (UOC's) which are created by production lines operations like metal covering, broiling of espresso and painting. Gasses which get discharged from the blast room of these gadgets have a temperature extending from 350°C to 640°C. This reasonable, warm gas is stream into a warmth exchanger and afterward moves through Cold Energy's Thermo Heart Engine, deliver power from the twirling cycle machine. This created power which decreases the general population's power bill and bill charges. Shape the enterprises which work on a 24*7 in Japan or Europe, the payback times is shorter than two n half years. Contamination control machines of such sorts are utilized crosswise over a wide range of procedures including metal completing, nourishment handling, soil remediation, paint showering and oil preparing.

2. Diesel :

Another application which is being focused for starting item work is squander warm recovery from the fumes of diesel gensets (DGs) and shipboard generators. With a simple retrofit, Cool Energy's motor can elevate the yield of DGs by 10% to 20% while recovering the waste warmth and in this way the generator depletes. There are two fundamental decisions accessible for utilizing the electrical vitality created by the Thermo Heart Engine: battery charging and stack decrease. In remote and military settings where completely troubled diesel fuel can cost up to $15/gallon including transportation costs, the payback time frame for motor can be short of what one-year term. Productive use and preservation of vitality is of vital significance in this day and age. Along these lines to do our bit for the earth, we have picked our venture with the target of changing over waste vitality from stack smoke as well as from electrical apparatuses to valuable voltage that might be utilized to work a portable charger or some different machines.

We are essentially utilizing "Thermocouple" – which is a gadget for measuring temperature which incorporates two wires of different metals associated at two focuses, a voltage is along these lines created between two intersections (i.e. the hot intersection and the cool intersection) in extent to the temperature distinction between the two intersections. This voltage which is produced can be opened up by interfacing with a DC-DC promoter circuit (Micro Voltage Booster circuit in our venture).

1.1 General Representation of TEGs on Chimneys

In this universe of headway and development, employments of thermoelectric advancement have been extensively focused in view of the extending emphasis on carbon diminishing and essentialness save finances with a specific end goal to make condition all around arranged mechanical assemblies. Thermoelectric generators (TEGs) have a boundless probability for the change of low-level warm imperativeness in transmission free electrical power. As squandered warmth recuperation, it is inconsequential to take it as the cost of the warm essentialness input. All things considered, a thermoelectric generator contains different semiconductor coordinates that are related electrically in course of action furthermore, thermally in parallel. Each match joins a p-sort and a n-sort part. The working standard of a TEG relies on upon the Seebeck affect which starts an electromotive urge in semiconductor materials as a result of temperature refinement between the two convergences of a TEG.

As the smokestack underpass is made of rectangular channels, it is commonsense to implant the sharp edge warm sink into it to develop the glow trade region and reduction warm impenetrability to the TEG module. Regardless, there is an injury of addition in the weight drop of the system.

1.1.1 Theoretical Model:

An illustrative graph of a squandered warmth recuperation framework with TEG modules is appeared in fig. 1.1. Every TEG module contains a TEG, a curved stick balance warm sink and a frosty plate in light of cooling of water. The surmised measurements of the collected square unit are 40 mm × 40 mm × 3.3 mm. This changes warm vitality into electric power utilizing 49 sets of n-sort and p-sort and the legs of semiconductor are associated thermally a similarity among warm waste gas and the chilly plate and electrically in arrangement for control of heap circuit. The TEG models can be streamlined by utilizing the comparable current strategies, which implies an equivalent current and further equivalent traverse zone of thermoelectric components, henceforth just a single combine of semiconductor components is to be considered for operation purposes. Furthermore, described in fig. 1.2, pin fin heat sink is further of 2 types, which are indicated as amazed and inline.

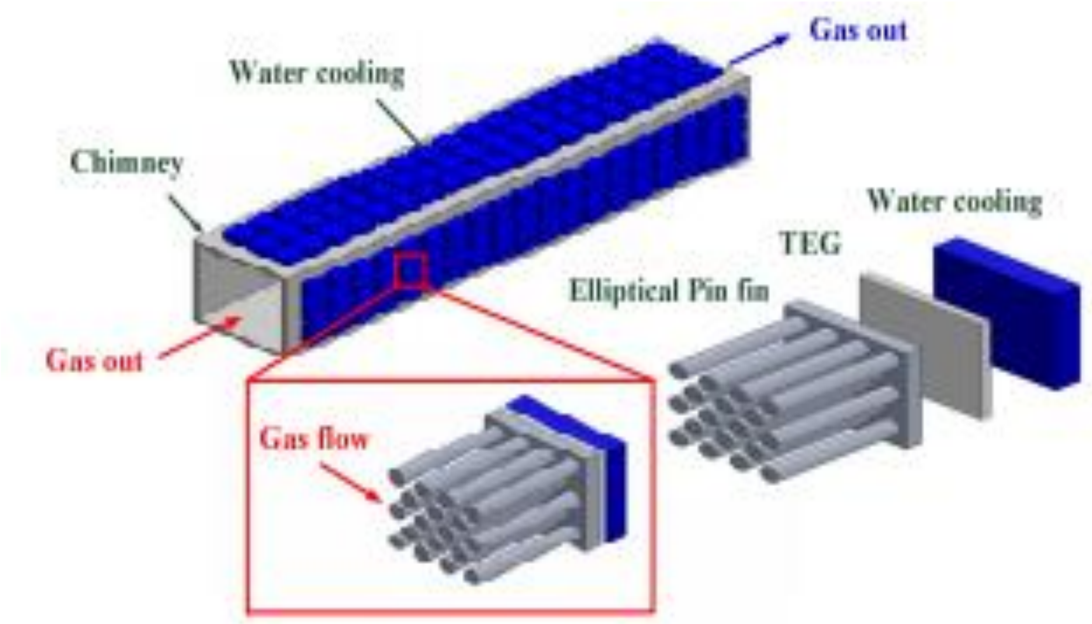
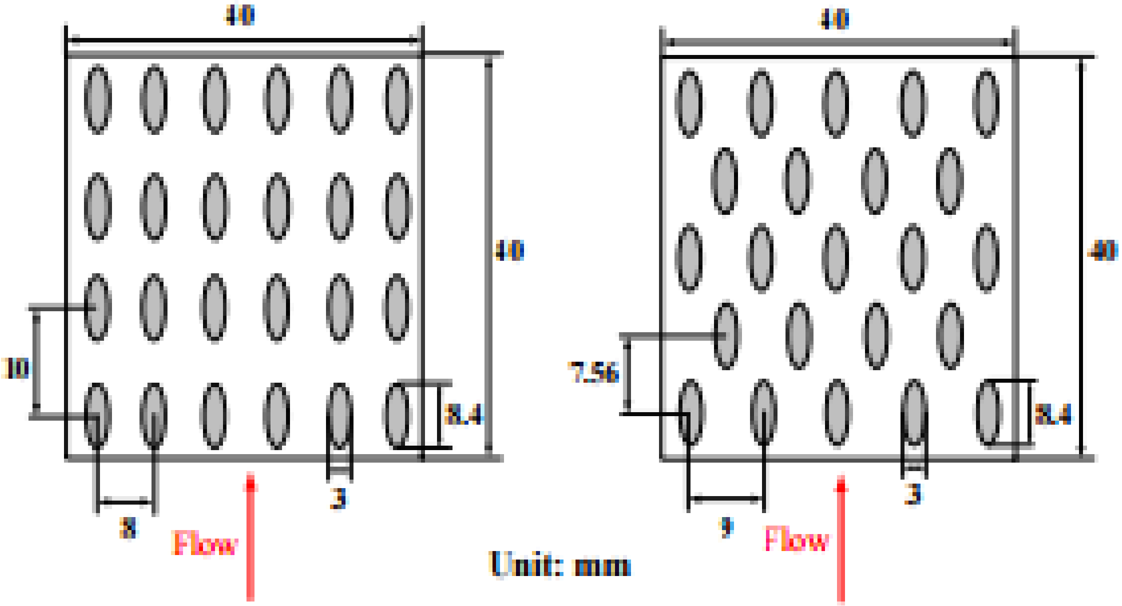


Fig. 1.1 Schematic diagram TEG modules. [3]



(a) Inline arrangement (b) Amazed arrangement

Fig. 1.2 Arrangement of pin fins [3]

CHAPTER - 2

THERMOELECTRIC GENERATORS

A Thermoelectric generator (likewise called a Seebeck generator) is a strong state gadget which changes heat energy (temperature difference between hot and cold junctions of a thermocouple) straightly into electrical vitality and the marvel called the Seebeck impact. Thermoelectric module like warmth warm gadgets yet they are less overwhelming and have no portable segments. Nonetheless, TEGs are costlier and less proficient.

2.1 Construction

Thermoelectric power generators have 3 main components: thermo modules, thermos materials and thermo systems that interact with the thermal supplies.

2.1.1 Thermoelectric materials

Thermoelectric elements produce electric energy straightly from heat energy by transforming temperature gradient into electric power-voltage which can be used for various application purposes. These elements should have high electrical conductivity as well as low thermal conductivity for best thermo elements. Due to less thermal conductivity as we can see that when one junction is made to be at a greater temperature (i.e. the hot end), the other side stays to comparatively smaller temperature (i.e. the cold end), that helps to produce high voltage as a result of large temperature gradient. The magnitude of electrons flow is measured from the temperature gradient across the two junctions is derived from the Seebeck coefficient (*S*). As the given element's efficiency to generate a thermo power is measured as a factor given as **Figure of Merit (zT):**

$$zT = S^2\sigma T/\kappa \qquad (1)$$

Since a long time, there are major 3 semiconductors known as having lessheat conductivity and large power factor as elements like lead telluride (PbTe), silicon germanium (SiGe) and bismuth telluride (Bi_2Te_3). These elements mainly have very unusual materials that make these semiconductors very rich in compounds.

Presently, the heat conductivity of semiconductors must be reduced without changing their electrical specifications. These can be attained by making Nano-scale specification like particles, connectors in heavy semiconductor elements. Therefore, the fabrication processes of Nano - materials is still very difficult.

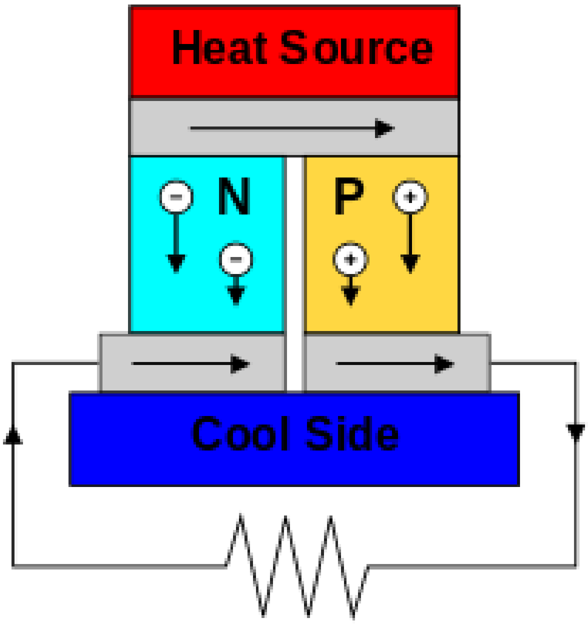


Fig. 2.1 A thermoelectric circuit of various Seebeck coefficient designed as a thermoelectric generator [6]

2.1.2 Thermo-electric module

A thermo-electric system is a circuit that contains thermoelectric materials used for delivering release free electric by the warm vitality straightly. A container electric system haves two dissimilar thermoelectric parts related at their convergence: a n-sort; and a p-sort semiconductor. A straight electric charges stream as there is a temperature slant between the two parts at two completions. Generally, the charge estimate has a quick relationship with the temperature slant. In thermo-electric generator control voltage make work in high mechanical and warmth conditions. As they can without quite a bit of an extend work in broad temperature differentiate, the application is always subjected to high warmth started strains or stresses for gigantic ranges of period. They are subjected to mechanical figures created by amazing number of warmth cycles. Thusly, the completions (crossing points) should be taken that can persist these broad warmth and mechanical conditions. In like manner, the generator must be made in such way that the 2 thermoelectric parts are in parallel, however electrically in game plan. The profitability of thermoelectric generator is, as it were, affected by its geometrical conditions.

2.1.3 Thermoelectric system

By selecting thermo modules, system produces energy by moving in heat from an input like heat from food that is being cooked. As to give it a shot, the system requires greater temperature gradient that is neither so much easy in real-world implementations. The colder part should be kept at cold water or room temperature. Heat exchangers i.e. heat sinks are implemented each side of the generators to provide this warm and cold.

There are numerous difficulties in creating a strong TEG framework that work at more noteworthy temperatures. Accomplishing more prominent productivity needs broad complex outline to keep up balance among the warmth move through the generators and upgrading the temperature contrast between them. In this way, the environments need limiting the heat losses because of the cooperation among components at a few places. Likewise, on the opposite side one more troublesome requirement is ignoring more noteworthy weight drops among the hot and cool inputs.

As dc heat from the TE generators goes along an inverter, TEG makes AC energy, which thus wants a combined power system so that it can used as electric power for operating other appliances.

2.2 Materials for TEGs

There are less components are perceived as thermo components. Practically every thermoelectric component today has estimation of around one, for example, in Bismuth Telluride (Bi_2Te_3) at room temperature, a zT, the figure of legitimacy also thelead telluride (PbTe) at 500-700K. In any case, to be focused with different power era frameworks, TEG materials ought to have zT of 2-3 territory. The greater part of the exploration in thermoelectric elements have concentrated on expanding the Seebeck coefficient (S) and in this way bringing down the warm conductivity, particularly by managing the nanostructure of the thermoelectric elements. As warm and electrical conductivity correspond with the charge bearers, this ought to be acquainted all together with intercede the inconsistency between low warm and high electrical conductivity.

Various different components ought to be considered while choosing the materials for thermoelectric era. Amid the procedure, in a perfect world the thermoelectric generator has a huge temperature angle crosswise over it which presents warm development. Warm extension will then influence worry in the contraption which may understand break of the thermoelectric legs, or division from the coupling elements. The mechanical properties of the materials must be considered and the coefficient of warm extension of the n and p-sort material must be encouraged sensibly well recalling a definitive target to stay away from naughtiness from the impelled worry because of warm change. The material's similarity should likewise be considered in various layers of thermoelectric generator. A material's similarity calculates (*S*) is characterized as:

$$\mathrm{s} = \frac{\sqrt{1-\mathrm{zT}}-1}{\mathrm{ST}} \qquad (2)$$

In an event that similarity component of one layer varies from another by more than one element then the gadget won't work productively. The material parameters that decide S and zT are temperature subordinate, such that similarity variable might transform through the hot end to the icy end of the thermocouple, even in a solitary portion. Such sort of conduct is alluded to as self-similarity and may turn into an essential viewpoint in a gadgets' plan for low temperature operations.

When all is said in done, thermoelectric materials can be sorted into two distinct sorts of materials:

1. Conventional Materials
2. New Materials

2.2.1 Conventional materials

Numerous TEG materials are utilized as a part of different business applications. These can be separated into three gatherings in light of the diverse range in temperature:

1. Larger temperatures elements (up to 1302K): materials created from silicon germanium (*SiGe*) composites.
2. Low temperature elements (upto 460K): Alloys in light of Bismuth (*Bi*) in blends with Antimony (*Sb*), Tellurium (*Te*) or Selenium (*Se*).
3. Transitional temperature (up to 856K, for example, elements in view of amalgams of Lead (*Pb*)

Thus, the foundation of materials for functional and business applications in thermoelectric power era, and further additions are made in forming new elements and building material structures with upgraded thermoelectric execution. Flow inquires about have been concentrated the change productivity, by diminishing the grid warm conductivity on enhancing the material's figure-of-legitimacy (zT), and along these lines, new materials are blended.

2.2.2 New materials

Thermoelectric materials for power period by strengthening figure-of-authenticity zT are being delivered by authorities. An instance of such materials is the semiconductor intensify that are *ß-Zn4Sb3*, that has uncommonly lowered warm conductivity and showcases the most outrageous *zT* of 1.3 at a temperature of 672K. Thus, the materials are furthermore relentless up to this temperature in a vacuum; reasonably shoddy that might be a better than average option in the temperature goes among materials in perspective of *Bi2Te3 and PbTe*.

Other than upgrading the figure-of-authenticity, it has an extending base on progression of newer elements by growing the electrical energy yield, cutting down value though developing earth welcoming materials. Like, the fuel tariff is free and low, for instance, in squandered warmth recuperation, the cost per watt is quite recently controlled by the power/unit locale and also the working time of the structure. In like manner, it had begun a sweep for elements with greater energy yield despite of change adequacy. Like, the phenomenal earth blends *YbAl3* have a low figure-of-authenticity, yet it has a power yield of any rate twofold that of some another material, and can work over the temperature extent to the warmth source.

2.3 Working of Thermoelectric Generators

Thermo generators are solid-state heat engines which work according to the Seebeck Effect – a theory which works on a principle that temperature distinction crosswise over thermoelectric material can be changed over straightforwardly into electrical power.

A thermo generator consists of various sets of p-sort and n-sort components. The p-sort components consist of semiconductor materials doped with the end goal that the charge transporters are certain (openings) and Seebeck coefficient is sure. The n-sort components are made of semiconductor material doped to such an extent so as the charge carrier transporters are –ve (electrons) and Seebeck coefficient is negative.

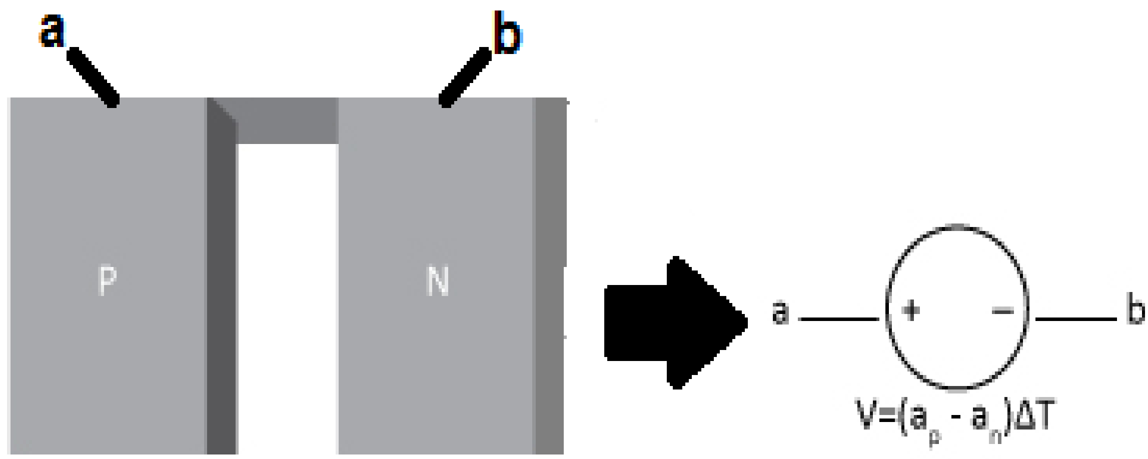


Fig. 2.2 Migration of Mobile Electrons [7]

Associating the p-sort part to an n-sort part makes a voltage potential over the convergence. This voltage potential is in respect to the refinements in the Seebeck coefficient in each part and the temperature of the convergence. At the point whenever the p-sort component and the n-sort component are electrically associated, the versatile openings in the p-sort part relocate towards the portable electrons in n-sort part because of fascination exactly the opposite side of the convergence (See Figure 2.2).

For every opening that moves into the n-sort part, an electron from the n-sort segment moves into the p-sort segment as a converse effect. Before long, each gap and electron that "switch sides" will be in harmony and act like an obstruction, containing more electrons or gaps from moving i.e. space charges are shaped over the intersection which make a consumption potential eV over the intersection. This is known as the exhaustion zone (see figures 2.3).

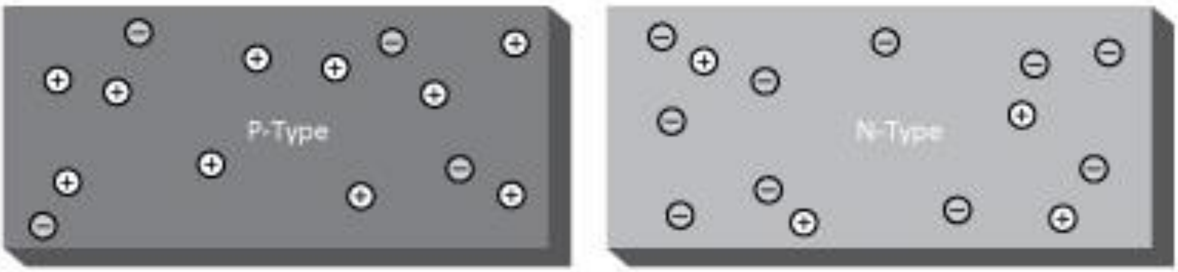


Figure 2.3 Formation of Depletion Zone [7]

Warming this utilization region district and cooling diverse completions of the part can isolate this weariness area. The adaptable crevices in the p-sort are invigorated by the glow and move help into the part with the extra element imperativeness. The same happens to the compact electrons in the n-sort material. The net effect: an extensive number of the openings load up at the crisp end of the p-sort part and a powerful segment of the electrons stack up at the cool end of the n-sort segment, in this way making a voltage potential overthe p-n convergence when measured from cold end to chilly end (see figure 2.4).

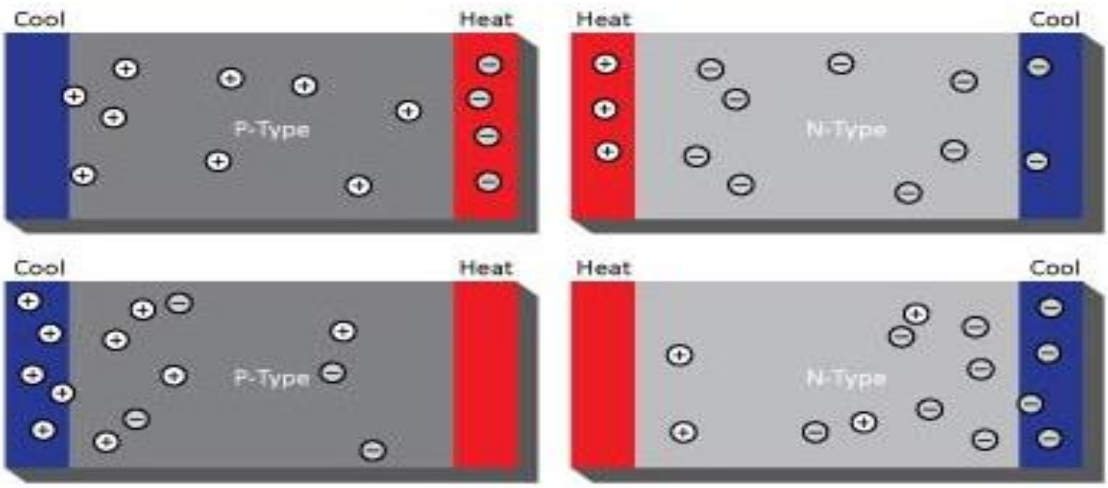


Figure 2.4 Development of Voltage Potential across the P – N Junction [7]

By fixing an electrical load or wire from the nippy end of the p-sort segment to the n-sort segment, the electrons from the n-sort component will look for larger segment of the openings piled up along finish of the p-sort segment and quickly mount beside the wire into the p-sort material. Thus, an opening from the p-sort component will "see" an opportunity in the n-sort segment and move in a similar bearing in which the opening is seen. The end impact is present stream over a voltage potential (shown in 2.5), and outflow free electrical power is made. This power is a component of numerous things, for example, temperature distinction, Seebeck coefficients, and the load that associates the cool sides. Also, obviously, this idea can be extended for some p-n couples.

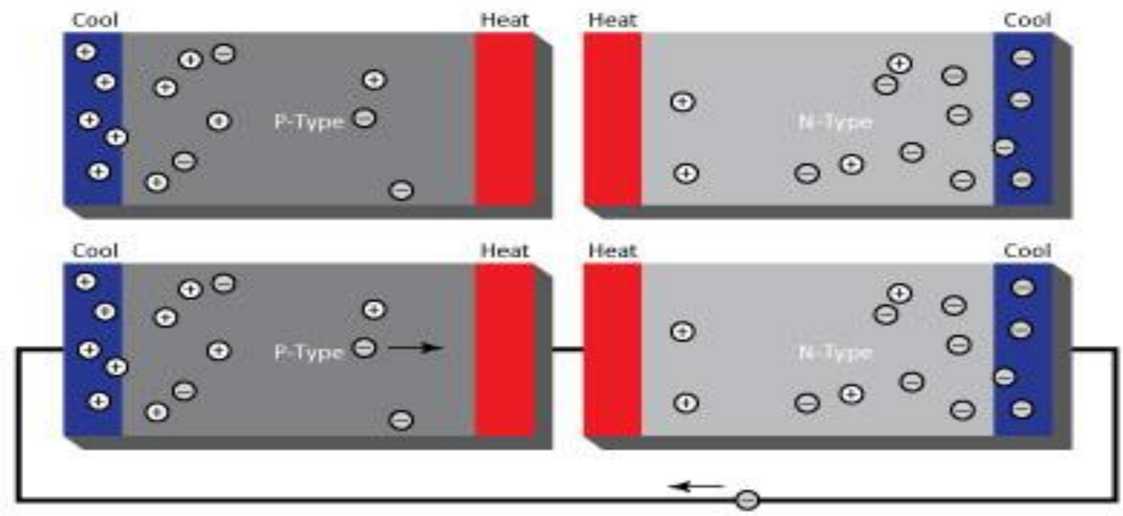


Figure 2.5 Current Flow across a Voltage Potential [7]

2.4 Practical Limitations

Other than low productivity and moderately high cost, some common sense issues exist in utilizing thermoelectric gadgets in specific sorts of uses coming about because of a generally high electrical yield resistance, which expands self-warming, and a generally low warm conductivity, which makes them unacceptable for applications where warm evacuation is basic, as with warmth expulsion from an electrical gadget, for example, microchips.

1) High generator yield resistance: keeping in mind the end goal to get voltage yield levels in the range required by advanced electrical gadgets, a typical approach is to put numerous thermoelectric components in arrangement inside a generator module. The component's voltages include, yet so do their individuals yield resistance. The most extreme power exchange hypothesis manages that greatest power is conveyed to a heap when the source and load resistances are indistinguishably coordinated. For low impedance stacks close to zero ohms, as the generator resistance raises the power conveyed to the heap diminishes. To bring down the yield resistance, some business

gadgets put more individual components in parallel and less in arrangement and utilize a lift controller to raise the voltage to the voltage required by the heap.

2) Low warm conductivity: Because a low warm conductivity is required to transport warm vitality far from warmth source, for example, a computerized microchip. The moderately high warm conductivity of a generator module with respect to copper and aluminium warm channels utilized as a part of warmth sinks implies the thermoelectric generator blocks the waste warmth expulsion bringing about the silicon gadget temperature to raise altogether.
3) Cold-side warmth evacuation with air: In air-cooled thermoelectric applications, for example, when reaping warm vitality from an engine vehicle's crankcase, the extensive measure of warm vitality that must be disseminated into surrounding air shows a huge test. As a thermoelectric generator's cool side temperature rises, the gadget's differential working temperature diminishes. As the temperature rises, the gadget's electrical resistance builds bringing about more noteworthy parasitic generator self-warming. In engine vehicle applications a supplementary radiator is some of the time utilized for enhanced warmth evacuation, however the utilization of an electric water pump to circle a coolant adds an extra parasitic misfortune to aggregate generator yield influence. Water cooling the thermoelectric generator's frosty side, as when producing thermoelectric power from the hot wrench instance of an inboard watercraft engine, would not experience the ill effects of this drawback. Water is a toll simpler coolant to utilize adequately as opposed to air.

2.5 Thermocouple

Thermocouples are most commonly used as temperature sensors but they can also be used for voltage generation. So, we can use them to convert thermal energy to electrical energy with the help of temperaturedifferences. By the use of the thermoelectric effect, waste heat of home chimney can be used for voltage generation.

There are mainly two junctions that are:

1. Hot Junction where hot junction is a heat source (comparatively at high temperature)
2. Cold Junction where cold junction is a heat sink (comparatively at low temperature).

Measurement of the temperature and changing the temperature of the objects are the further applications of thermoelectric effect. Thermoelectric effect includes three independently recognized effects: The Seebeck effectt (temperature difference between two dissimilar conductors), Peltier effect (voltage difference or current can produce a heat flow), and Thomson effect (thermoelectric material which can be used to generate temperature difference by generating power).

Change in temperature at different length across metal result in increase or decrease in emf (*E*). This phenomenon is known as the Seebeck Effect .Seebeck effect is just another example of emf (*E*) where all the voltages and currents are measured by the conventional methods only.

$$E = - S\nabla T \qquad (3)$$

where *S* in the equation is the Seebeck Coefficient, a trait of the material and ∇T is the difference in the temperature *T*. Seebeck coefficient strongly depends upon the composition of the material and varies according to the temperature.

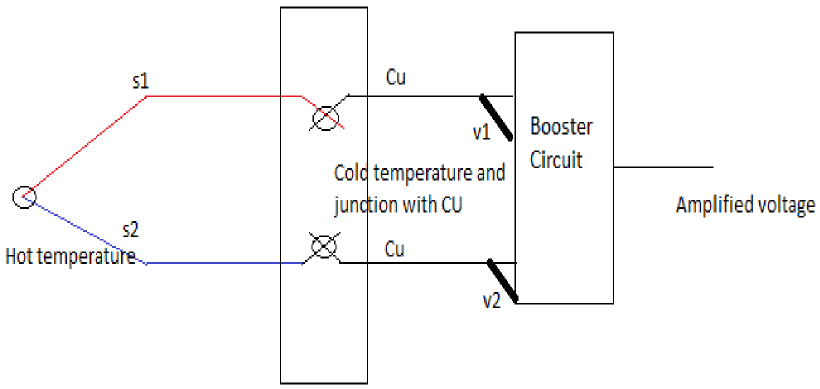


Fig.2.6 Structure of a thermocouple made up of two metals having relative Seebeck coefficient s_1, s_2. Seebeck coefficient of the thermocouple $S=s_1-s_2$. One terminal is welded together at hot temperature and the other are connected with copper(Cu) wire at different temperature (preferably lower). V_1 and V_2 are the terminal voltages. $E = V_1 - V_2$

A thermocouple can be described as a combination of two dissimilar conducting wires joined to each other at both ends as shown in Fig.2.7. One wire is called positive leg and the other negative leg because of their relative Seebeck coefficient.

The temperature of one of the joined end is held constant or is accurately measured and is used as a reference temperature, can be called as cold junction. The other joined end of the thermocouple is kept at a comparatively different temperature than the cold junction and is known as the measuring end or the hot junction. Seebeck current or the electric current starts to move in a closed loop consisting of two variant conductors whenever two ends are kept at various temperatures. A potential difference is generated (Seebeck voltage) at the reference end (the open end) that is in proportion to the difference in the temperature and type of the alloys or the composition of the conductors in the alloys.

The efficiency of the cooking appliances is only around 35% and the remaining 50 - 55% of energy is lost as heat to the environment. The major source of loss in the conversion process is the heat rejected to the surroundings due to the many inherent constraints. Therefore, the power saving is one of the key issues, from aspect of LPG utilization so as to provide every single household a LPG subsidy. Waste heat from the LPG can be easily restored either by exchanging this form of energy with other materials/fluids (such as in heat exchangers) or by converting to another form of energy (e.g., thermal to electric i.e. Thermocouples).

2.5.1Principles Involved in Thermocouple Circuit

Effect of the additional thermocouples and variance in the temperature on our circuit can be minimized by considering the following principles:

1. **Law of Homogenous Materials:** Heat or temperature difference alone won't be able to sustain the thermoelectric current in the circuit comprising of single homogenous material only. The output of the circuit will not be altered on the basis of the temperature difference between the input and output, given that all the wires connected in the circuit are of the same material which is the same as the material of the thermocouple. The current can't flow in the circuit which is made of a single material even after the application of the heat.

2. **Law of Intermediate Materials:** If all the junctions are kept at the same temperature, no matter how many dissimilar materials it comprises of, the sum of all the emf (E) in a circuit adds up to zero. Therefore, if any other material is attached to one or both wires while making a cold junction connection, no potential difference

or voltage is generated by the insertion of new material till the time both the junctions are maintained at same temperature.

3. **Law of Intermediate Temperatures:** In fig.2, thermal emf (*E*), V_3 has been produced by two homogenous dissimilar materials when the temperature of the two junctions are T_1 and T_2 and thermal emf (*E*), V_2 is being produced when the temperature of the junctions are T_2 and T_3 and thermal emf (*E*), V_1 is being produced when the temperature of the junctions are T_1 and T_3.

$$V_1 = V_3 + V_2, \text{ if } T_1 < T_2 < T_3 \quad (4)$$
$$V_1 = -(V_2 + V_3), \text{ if } T_1 > T_2 > T_3 \quad (5)$$

Because as emf (*E*) produced is directly proportional to the temperature gradient. Therefore, when the sign of the temperature gradient is changed so of the emf (*E*) produced.

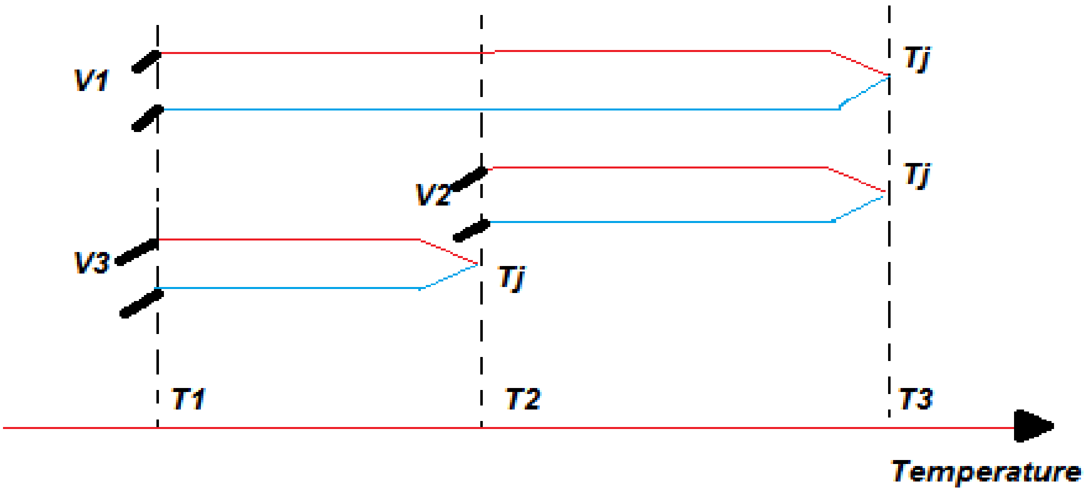


Fig. 2.7 Different temperature gradient gives different potential difference.

2.5.2 Functionality of a thermocouple:

The conductors should be dissimilar in so that it can achieve **current flow** in the existence of a temperature difference. This current flow generates voltage at the hot side to the cold side end connections. The potential generated depends upon the conductors used to form the thermocouple and on the thermal potential, thus finally equation can be determining by

$$V = \int (S_S(T) - S_P(T))\, dT \quad (6)$$

while SP and SS are the Seebeck coefficients of the both essential and auxiliary conductors, individually. In the event that the coefficients are consistent over raising the temperature run, the condition can in this manner be disentangled to

$$V = (S_S - S_P)\,(T_2 - T_1) \qquad (7)$$

Seebeck effect, may be easily seen in semiconductor devises, are generally implemented for power generating modules. The device that connect several thermocouples in series such that the alternate junctions are at two different temperatures amplifies the thermoelectric voltage of a single thermocouple by the number of thermocouples, N, connected in series

$$V_{\text{thermopile}} = N.V_{\text{thermocuple}} \qquad (8)$$

Device that connects many thermocouples in series is known Thermopile. Thermocouple have a property to generate a voltage when there is a temperature gradient and it is uses as a heat engine that can easily produce electricity directly.

2.5.3 Types and Length of Alloys Used:

There are various types of thermocouple namely J, K, T, E, N, S etc. but we are working on the following:

1. **J-Type**: This nickel alloy thermocouple is formed by iron and constantan connected or welded together in series combination. Iron being positive leg or hot junction known for positive Seebeck coefficient and constantan as negative leg or cold junction, having negative Seebeck coefficient. Therefore, the difference between the two junctions gives us the Seeback coefficient as 52μV/°C. It can be used in vacuum or air where the atmosphere may be reducing or oxidizing. Avoid the use of this type of alloy in highly oxidizing atmosphere with temperature exceeding 900°C. The positive leg is magnetic while the negative is non-magnetic. Therefore, changes in the characteristics of iron can take place above Curie temperature i.e. ~770°C. So the application temperature range limits to 760°C.

2. **T-Type**: This nickel alloy thermocouple is formed by copper and constantan connected or welded together in series combination. Copper being positive leg or hot

junction known for positive Seebeck coefficient and constantan as negative leg or cold junction, having negative Seebeck coefficient. Therefore, the difference between the two junctions gives us the Seebeck coefficient as 41µV/°C. One of its best features is that it can be used in any environment-oxidizing, reducing or inert gases. Due to its property of being corrosion resistant it is suitable for humid atmosphere.At low levels of oxygen, it can generate "green rot", specifically in the range of 816-1038°C. Its stability increases and is maximum at sub-zero temperatures.

3. **K-Type**: This nickel alloy thermocouple is formed by chromel and alumel connected or welded together in series combination. Chromel is 90% nickel and 10% chromium makes positive leg or hot junction and alumel which comprises of 1% silicon, 2% aluminum, 2% nickel and 95% nickel, makes the negative or the cold junction of thermocouple. Its Seeback coefficient is 41µV/°C. Favorable environment is vacuum and low oxidizing environment. Try to avoid its use in atmosphere containing Sulphur. Its application range is limited to only 1260°C and is not recommended to cycle around that temperature because of the chances in the alteration of emf (*E*) generated due to hysteresis effect.

TABLE 2.1: Comparison between the type of alloys according to the gauge number

Types	**Temp. Range**	**Diameter (AWG) (cm)**	**Diameter (SWG) (cm)**	**Gauge no.**	**Length Used (cm)**
J	200-1400F 95-760°C	0.102	0.122	18	32.5
K	200-2300F 95-1260°C	0.129	0.163	16	32.5
T	32-660F 0-350°C	0.0511	0.0559	24	32.5

2.5.4 Advantages of Conventional Thermocouple:

Thermocouples are very useful as they are durable, less in size, versatile, long lasting, non-moving thus resistance free, change heat flow directly to electrical power-energy, and silent. Portable as the size are very small and start from about 30 × 30 mm to about 75 × 75 mm with thicknesses of only some mili-meters. These devices are designed in that way that they can easily work in high heating environment, and they have long lasting life spans, similarly to many other semiconductor materials. They have a very large variety of applications as they have ability to generates electricity in the presence of temperature gradient without any moving parts or making any sound.

2.5.5 Disadvantages of Conventional Thermocouple:

Thermocouple generally have very less changing efficiency, and as they are little costly, and the output voltages directly proportional to the temperature gradient as well as the connected devices like loads. The efficiency of these conventional devices is very less, mainly less than 6%, due to properties of the semiconductor materials and for individual modules prices range from about $20 to $200 dollar. Heat flow is very necessary for these devices for operating. Electricity will not be generated, without an available temperature gradient.

2.6 Thermopile

A thermopile is an electronic gadget which made out of thermocouple in arrangement (less normally, in parallel) that proselytes warm energy into electrical power.

Thermopiles are for the most part don't react to absolute temperature, yet they for the most part create an output voltage corresponding to a temperature angle. Thermopiles are utilized to get good output because of temperature as a feature of a temperature measuring gadget, for example, the computerized thermometers utilized by Doctors to gauge body temperature. Thermopile are additionally utilized as a part of a gas burner security controls and in a heat flux sensor. The output produced by the thermopile is in the scope of tens or many mili - volts. By expanding the flag value, the thermopile likewise be utilized to give spatial temperature averaging. Thermopiles fundamentally used to produce electrical vitality from the warmth from electrical parts, as sunlight based vitality, radioactive materials, laser radiation or burning. This is a phenomenon of the Peltier effect (electric current transferring heat energy) as the process transfers heat from the hot end to the colder end.

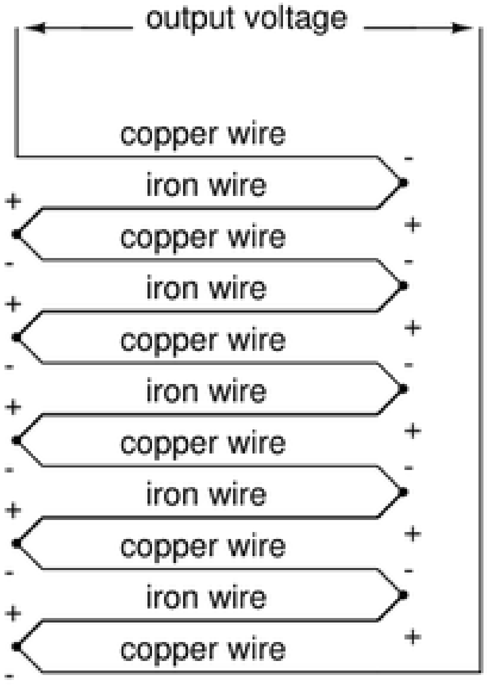


Fig. 2.8Thermopile: composed of multiple thermocouples in series.

Chapter – 3

Voltage Booster Circuits

3.1 Introduction

DC-DC converters go under power converters. It changes a DC source at a particular voltage value to the high voltage value. As in new electronic-electrical devices, DC-DC converters change over the source voltage from the power source to the voltage level required by the target devices. DC-DC converter is mainly used to control the yield-output voltage. For the utilization of TEG in stack devices, DC-DC converter is mostly utilized for boosting up voltage provided by the TEG changed over power source, so it can reach to voltage levels required by various essential home applications.

A booster converter is a DC-DC control converter which venture up voltage and venturing down current from its supply to its yield. Essential DC-DC converter is a class of switched-mode power supply (SMPS) containing two semiconductors primarily comprise of a diode and a transistor and one connected vitality storage-box component, and a capacitor, an inductor, or both in mix. To lessen undulated(ripple) voltage, channels are comprised of capacitors (at times in mix with inductors will likewise work) are ordinarily added to such a converter's output and supply-side channel.

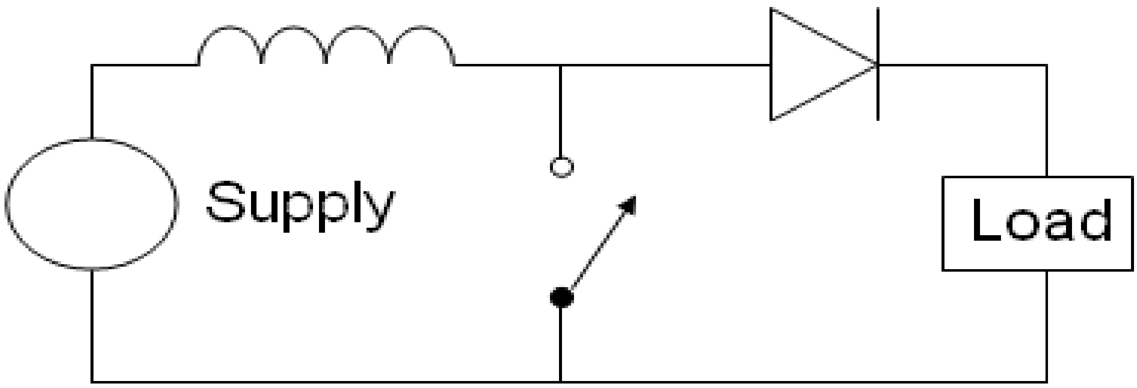


Fig. 3.1: Generic DC-DC booster circuit [10]

Battery control structures are frequently used to collect battery-cells in plan to finish the high required voltage thus sufficient collecting of cells is impossible in various large voltage home devices as a result of non-attendance of space. Boost converters can extend the voltage and can easily decrease the amount of cells [18]. Boost converters are known as power contraptions at small scale home or plant applications, crucial good position is that they are reduced light systems. A white LED basically require 3.3 Voltage so that in can exude light, and a boost converter can without a lot of an extend increase the voltage from a singular 1.5 V alkaline battery-cell to control up the light. Boost converters can in like manner make larger voltages to work cold cathode fluorescent tubes (CCFL) in contraptions, for instance, LCD background enlightenments and a couple of electric lights.

'Joule Thief' is new word turn out which implies when a non-regulation supporter changes its utilized as the voltage increment [12] [16] in this circuit topology is used with low power battery devices, and which have the capacity of a lift converter to "take" the remaining of the voltage left in a battery-cell. This vitality generally will be completely squandered as the very low voltage left in a battery is unusable for any ordinary load. This vitality would stay hindered as in numerous applications they don't sufficiently enable current to course through a heap when voltage diminishes. This abatement in a batteries happen as they wind up plainly exhausted, and is a normal for the pervasive basic battery [12]. Thus the condition of power become

$$P = \frac{V^2}{R} \quad (9)$$

where *R* always remain constant, power across the load goes down significantly as voltage tends to decreases.

The booster converters are very much non-similar from the Buck Converters as in these it’s resultant output voltage equivalent to, or greater than its applied supplied voltage. As we can see it is very important to remember that, as power (*P*) = voltage (*V*) times current (*I*), if the output voltage is increased or decrease, the output current must decrease or increase respectively [14].

Circuit Analysis

Operation:

The rule behind the lift converter is the propensity of an inductor to store changes in current by making and pulverizing a magnetic field in a circuit. In supporter converters, the yield voltage get is continually higher than the associated input voltage. A fundamental circuit of a lift control stage is showed up in Fig. 3.2.

a) At the time when switch is shut, electrons tries to pass through the inductor in against clockwise bearing in this way magnetic field is created because of which the inductor stores some vitality. Left side extremity of the inductor is positive.

b) At the time when the switch is opened, as the impedance is higher current will be decrease. Already made magnetic field will be decimated to keep up the current over the heap. Bringing on turned around the extremity (implies left side extremity of inductor will be negative at this point). Thus, two sources will now progress toward becoming in arrangement making a higher voltage charge the capacitor through the diode *D*.

In case in view of some reason switch is cycled adequately fast, the inductor won't discharge totally and will remain between charging state, and the stack will constantly have a voltage more prominent than that of the data source when the switch is opened. In like manner when the switch is open express, the capacitor which is parallel with the load is charged to join this voltage. AT the period of close switch, the right hand side is shorted out from the left hand side, the capacitor is then prepared to give the imperativeness and voltage to the load. Starting at now, the blocking diode tries shields the capacitor from discharging through the switch, in this way the switch must be opened speedy again enough to shield the capacitor from discharging exorbitantly.

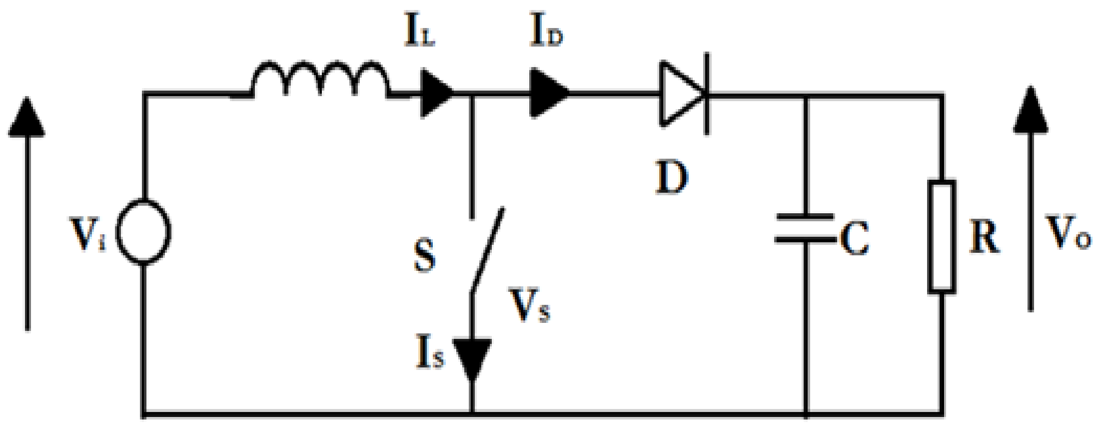


Fig 3.2: Working (Current and Voltage) of the Booster Circuit

The basic principle behind the Booster converter consists of two distinct states (see in fig 3.3) at the time of On-state, the switch S is closed, causing an expansion in the inductor current; at the time of Off-state, the switch is open and the main way inductor flow take is through the fly-back diode D, the capacitor C and the output load R. Consequently, last outcomes are exchanging the vitality collected amid the On-state into the capacitor.

The input current remains same to the inductor current as can be seen in fig 3.3. So it is not discontinuous as in the buck converter and the requirements on the input filter are relaxed compared to a buck converter [10].

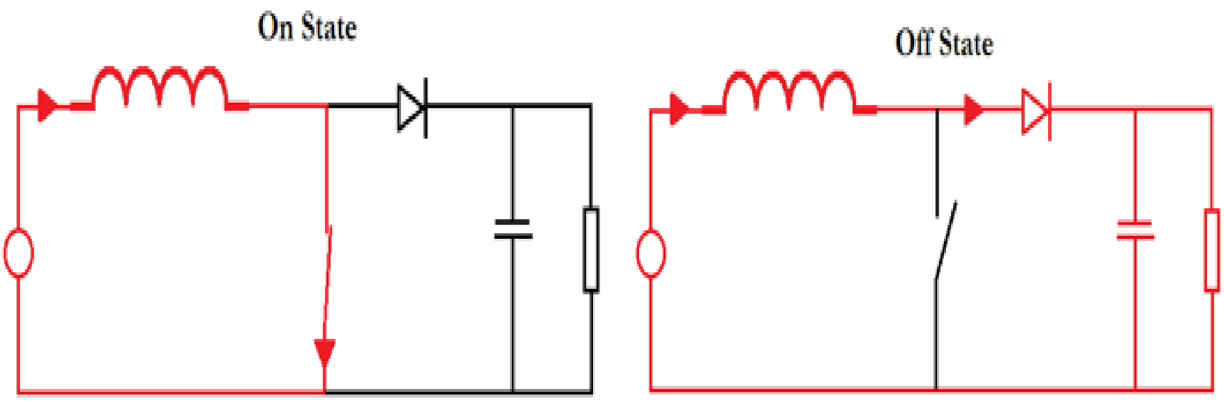


Fig 3.3:Onand Off state of Booster Circuit

Continuous Mode

Amid the consistent mode in the sponsor circuit, the inductor current (I_L) can never end up plainly equivalent to zero. Along these lines yield voltage can be computed in various routes, on account of a perfect converter working in unfaltering conditions.

The switch S is shut, amid the On-state, which makes the information voltage (V_i) over the inductor, because of which there is an adjustment in current (I_L) moving through the inductor amid a time period (t) by the recipe:

$$\frac{\Delta I_L}{\Delta t} = \frac{V_i}{L} \qquad (9)$$

when On-state is end, there is increase of I_L is therefore:

$$\Delta I_{L_{On}} = \frac{1}{L}\int_0^{DT} V_i dt = \frac{DT}{L} V_i \qquad (10)$$

Duty cycle (D) speaks to the division of the communication time frame T when switch is on. Subsequently, D ranges from 0 (S is never on) to 1 (S is dependably on).

At the Off-state time when the switch S is open, so the inductor current tries to flow through the connected load. If considering zero voltage drop across the diode, and making the capacitor large enough so that voltage remains constant, we can see I_L becomes is:

$$V_i - V_o = L\frac{dI_L}{dt} \tag{11}$$

Therefore, during the Off-period, the variation of IL is:

$$\Delta I_{L_{Off}} = \int_{DT}^{T} \frac{(V_i - V_o)dt}{L} = \frac{(V_i - V_o)(1-D)T}{L} \tag{12}$$

As we taken that the converter works just in consistent state conditions, the vitality put away in each of its segments must be the equivalent toward the start and toward the finish of a recompense cycle. As we probably a aware, the vitality put away in the inductor is given by:

$$E = ½ LI^2 \tag{13}$$

In this way, as the inductor current is same toward the begin and end of the compensation cycle. Subsequently creating the entire change in the present which is the aggregate of the progressions is zero:

$$\Delta I_{L_{On}} + \Delta I_{L_{Off}} = 0 \tag{14}$$

taking expression $\Delta II_{L_{On}}$and $\Delta II_{L_{Off}}$yields:

$$\Delta I_{L_{On}} + \Delta I_{L_{Off}} = \frac{V_i DT}{L} + \frac{(V_i - V_O)(1-D)T}{L} = 0 \tag{15}$$

By simplification we can easily write:

$$\frac{V_O}{V_i} = \frac{1}{1-D} \tag{16}$$

The equation number (16) shows that the obtain output voltage is always higher than the applied input voltage (as the duty cycle goes from 0 to 1), and that it increases as *D* (duty cycle) increases, theoretically at infinity as *D* approaches to 1. That is why this booster converter is sometimes referred to as a step-up converter.

Rearranging the equation, we can obtain duty cycle:

$$D = 1 - \frac{V_i}{V_O} \tag{17}$$

Discontinuous Mode

Here and there swell adequacy of the current turns out to be too high, hence bringing on the total release of inductor before the finish of an entire compensation cycle. This variable basically emerges under light loads consequently bringing on the current crosswise over inductor tumbles to zero amid that piece of the period. Despite the fact that, we can undoubtedly observe the distinction strongly affects the yield voltage condition. It can be figured as follows:

As the inductor current at the beginning of the cycle is zero, its most extreme value I_{Lmax} (at t = DT) is

$$I_{L_{Max}} = \frac{V_i DT}{L} \tag{18}$$

At the time-off, I_L value becomes zero after δT:

$$I_{L_{Max}} + \frac{(V_i - V_O)\delta T}{L} = 0 \tag{19}$$

Using equations 18 and 19, we can see δ is:

$$\delta = \frac{V_i D}{V_{O-}V_i} \tag{20}$$

The output current Io is equivalent to the normal diode current (ID). The diode current is equivalent to the inductor current amid the off-state. Thusly, the yield current can be composed as:

$$I_O = \bar{I}_D = \frac{I_{L_{max}}}{2}\delta \tag{21}$$

Changing I_L max and δ by their respective coming expressions:

$$\mathrm{I_O} = \frac{\mathrm{V_i DT}}{2\mathrm{L}} . \frac{\mathrm{V_i D}}{\mathrm{V_O - V_i}} = \frac{\mathrm{V_i^2 D^2 T}}{2\mathrm{L(V_O - V_i)}} \tag{22}$$

However, the output voltage gain can be express as shown in eqn no (23):

$$\frac{V_O}{V_i} = 1 + \frac{V_i D^2 T}{2LI_O} \tag{23}$$

After comparing the outflow of the yield voltage gain up for persistent mode, this expression turns out to be more convoluted. Besides, in discontinuous operation, the yield voltage gain depends both on the duty cycle (D) and on the inductor value (L), the input voltage (Vi), the communication time frame (T) and the yield current (Io).

In this project, we experimented with three different types of booster circuits namely

- Closed-loop Non-Inverting Circuit
- DC-DC Converter (step up) Circuit
- Micro Voltage Booster Circuit

3.1.1Closed-loop Non-Inverting Circuit

Op-amp is utilized as a part of two essential arrangements to lift voltage in circuits. One is the non-inverting amplifier where the yield is in a similar stage with the given input and the other is the transforming enhancer where the yield is the reverse with the connected input.

In this sort circuit it is extremely important to know the input impedance. The input impedance of non-inverting amplifier circuit is ought to be high, and might be kept more than $10^7\Omega$. This is a huge distinction to the inverting design of an op-amp circuit which gave just a low impedance subordinate upon the estimation of the input resistor.

Voltage series Feedback Amplifier

Voltage series feedback amplifier circuit as appeared in fig 3.4 is otherwise called non-inverting amplifier with input or otherwise called closed loop non-inverting amplifier. In this information flag is connected to the non-inverting input end of the amplifier [15]. As the gain feedback is taken from the yield end by putting a resistor to the transforming contribution of the operational enhancer where another resistor is associated with the ground. By doing the experiment we can easily see that it is not the value of these two resistors that govern the gain of the op-amp circuit but is their ratio [15] i.e.

$$\text{Gain,} \quad A_v = \frac{Vout}{Vin} = 1 + R_f/R \qquad (24)$$

Where R_f is the feedback resistor (in our case, R_f=33.33kΩ) and R = 2.22kΩ is the external input resistance.

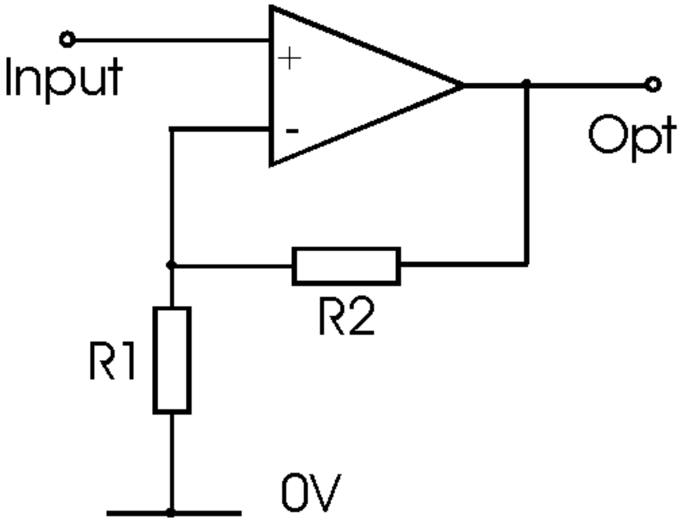


Fig 3.4: Block Diagram of an Op-Amp [7]

We can without much of a stretch decide the pickup of the non-upsetting intensifier circuit for the operation amp. The computation moves around the way that the voltage at the both sources of info (rearranging and non-altering) is the same. Along these lines emerging the way that the pickup of the enhancer is exceptionally surpassing. [7].

As the input to the operational-amplifier draws no charge this implies the charge streaming in the both resistors R_f and R is the same. The voltage at the transforming input end is produced from a potential divider comprising of Rf and R, and as the voltage at both data sources closes inverting and non-inverting end is the same. This means that

$$V_{in} = V_{out} * \frac{R_f}{R_f + R} \quad (25)$$

The amplifier output will go into saturation if the input is allowed to float [17].

An external supply of 12-15V has to be applied. It only amplifies the voltage not the current but is enough to glow a LED. Therefore, we do not prefer such type of circuit to boost up the voltage.

3.1.2 DC-DC Converter (using IRF 150) Circuit

In the DC-DC converter we for the most part utilize the DC input (V_{in}) = 0.3V. Where MOSFET (*M1*) go about as a switch control is shut for the timeframe *t1*, accordingly in the inductor (*L1*) current begin rising and vitality is begin putting away in the inductor and as the switch is opened for the timeframe t2, the vitality put away in the inductor is begin to exchange from inductor to stack through thyristor (*X1*) in this way creating the present fall in inductor current.

For our venture we utilized MOSFET *M1* (IRF-150) transistor and the pulse voltage (V_S) is V_1=0.0V, *TD*=1.0m, *TR*=0.0us, *TF*=0.0us, *PW*=7.0ms, *PER*=10.0ms is provided for an exchanging reason for opening and shutting purposes. As an expansive capacitor (*C1=100uf*) is associated parallel to the heap, along these lines making the yield voltage is ceaseless and Vout turns into the normal esteem. By differing the obligation cycle we can undoubtedly have ventured up the voltage and the base yield voltage which we can acquire is Vin when obligation cycle = 0. For our trial we utilized inductor (*L1*) 4.7uH for putting away the present, Resistor (*R1*) is 10kΩ utilized for the best yield, we utilized capacitor (*C1*) 100uF for putting away voltage so that yield voltage can be channel to lessen creating swell. Ultimately we can accomplish the yield voltage of 1.78V subsequent to utilizing the DC-DC converter.

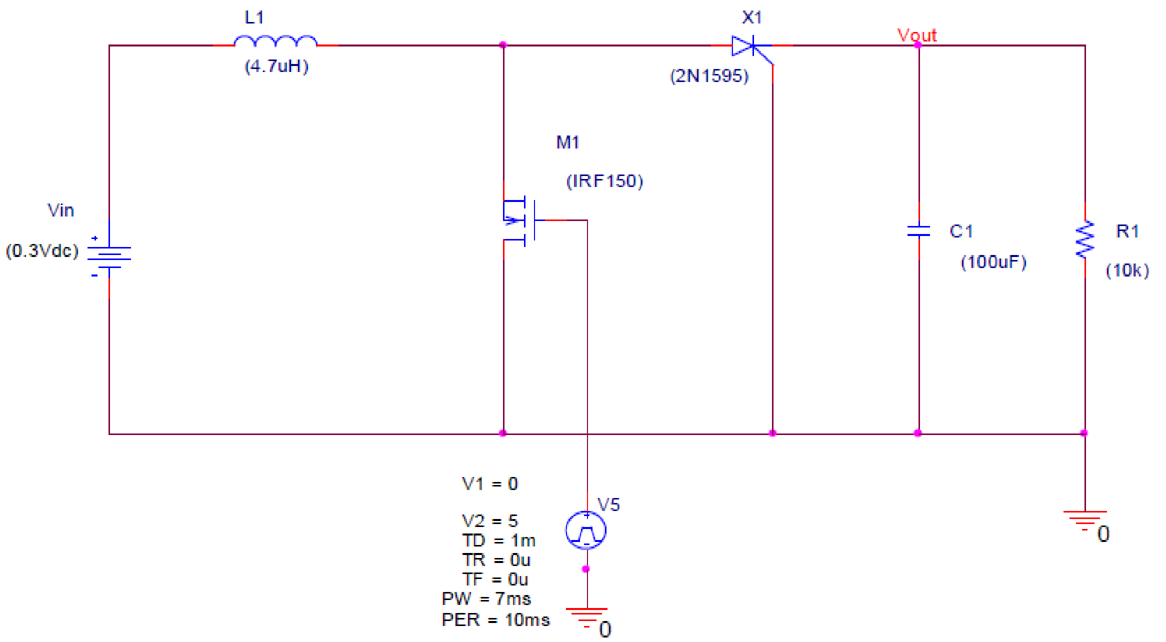


Fig 3.5: DC converter (using IRF 150) circuit. [12]

External pulse is supplied to the circuit. Moreover, the MOSFET used in the circuit is not readily available. Therefore, we do not prefer such type of circuit to boost up the voltage.

3.1.3 Micro Voltage Booster Circuit

This Circuit consists of a **Sziklai Darlington Pair**. Hungarian inventor George Sziklai design this **Sziklai Darlington Pair**, it consists of compound and complementary Darlington pair device that contain of both PNP and NPN complementary transistors connected side by side as shown fig 3.6:

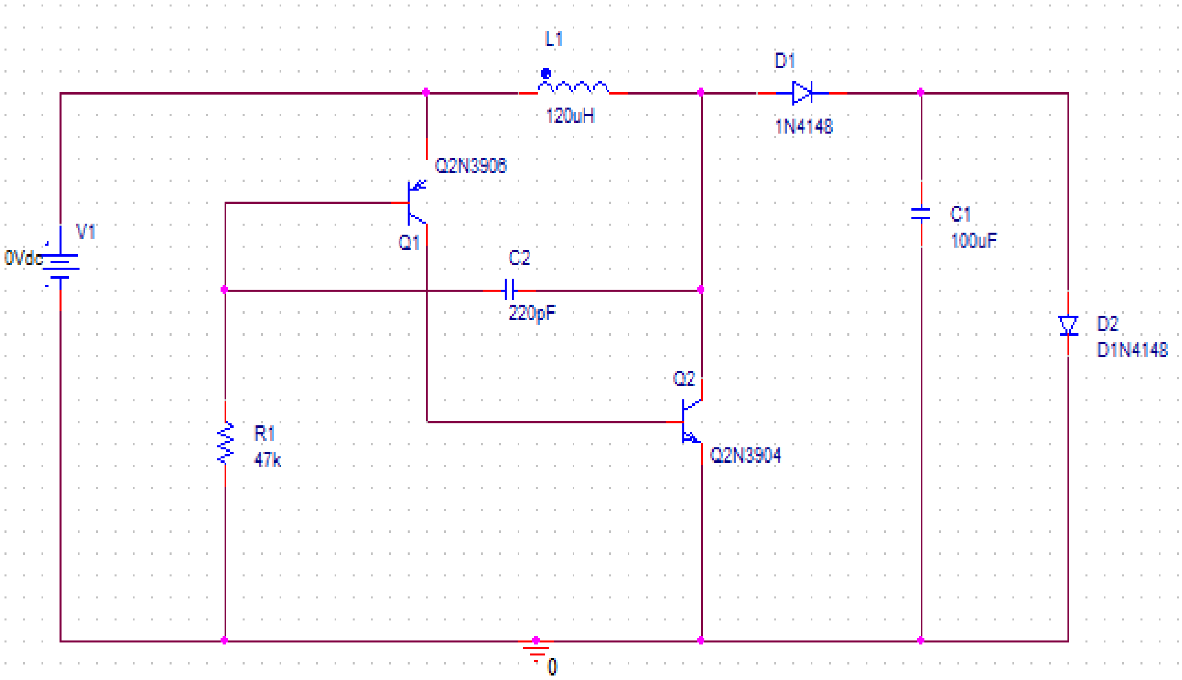


Figure 3.6: Circuit of micro-voltage booster. [13]

This cascaded circuit of both PNP and NPN transistors has the advantage over other booster circuit as the other Sziklai Darlington pair fulfil the common properties of a Darlington pair but as it requires *0.6V* for excitation (turn-on) and like the other standard Darlington setup, the present current gain ends up to noticeably equivalent to β2 for similarly coordinated transistors or is taken by the augmentation of the two current gains for unmatched individual transistors.

The circuit takes very low input values, which are stepped up to a value that is sufficiently higher than the input. To demonstrate the working of the circuit, an LED is connected across the output. Input voltage in the range of 0.6 to 1V is given. The input is boosted up and is used to glow the LED.

Chapter – 4

Indigenous Development of Project

4.1 Proposed Work

The whole process was carried out while cooking food on a burning furnace in the mess of Jaypee University of Information Technology, Waknaghat. Junction temperature that was marked as cold or surrounding temperature at the time when experiment took place was 11-16°C.The potential difference so obtained by thermopile of J, K and T type was highly fluctuating. The voltage obtained shows its peak value in the initial cooking stage when food requires maximum heat since the amount of waste heat generated was large. This voltage is generated while holding the aluminium sheet with thermocouples or thermopiles stuck on it in hand since the chimney in the student mess at Jaypee University, Waknaghat is at a certain height but the chimneys in our homes is located just above the cooking stove thus we can stick the aluminium sheet on the chimney itself.

4.1.1 Home Chimney

The chimney used for this project is a basic home chimney. To capture the waste heat from the food being cooked, we used two metal sheets, one of a tin alloy and another of iron. The dimensions of the sheets being used are 40cm × 27.5cm. Referring to the table 2.1, total length of the thermocouples taken is of 32.5cm of each type. Time taken to heat up so as to provide potential difference of 1mV is 35secs to 1min.

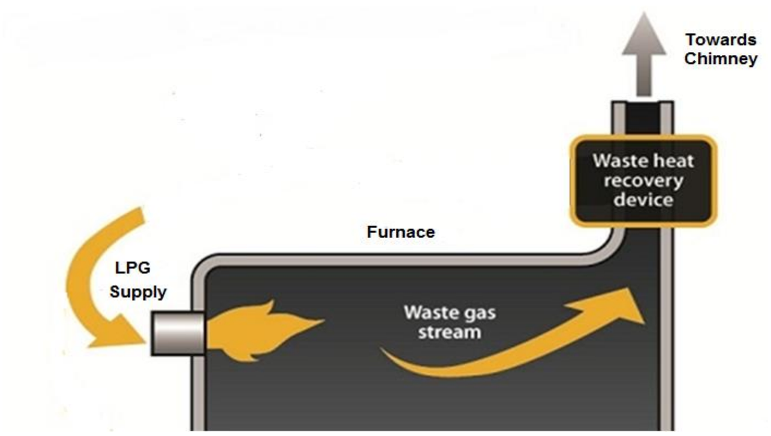


Fig. 4.1 Home chimney energy harvesting process (block diagram).

Placing of Thermopiles on the Metal Sheet Placed on the Chimney

After welding and combining the thermocouple wires, the thermopile so generated is now placed in such a way so that the efficiency as a whole is maximized. All the connections are done in series with one of the temperature zone, here the hot temperature zone is kept towards the captured waste heat, with the cold junctions being placed in the surrounding air so that sufficient amount of temperature difference is generated for the production of electricity. The thermopiles are stuck to the metal sheet using the kapton tape. The kapton tape is heat resistant and works well for holding a thermocouple temporarily in place. Referring to Table 2.1, the length of the Type- J, K and T alloys, are so chosen that 22.5cm length of alloys were exposed to the captured heat and 10 cm length of alloys were placed on the metal sheet to remain stuck to it. Four thermocouples were being gas welded together so as to get a combined result of the thermopile. Copper wires that were attached to get the readings from the thermopile were kept at the same temperature as that of the temperature of cooler region. There by obeying with the Law of Intermediate Materials and thus not affecting the readings much.

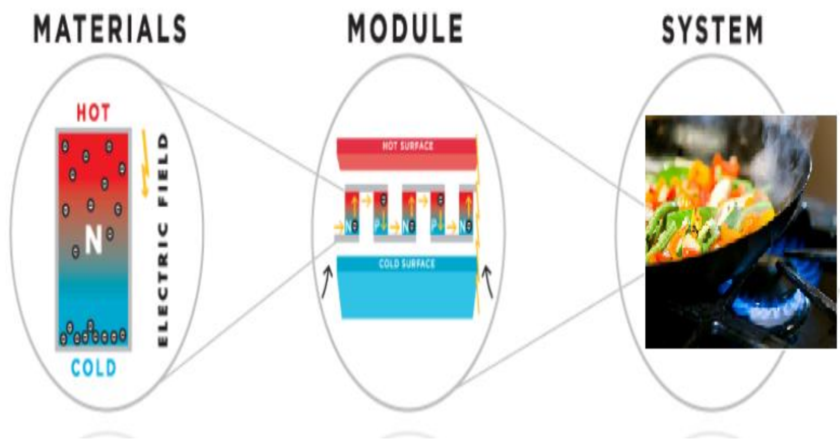


Fig. 4.2: Diagram to show working of thermoelectric generators [10]

J-type, on an average gave 14-15 mV(shown in table 4.1) on normal conditions i.e. when the difference in the temperature between the captured heat and the surroundings were sufficient enough. That happened after 10-12 mins of cooking at low flame. After every 50-60 secs of cooking at low flame, there was 1mV rise in the potential till the temperature becomes constant. After every 30-40 sec, 1mV rise in the potential was observed when food was cooked at high flame, till the temperature becomes constant.

K-type gave an average value of 10.5mV on the low flame and on full flame, reached a peak of 20-25mV (shown in table 4.1). There were high chances of error in K-type due to the thickness of the alloy (16 gauge). Voltages in most of the cases were constant and fluctuations though appeared but were stabilized when it reached a specific temperature.

T-type with the least thickness (24 gauge) comparatively produced less significant results. Average voltage that appeared when T-type was being used is 8.5-9 mV (shown in table 4.1).

Table 4.1 Voltage Generation by a Single Thermocouple

Types	**Voltage Generated**
J	14 - 15 mV
K	10.5 mV
T	8.5 - 9 mV

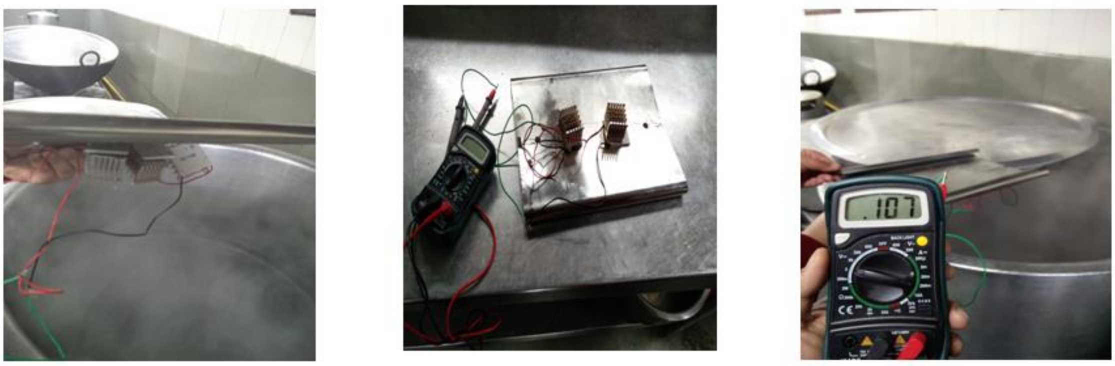


Fig 4.3 Capturing heat while using a number of thermopiles in series

Table 4.2 Voltage Generation by Thermopile in Series

No. of TEG's in series	**Time (1 min)**	**Time (4 mins)**	**Time (7 mins)**	**Time (10 mins)**
2	110 mV	147 mV	182 mV	212 mV
3	125 mV	172 mV	257 mV	341 mV
4	182 mV	293 mV	375 mV	491 mV

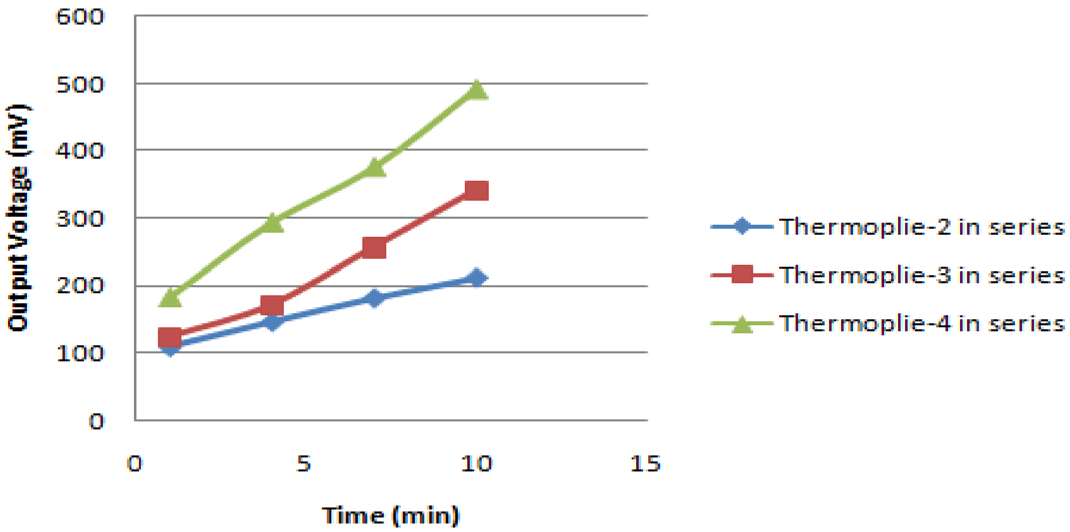


Fig 4.4 Graphical Representation for using a number of thermopiles in series

4.1.2 Results with Micro Voltage Booster Circuits

Micro Voltage Booster (with Capacitor 100uF)

As mentioned, operational amplifier requires an extra external voltage therefore, we moved to micro booster circuits. A voltage booster circuit that takes very low input values (in the range of mV) and gives a boosted output and can drive low power devices. The circuit employs a Sziklai Darlington pair. In this circuit, we use capacitor of value 100 µF is the boosting device. The circuit takes very low input values, which are stepped up to a value that is sufficiently higher than the input (shown in table 4.3).

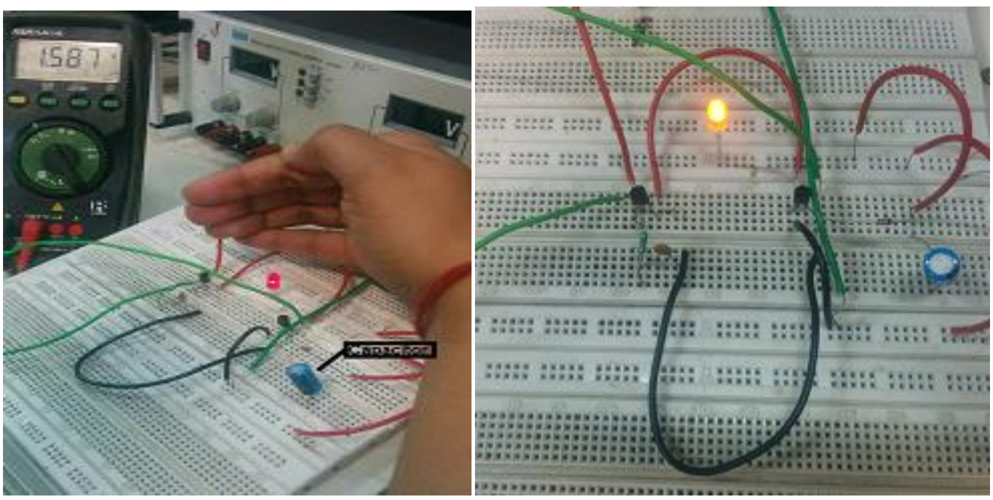


Fig. 4.5 Micro Voltage Booster Circuit (with Capacitor 100uF)

Table 4.3**:** Output Voltage and Output Current due to Capacitor (100 µF)

V_i(V)	Observed Voltage		Calculated Voltage		% Error		LED
V_i(V)	V_o(V)	I_o(mA)	V_o(V)	I_o(mA)	Voltage	Current	On/Off
0.028	0.387	0.024	0.452	0.027	14.38%	11.11%	Off
0.1	0.571	0.047	0.654	0.052	12.69%	9.61%	Off
0.2	0.780	0.079	0.819	0.085	4.76%	7.05%	On
0.3	0.992	0.164	1.066	0.172	6.94%	4.65%	On
0.4	1.178	0.178	1.243	0.189	5.23%	5.82%	On
0.5	1.286	0.187	1.354	0.193	5.02%	3.11%	On
0.6	1.497	0.198	1.582	0.204	5.37%	2.94%	On
0.7	1.612	0.211	1.694	0.216	4.84%	2.31%	On
0.8	1.723	0.223	1.755	0.227	1.82%	1.76%	On
0.9	1.887	0.231	1.966	0.236	4.02%	2.11%	On
1	1.998	0.239	2.056	0.244	2.82%	2.05%	On

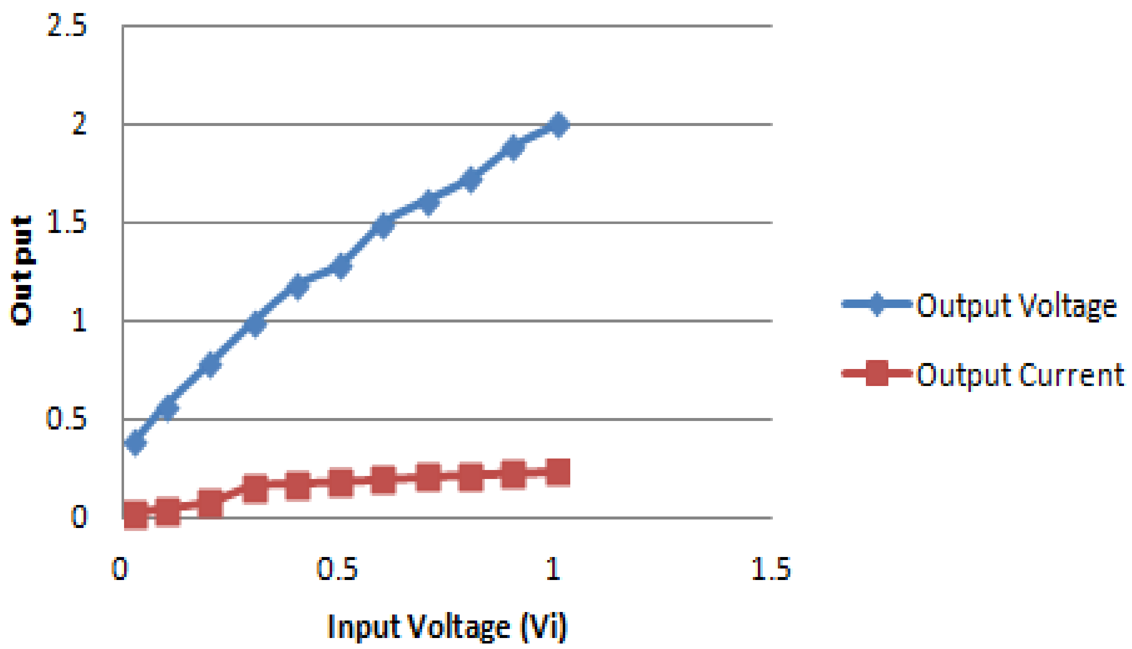


Fig 4.6: Input Voltage v/s Output for Capacitor (100 µF)

Micro Voltage Booster (with Resistor 2.2 kΩ)

As mentioned, operational amplifier requires an extra external voltage therefore, we moved to micro booster circuits. (fig :4.7) In this circuit, inductor of value 2.2 kΩ is the boosting device (shown in table 4.4).

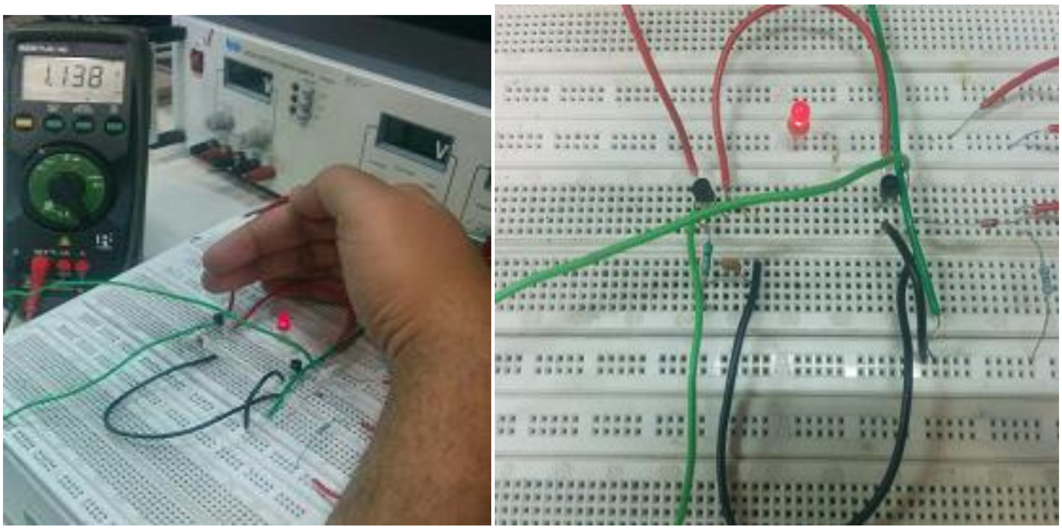


Fig. 4.7: Micro Voltage Booster Circuit (with Resistor 2.2 kΩ)

Table 4.4**:** Output Voltage and Output Current due to Resistor (2.2kΩ)

V$_i$**(V)**	**Observed Voltage**		**Calculated Voltage**		**% Error**		**LED**
V_i**(V)**	V_o**(V)**	I_o**(mA)**	V_o**(V)**	I_o**(mA)**	**Voltage**	**Current**	**On/Off**
0.028	0.358	0.159	0.37	0.168	3.24%	5.35%	Off
0.1	1.215	0.562	1.257	0.571	3.34%	1.57%	On
0.2	1.798	0.818	1.817	0.826	1.05%	0.96%	On
0.3	2.089	0.947	2.114	0.961	1.18%	1.45%	On
0.4	2.304	1.048	2.332	1.06	1.20%	1.14%	On
0.5	2.510	1.136	2.528	1.149	0.71%	1.13%	On
0.6	2.651	1.204	2.664	1.211	0.49%	0.58%	On
0.7	2.801	1.263	2.813	1.279	0.43%	1.25%	On
0.8	2.925	1.326	2.936	1.334	0.37%	0.59%	On
0.9	2.998	1.372	3.05	1.386	1.70%	1.01%	On
1	3.152	1.429	3.17	1.441	0.57%	0.83%	On

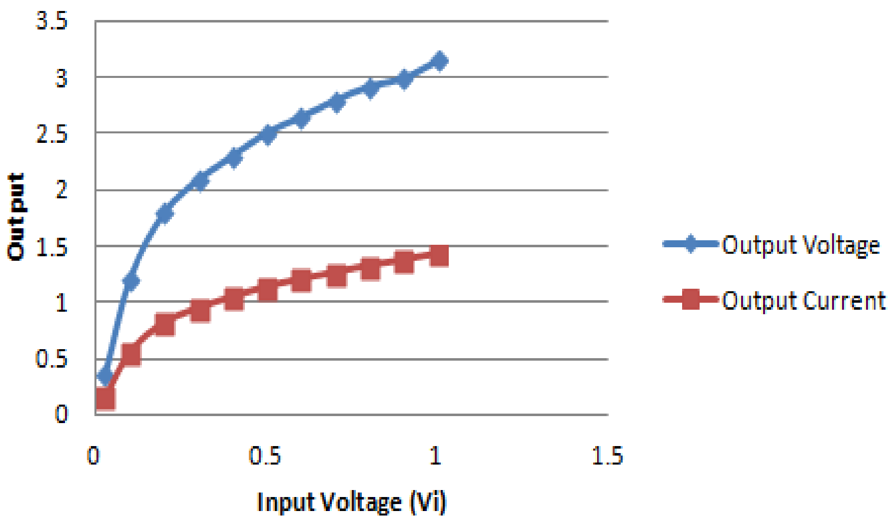


Fig 4.8: Input Voltage v/s Output for Resistor (2.2 kΩ)

Micro Voltage Booster (with Inductor 21 mH)

As mentioned, operational amplifier requires an extra external voltage therefore, we moved to micro booster circuits. (fig :4.9) In this circuit, inductor of value 21 mH is the boosting device (shown in table 4.5).

Table 4.5**:** Output Voltage and Output Current due to Inductor (21mH)

V_i(V)	Observed Voltage		Calculated Voltage		% Error		LED
V_i(V)	V_o(V)	I_o(mA)	V_o(V)	I_o(mA)	Voltage	Current	On/Off
0.028	0.407	0.182	0.42	0.191	3.10%	4.71%	Off
0.1	1.612	0.728	1.623	0.737	0.68%	1.22%	On
0.2	3.381	1.535	3.394	1.543	0.38%	0.52%	On
0.3	4.783	2.176	4.791	2.184	0.17%	0.37%	On
0.4	6.321	2.704	6.337	2.712	0.25%	0.29%	On
0.5	7.914	3.413	7.928	3.421	0.18%	0.23%	On
0.6	9.506	4.291	9.516	4.302	0.11%	0.26%	On
0.7	11.369	5.107	11.384	5.118	0.13%	0.21%	On
0.8	12.763	5.665	12.773	5.675	0.08%	0.18%	On
0.9	13.927	6.624	13.936	6.631	0.16%	0.11%	On
1	13.938	6.677	13.948	6.682	0.07%	0.07%	On

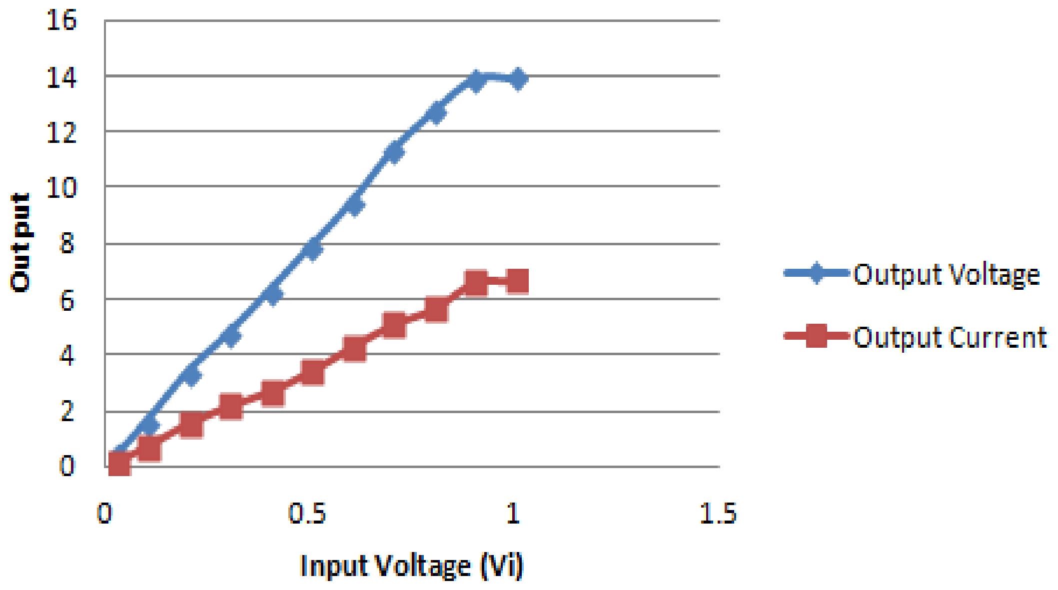


Fig 4.9: Input Voltage v/s Output for Inductor (21 mH)

After comparing all the booster circuit (with inductor, capacitor and resistor), we can see best result we are getting from inductor (see fig 4.10).

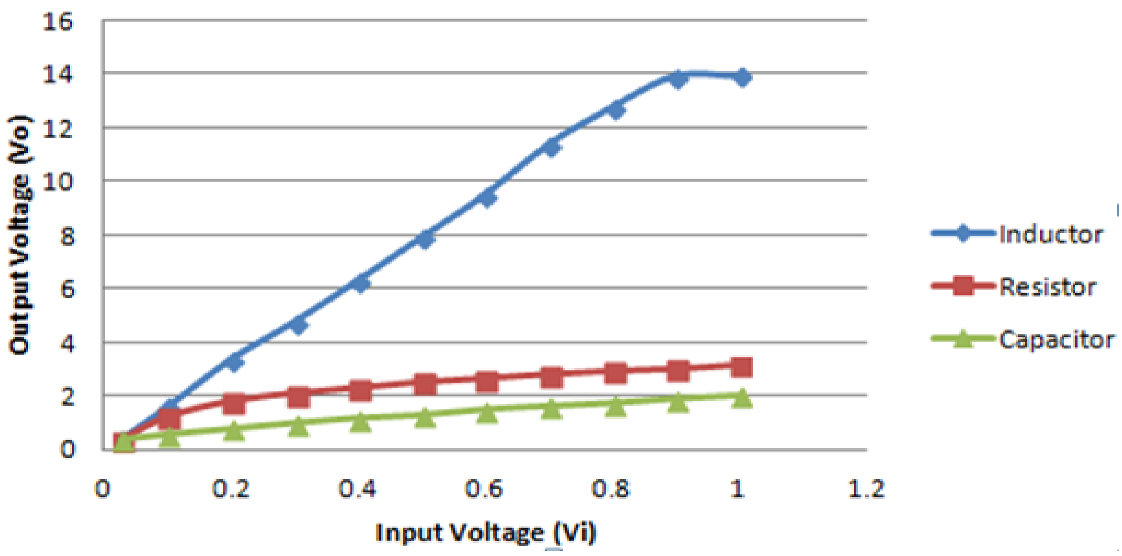


Fig 4.10: Comparison between different Micro Voltage Booster Circuits

Fig 4.11: Final circuit (including both thermopile and booster circuit)

From these readings, we infer that amongst all, inductor is the best one to be tapped because like resistor, the output increases with the increase in input voltage but to a greater value.

From all the results, we can easily see that best output is coming from inductor, but as we know inductor make circuit complex, so we used capacitor for our final circuit and connected thermopile with our best booster circuit (micro voltage booster) as shown in fig 4.11. In this we have connected four thermopiles in series with micro voltage booster to glow the LED.

During the project, there were certain sources of error. Few of them have been listed here.

i) While placing the thermopiles on the metal sheet, there are chances that you may fail to get an output. This is so because the heat is not captured in a correct manner which is therefore not able to generate a minimum amount of temperature gradient between the hotter and colder junction thereby not giving significant results.

ii) On measuring, there were fluctuations in the readings. This can be due to the fact that the heat being captured is not constant throughout the cooking process or the thermopiles are not firmly stuck to the metal sheet. Moreover, the temperature of the hot leg highly depends on the heat being generated during the cooking process. The reason for fluctuation in the readings may also because of the susceptibility of thermocouples to noise. Another factor may be the aging of thermocouples.

iii) At certain time, there was a sudden increase in the peak voltage due to the surroundings conditions. This may damage any circuit that can be implemented further. Thus, proper measurements have to be taken to avoid the hike.

iv) All the outputs highly depend upon the vicinity; therefore, the results may vary accordingly.

CONCLUSION

In this project, we have tried to show the utilization of waste heat which could be extracted out from the food being cooked and harvest this heat to generate electricity. We have contrasted the working and the output voltages of the three types of alloys used to convert heat energy to electrical energy. The values fluctuate with the change in the ambient conditions. All the three types of thermocouples namely J, K and T gave the satisfactory results though in mill volts but on using booster circuit, we can amplify the output voltages and this voltage can be brought into use in various forms. This is one more step towards greener source of energy as it doesn't hinder the normal cooking process and the waste heat which is usually emitted out in the atmosphere is now of use. The amplified output voltage can be thus used for operating home appliances.

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List of Publications

1. Kaushik Raj Singh, Ossein Sharma . Mansi Kathuria, Shruti Jain, " Design of Energy Harvesting Generators from Waste Heat of Home Chimney using Thermocouples" March 1st - 3rd , 2017, pp 6278-6281, Proceedings of the 11th INDIACom: 4th 2017 International Conference on Computing for Sustainable Global Development, BVICAM, New Delhi.

Design of Energy Harvesting Generators from Waste heat of Home Chimney using Thermocouples

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***Abstract* - In this paper we are going to convert waste thermal energy into productive electrical energy. With increase in the number of industries day by day, we continuously read about the thermal energy wastage and the harm it is causing to our environment. To use and conserve energy efficiently is of paramount importance. Thus to do our bit for the environment, conversion waste energy not only from smoke but also from electrical appliances to useful voltage that may be used to operate a mobile charger or some other appliances. We have obtained 43.3mV as cold junction of thermocouple in cold water. To widen our scope we further input our thermocouple voltage to DC-DC booster circuit to boost up the voltage to greater scale with negligible effect on current.**

Keywords : Waste thermal energy, thermocouples, mobile charger

I. INTRODUCTION

The efficiency of the **cooking appliances** is only around 35% and the remaining 50 - 55% of energy is lost as heat to the environment. The major source of loss in the conversion process is the heat rejected to the surroundings due to the many inherent constraints. Therefore, the energy saving is one of the key issues, from the view point of LPG consumption so as to provide every single household a LPG subsidy. Waste heat can be recovered either by exchanging the energy with other materials/fluids (such as in heat exchangers) or by converting to another form of energy (e.g., thermal to electric i.e. **Thermocouples**).

Thermocouples are most commonly used as temperature sensors but they can also be used for voltage generation. So, we can use them to convert thermal energy to electrical energy with the help of temperature differences. By the use of the thermoelectric effect, waste heat [1- 4] of home chimney can be used for voltage generation. Thermoelectric effect is the conversion of temperature differences into electric potential