Palestine Polytechnic University

Collage of Engineering

Mechanical Engineering Department

Hebron – Palestine

Building A Solid-State Refrigerator Using Thermoelectric Cooler

By

Shadi Sarahneh Momen Al-Himony

Submitted to the Collage of Engineering

In partial fulfillment of the requirements for the

Bachelor degree in Automotive Engineering.

Supervisor Signature

………………………………………………….. 5/2/2020

Department Head Signature

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Jan. 2020

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إلى المعلم الأول .. إلى قائد هذه الأمة وقدوتها .. رسولنا محمد صلوات الله سلامه عليه

إلى من كلله الله بالهيبة والوقار .. إلى من علمني العطاء دون انتظار .. إلى من أحمل اسمه بكل افتخار .. أرجو من الله أن

يمد في عمرك لترى ثماراً قد حان قطافها بعد طول الانتظار وستبقى كلماتك نجوما اهتدي بها اليوم وفي

الغد والى الابد

(والدي العزيز)

إلى ملاكي في الحياة .. إلى معنى الحب والحنان والتفاني .. إلى بسمة الحياة وسر التميز

إلى من كان دعائها سر نجاحي وحنانها بلسم جراحي إلى أغلى الاحباب.

(أمي الغالية)

إلى الشموع التي تحترق لتنير لنا الطريق .. إلى منهل العلم والمعرفة .. إلى من عبرنا على أيديهم وبمساعدتهم

ورعايتهم إلى بر الأمان .. إلى من علمونا حروفاً من ذهب وكلمات من درر.

(أساتذتنا الأفاضل)

إلى من سرنا سويا نشق الطريق معا نحو النجاح والابداع... وإلى كل من مررنا بهم على الدرب العلم والمثابرة.

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إلى رفقاء الدرب .. رجال المواقف .. أصحاب الهمم والطموحات العالية .. عنوان المثابرة .. إلى من تحلوا

بالإخاء .. وتميزوا بالصدق والعطاء

(أصدقائي الأحباب)

إلى الوطن الغالي .. إلى الأرض التي احتضنتنا

إلى السنبلة الذهبية في بلادي و بيارات البرتقال...إلى كروم العنب وغصن الزيتون.. ودم الشهداء

الى تلك التي صنعتني كي أكون هنا

(فلسطين الحبيبة)

Abstract

The goal of this project is to build solid-state refrigerator that can be imbedded inside vehicle and passenger compartment using Thermoelectric Cooler (TEC). Its main aim is to help people who need cooler for their personal purposes, such as medicine, food and drink. The most important utilization is for the preservation of medicine like insulin that needs to keep temperature under control. A Thermoelectric Module (TEM) is used instead of traditional design that used compressor, so it becomes solid-state as it is based on the principles of Peltier effect. The use of Peltier effect is to create heating and cooling sides, also to maintain effectiveness, where electric power supply is used from waste energy like heat from exhaust or cold water from radiator.

The design of the refrigerator is based on heat transfer principle of thermoelectric generator in order to develop the cooling effect, in addition to the heat sink and fins are added to the hot side for cooling down the temperature.

The design should be able to keep a suitable temperature (10-14)°C inside the refrigerator, which is suitable for preserving food and medicine. Furthermore, it creates no vibration or noise in the system.

الملخص

الهدف من هذا المشروع هو بناء ثلاجة (Solid-state) يمكن دمجها داخل مقصورة السيارة والركاب باستخدام مولد حراري كهربائي (TEC). الهدف الرئيسي منه هو مساعدة الأشخاص الذين يحتاجون إلى تبريد أغراضهم الشخصية، مثل الدواء و الطعام والشراب. الاستخدام الأكثر أهمية هو الحفاظ على الدواء مثل الأنسولين الذي يحتاج إلى الحفاظ على درجة الحرارة مناسبة ومسيطر عليها. يتم استخدام الوحدة الحرارية (TEM) بدلاً من التصميم التقليدي الذي يستخدم الضواغط والأجزاء الأخرى في الثلاجة التقليدية بحيث تصبح قابلاً للنقل وسهلة التعامل معها، تعتمد في عملها على مبدأ تأثيرPeltier. يتمثل استخدام تأثير Peltier في إنشاء جانب ساخن وجانب بارد يتم استخدامه في تبريد الثلاجة. مصدر الطاقة الكهربائية هو من الطاقة المهدرة على شكل حرارة مثل الحرارة الخارجة من العادم أو من الحرارة الناتجة من مياه تبريد المحرك.

تصميم الثلاجة يقوم على علوم انتقال الحرارة لتقديم التبريد اللازم ولزيادة كفاءة التبريد تم إضافة مشتت حراري مع مروحة على الجهة الساخنة للقطعة.

يجب أن يكون التصميم قادراً على الحفاظ على درجة الحرارة مناسبة إلى (14-10)°س داخل الثلاجة، وهي درجة الحرارة المناسبة للحفاظ على الطعام والأدوية، ولا يخلق أي اهتزاز أو ضوضاء في النظام.

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We would like to thank our supervisor Dr.Momen Sughayyer, who gave us a lot of his time and expertise to complete this project and to achieve its objectives. Eng. Mosa Zalloum, who gave us what we need to accomplish our goals, and gave us the chance to put our knowledge into our professional life.

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Finally, we must express our very great to our parents for providing us with support and continuous encouragement throughout our years of study and through the process of researching and writing this project. This accomplishment would not have been possible without them.

Thank you

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List of Abbreviations

Q_{active}	Active heat load	TEG	Thermoelectric generator
TEC	Thermoelectric cooler	COP	Coefficient of performance
m	Mass of products	C_p	Specific heat capacity of water
Δt	Desired cooling time	C_p	Specific heat capacity of air
T_i	Initial air temperature	V	Volume of product
ρ	water density	m_f	Mass product of infiltrated air
Q_{ifn}	Heat losses by air change	T_i	Inside air temperature
T_0	Outside air temperature	A	Heat transfer surface area
V_f	Volumetric flow rate of infiltration air	T_h	The hot side of the couple
ΔT	Temperature difference	x	Thickness of the wall
k	Thermal conductivity for material	h	Convection heat transfer coefficient
Rth	Thermal resistance of heat sink	Q(p,tot)	Total heat that to be dissipated by Peltier module hot side heat sink
Vf	Volumetric flow rate of inflation air	T_{avg}	Average temperature
Q_p	Heat produced by the Peltier module	V	The output voltage from the couple

Chapter 1
Project Overview

1.1 Introduction

People travel all over the country for hours and don't have enough space to bring a large refrigerator to put things they need either food, drinks or medicine during their track and outdoor activities. In addition, it is useful when there are no break stations along the trips. It is not practical to start cooling things at home before travelling. By the time, things lose their coolness. Our purpose is to Build a solid-state automotive refrigerator for automotive application to meet all these cooling demands, as shown in Figure 1.1.

Figure 1.1: Solid-state Refrigerator

While traditional refrigerators have a compressor, a condenser and a liquid refrigerator to maintain the suitable temperature that causes noise and uncomfortable vibes, it absorbs a lot of power. The thermoelectric cooler (TEC); is a solid-state cooling which uses DC power, heat sink and semiconductors. The figure 1.2 it shows type of refrigeration.

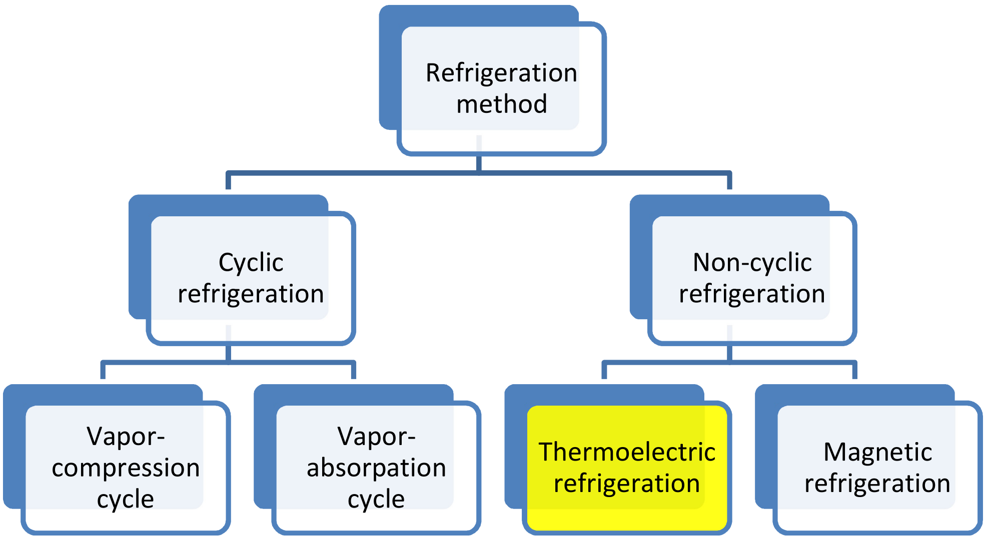

Figure 1.2: Refrigeration Method

A (TEC) is a small refrigerator which has no moving parts and is used in automobile where the space limitation and light weight could be portable and could be could be realized in almost in any shape.

The solid-state refrigerator is designed to utilize power from wasted energy in the automobile by using thermoelectric generator (TEG) to power the modules which the vehicle electric system should be completely off. The wasted energy like exhaust heat energy is going to be absorbed, transformed and fed back to the vehicle to power the modules. Table 1.1, is shows the Comparison between thermoelectric refrigerator and conventional refrigerator.

Table 1.1: Comparison with conventional refrigerator

No	Criteria	TE refrigerator	conventional refrigerator
1	**Cooling method**	Noncyclic refrigeration	Vapor compression cycle
2	**Components**	Thermoelectric module	Condenser, Compressor, Evaporators
3	**Main advantage**	Environmentally friendly	Not environmentally friendly
4	**Operation volts**	12 Volts -DC	220 Volts -AC
5	**COP**	Comparatively low	High COP
6	**Uses**	Preservation Insulin etc.	Ice, Cold water etc.

1.2 Goals and Objectives

The general goal of this project is to build a solid-state refrigerator air conditioning system which is easy to be installed everywhere inside the passenger compartment that uses thermoelectric generator (TEG) rather than using conventional refrigerators and the use of compressor and refrigerants that are harmful to the environment due to the emission of gases such CO_2 as caused by the production of the refrigerants and refrigeration cycle components. This refrigerator takes the power from the wasted energy like heat from exhaust and controls the temperature heated.

1.3 Methodology

In this project, the refrigeration chamber geometry is designed, based on the average of capacity that exists to cooling the objects inside the refrigerator. Calculation the refrigeration heat load is used to determine the load in the refrigerator. Selecting the suitable Peltier module is vital to give us the desired electricity from wasted energy and to get the desired cooling to the refrigerator, and to choose the suitable way for controlling the temperature.

1.4 Literature review

This subject is about previous studies which presents the methods used by researchers in this topic which can be beneficial from their experiences.

1. S. Chinguwa, C. Musora, and T. Mushiri, "The design of portable automobile refrigerator powered by exhaust heat using thermoelectric," Procedia Manuf., vol. 21, no. 2017, pp. 741–748, 2018.[1]

A cool box for passenger car refers to a kind of box which is designed and fabricated using well insulating materials in order to ensure the coolness inside the cool box is always stable. Convectional refrigeration systems use ChloroFluoro Carbons (CFCs) and Hydro-Chlorofluorocarbons (HCFCs) as heat carrier fluids. The use of such fluids has over the years raised some very serious environmental concerns which has resulted in extensive research into development of novel refrigeration technologies. Thermoelectric Refrigeration (TER) has emerged as a promising refrigeration technology as it comes with far more distinctive advantages over conventional refrigeration systems. The research and development work carried out by different researchers on TER is thoroughly reviewed in this research. Having looked on these refrigeration systems Thermoelectric Cooler (TEC) refrigeration was used in the design of a 20-liter portable automobile refrigerator. In this design a Thermoelectric Generator (TEG) waste heat recovery system was designed to meet all the TEC refrigerator power requirements. Thus, an internal combustion engine TEG system designed includes a stainless-steel exhaust gas heat exchanger having an interior portion defined by a stainless-steel wall and an exterior surface of the stainless-steel wall distal to the interior portion. The exhaust gas heat exchanger receives a pressurized exhaust gas stream from the internal combustion engine and extracts thermal energy from the exhaust gas stream. The TEG modules converts thermal energy directly into electrical energy for TEC refrigerator consumption as well as storage for later use. Thus, in this design a percentage of exhaust heat that could have otherwise be rejected into the environment is used in the generation of DC power to meet the TEC electrical power requirement making this system an independent system altogether thereby reducing the number of mechanical loads on the vehicle itself

- **The study conclusion that:**

TEG waste heat recovery system to power the portable automobile TEC refrigerator was designed step by step. The first step was to design the independent electrical power source considering all the design requirements. The second step was to design the power conditioning unit (DC-DC Converter) to ensure stable and constant voltage supply to meet TEC fridge requirements. The third step was to design the portable automobile TEC refrigerator considering all the design requirements

2. B. Orr and A. Akbarzadeh, "Prospects of Waste Heat Recovery and Power Generation Using Thermoelectric Generators," Energy Procedia, vol. 110, no. December 2016, pp. 250–255, 2017.[2]

Thermoelectric generators (TEGs) are small solid-state devices that generate electricity directly from heat. They have the potential to be applied in waste heat recovery systems and be used as a primary heat engine as a generator. Two case studies are discussed showing the potential power generation from the exhaust gases of a car engine and an open loop gas turbine power plant. It was determined that it is possible to generate 1.4 kW of electricity from a car exhaust heat recovery system if the engine produces 150 kW. It was also determined that it is possible to generate 5.9 MW of electricity from a 500 MW gas turbine power plant waste heat recovery system. A design is proposed to show how TEGs could be used as a primary power source but TEGs must improve their power per unit cost before they become a viable alternative to petrol generators.

- **The study conclusion that:**

TEGs have been shown to have the potential to be applied to car exhaust heat recovery systems, industrial waste heat recovery systems and possibly primary power sources. A case study has shown that from a car with a 150-kW engine, it is possible to generate 1.4 kW of electricity from an exhaust heat recovery system. This is enough power to replace the alternator of the car and consequently reduce the fuel consumption. Another case study has shown that from a 500 MW open loop gas turbine power plant, it is possible to generate an extra 5.9 MW of electricity. This is enough power to power an extra 2950 homes with any extra fuel costs. In both cases only 0.59% of the waste heat is converted into electricity. The proposed design demonstrates how TEGs can be used as a primary power source. If the power per unit cost of TEGs keeps increasing with time, they will become more cost competitive with traditional petrol generators.

3. S. A. Abdul-wahab et al., "Design and experimental investigation of portable solar thermoelectric refrigerator," vol. 34, pp. 30–34, 2009.[3]

Conducted a construction for an affordable solar thermoelectric refrigerator for the Bedouin people living in remote parts of Oman where electricity is still not available. The refrigerator could be used to store perishable items and facilitate the transportation of medications as well as biological material that must be stored at low temperatures to maintain effectiveness. The design of the solar-powered refrigerator is based on the principles of a thermoelectric module to create a hot side and a cold side.

- **The study conclusion that:**

Experiment results demonstrated that the system performance was strongly dependent on the intensity of solar insolation and the temperature difference of hot and cold sides between the thermoelectric modules. The results indicated that the temperature of the refrigeration was reduced from 27 to 5 C in approximately 44 min. The (COP) is about 0.16

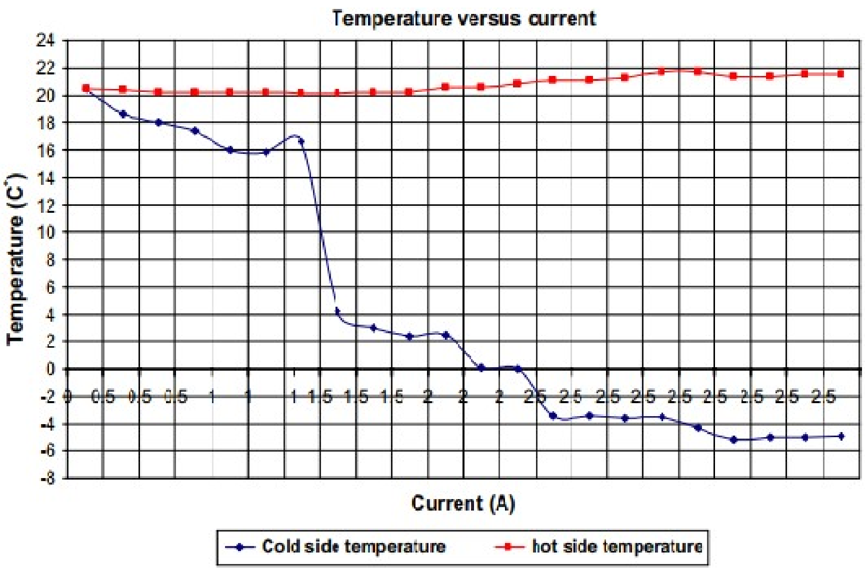

Figure1.3: Relationship between temperatures of sides of thermoelectric module and current

1.5 Time schedule of the project

Table 1.2: Time schedule of the first semester

Task/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Project selection																
literature review																
Planning																
Design and analysis																
Documentation																
Preparing and printing																
Preparation of presentation																

Table 1.3: Time schedule of the second semester

Task/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Refrigeration building																
Accessory selection																
System test																
Comparison																
Conclusion																
Preparing and printing																
Preparation of presentation																

1.6 Project cost table

Table 1.4: Project cost (NIS)

Component	Quantity	Cost of one unit (NIS)	Total (NIS)
TEG module	10	87.5	875
Heat sink	12	------	------
Refrigerator chamber	1	400	400
Battery	1	-----	-----
Boost converter	1	25	25
Temperature control switch module	1	6	6
TEC module	8	20	160
Total cost			1466

Chapter 2
Solid-State Refrigerator

2.1 The principle of Solid-State Refrigerator

The principle of Solid-State Refrigerator that use in this project, is cooling without using the compressor and evaporator, as the traditional refrigerator, the solid-state refrigerator will contain group of thermoelectric semiconductors. When applying the 12Volt-DC power source to the refrigerator. The one side of the semiconductor will be produced cooling and the other side produced heating. The solid-state operate principle by Peltier effect. The Peltier effect is converting the current and voltage to temperature when the flow of current will pass during the junction, and the power consumption of this refrigerator operate by SEEBECK effect. The SEEBECK effect is converting the heat from waste energy like heat in exhaust to voltage and current[3].

2.2 Construction of Peltier module

The is current is move through a two dissimilar semiconductor there will be a high or down of temperature at junction depending on direction of current flow. Electrons moved from p-type to n-type, Peltier module is constructed by two unique semiconductors materials most commonly is Bismuth Telluride (Bi_2Te_3). These p-type and n-type are linked, electrically in series and thermally in parallel and sandwiched between the ceramic plates, which they're ridged, thermally conductive and excellent electrical insulators, one side of junction is called cold side “heat absorbed “ and other side is called hot side “ heat rejection “, as shown in Figure 2.1

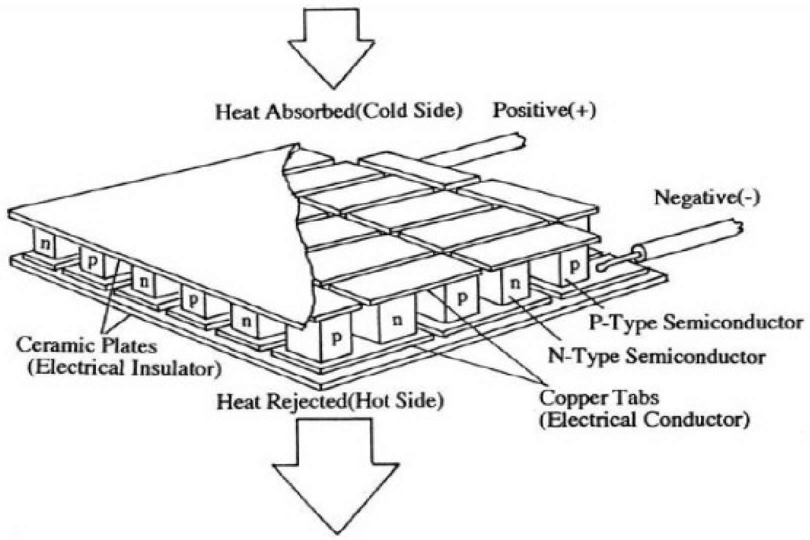

Figure 2.1: Construction of Peltier module[4]

2.3 Thermoelectric Generator

In an internal combustion (IC) engine, only 30% of the total heat produced in the fuel combustion is utilized for the vehicle, while the remaining 70% goes as waste energy like fraction, coolant and exhaust gas. The exhaust gas is mainly at a higher temperature compared to the engine coolant, as shown in figure 2.2.[1]

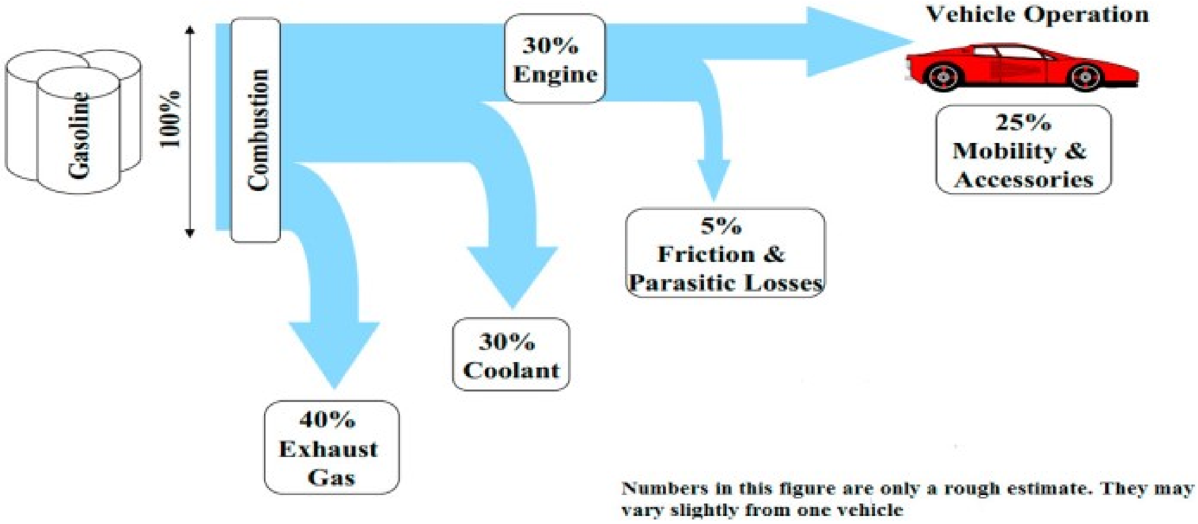

Figure 2.2: Energy losses in internal combustion engines.[1]

Thermoelectric generator (TEG) is also called SEEBECK generator that converts wasted energy like heat in exhaust (temperature difference) into electrical power without any rotating part. The best wasted energy that can be taken is exhaust energy and coolant energy. We chose to take the power from the exhaust because the pipe temperature can reach as far as (500-700) °C or more, this temperature difference between the hot side (exhaust pipe) and cold side (ambient temperature) can thus be several hundred Celsius degree. The TEG generate the power from potential temperature that generate between two sides of plates.

The high temperature that can be achieved in the exhaust pipe to operate the potential temperature between hot side and cold side sometimes is it be problems because we don't know where the idle spot for us putting the TEG. The idle location of TEG to achieve the potential temperature is before the catalytic converter (CC), because the catalytic converter is the last point of the exhaust system and the heat reduce through it, as shown in figure 2.3.

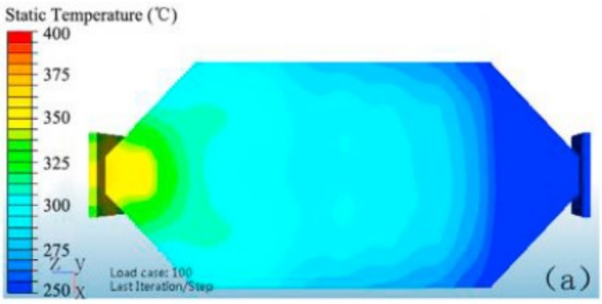

Figure 2.3: Simulation result for catalyst converter[1]

Another place in the car that can get high temperatures is the thermal radiator, which is used to get rid of excess engine heat and keep it constant, as show in figure 2.4.

And the advantages of thermal radiator are:

1. Constant temperature differentials can be obtained during its work. Can obtain constant and non-oscillating voltage differentials, thus better than using exhaust gases to generate energy.

2. It is a good source of power generation and utilization of lost heat.

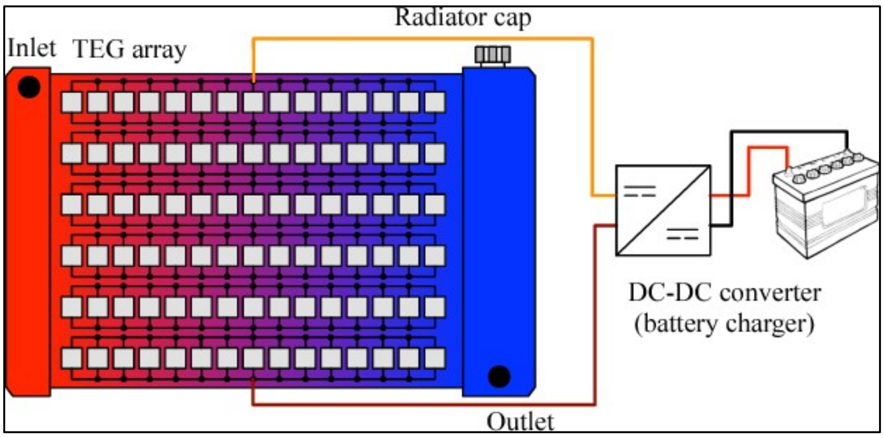

Figure 2.4: A fixed regular array, a series-parallel, connected TEG module array on a radiator[5]

2.4 Advantages of thermoelectric refrigerator system

The thermoelectric cooling system have many advantages:

- The refrigerator could be portable.
- Lightweight.
- Reliable.
- Noiseless.
- Fast, dynamic response.
- Use electrons rather than refrigerant as a heat carrier.
- Feasible for outdoor purpose.
- Ability to heat and cool with the same module.
- Environmentally friendly because it doesn't use any refrigerant gas.

2.5 Disadvantage of thermoelectric refrigerator system

The thermoelectric cooling system have some disadvantages:

- poor power efficiency
- high cost compared to the given cooling capacity
- TEC material is expensive
- need a heatsink to work properly

2.6 Applications for Thermoelectric refrigerators

This project can be used in many fields:

- Indoor space cooling.
- For preservation of insulin and other drugs.
- For preservation of food stuffs.
- For cold water.
- For beverages.

Chapter 3
System Design

3.1 Introduction

This chapter will divide to two main parts first one contains geometry of refrigeration chamber and calculation of refrigeration load required to reach the cooling chamber to the desired temperature, to select the necessary components for the project, second part will include the calculations related of thermoelectric regeneration (TEG) which will feed the cooling part by power needed.

3.2 Geometry and location

The location of the refrigerator used in this project is glove compartment, is a compartment built into the dashboard of an automobile, located over the front-seat passenger's footwell, and often used for miscellaneous storage. This location is simple and easy to build and is suitable for the place where will put it in the interior of the car and also this location is considered an easy place to reach it without having to get out the vehicle, see figure 3.1.

Figure 3.1: Glove compartment

3.3 Material and components selection

3.3.1 Refrigerator materials selection

The selection of materials in the refrigerator industry is mainly based on the most isolate so as to reduce energy consumption and keep the internal temperature low for as long as possible so as not to damage the things inside. Also, materials are chosen based on price, and there are many other considerations in the industry. Several options for the materials using in manufacturing, the first option is the foam is characterized by cheap price its conductivity is very low, and can be configured in many images to fit the shape of the refrigerator in the vehicle compartment, we also have the option of fiberglass also characterized by high thermal isolated, lightweight and also can be configured for many shapes in proportion to the size and shape of the refrigerator and the walls is made in plastic that be inside the vehicle compartment " glove compartment ".

3.3.2 Cooling system selection

This system that expels heat from the hot surface of the Peltier unit away from it so that it works well and keep it from overheating, when choosing a cooling system, we will be under two options. The first is to use the cooling system with water or cooling using heat sink with fan, In terms of the high efficiency of cooling is in the system of water cooling, but its components are many and expensive price, it causes inconvenience and needs a large size, especially as we want to put it on the refrigerator, which will be located inside the cabin of the car near the driver place hand rest or other similar places, because we chose the heat sink with fan in the cooling system it needs less volume, produces fewer sounds, and its efficiency in cooling is not bad. Show the figures (3.2), (3.3) which shows the difference between the two cooling systems.

Figure 3.2: Heat sink with fan.

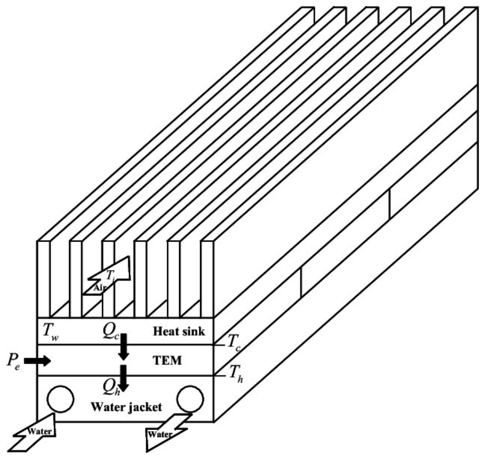

Figure 3.3: Water cooling system

3.7 Specifications of refrigerator

Table 3.1: Specification of refrigerator

Dimension of refrigerator chamber	280mm X 300mm X 110mm
Model number of TEC	TEC1-12706
Internal resistance	2.0 Ohm +/- 10%
Voltage	12 Volt-DC
Thermoelectric cooler dimensions	40mm X 40mm X 3.8mm
Maximum current	25 Ampere
Volume of refrigerator chamber	9.2 Liters
Inside temperature	(10-13) °C
Desired time period	(10-15) minutes

3.4 Conceptual Design

This project consists of five major components: the refrigerator cabinet, outer casing, Peltier Module, heat sink and insulation sheet. As shown the figure 3.4.[6]

Figure 3.4: Schematic diagram of glove thermoelectric refrigerator cabinet (1) outer casing (2) Peltier Module (3) Heat sink (4) insulation sheet

3.5 Mathematical Modeling

The cold space of the refrigerator will be maintained at (11-13)°C, the heat sink will be remove the heat and the temperature will be maintained at 30°C depending on the Palestinian reference that shows the maximum temperature of the atmosphere in the city of Hebron[7], see table A-1, that difference is important to operate the TEC, therefore, there is considerations to be taken as follows.

3.5.1 Cooling load calculation

The total heat required to be removed from the refrigerator chamber to reach it to desired temperature and maintain it by the refrigeration equipment is known as refrigeration load. The aim of estimating of cooling load is to determine the size and number of thermoelectric generators

(TEGs) required to produce sufficient power to work it without any shortage of energy during different working conditions and changing ambient temperature inside the car compartment.

The refrigeration heat load is estimated in the refrigerator on the divide into three main parts:

- Active Heat Load.
- Air changing Load (Infiltration).
- Passive Heat Load (sometimes called heat leak or parasitic heat load).

The quantity of heat to be removed from refrigerator to maintain the desired temperature that is called cooling load. The design load calculation inside and outside refrigerator, and the capacity of refrigerator to produce the idle cooling inside the cabinet. The volume of the refrigerator cabinet to be cooled is (7-10) liters and the desired cooling time is (10-15) minutes.[8]

3.5.1.1 Active heat load

The active load is the heat removed from a mass which is kept inside the cabinet during the cooling and is calculated by:

$$Q_{active} = \frac{m\, C_p \Delta T}{t} \tag{3.1}$$

Where:

Q_{active}: Heat load [W].

m: mass of air [kg].

C_p: Specific heat capacity of air [1 kJ/kg.°K].

ΔT: Difference temperature [°C].

Δt: Desired cooling time period [sec].

$$\Delta T = T_i - T_f \tag{3.2}$$

Where:

T_i: Initial temperature [30°C].

T_o: Outlet temperature [13°C].

$$m = \rho V \tag{3.3}$$

Where:

ρ: Air density [0.001225 kg/L], at temperature 30 °C, see figure A-3 in appendix A.

V: Volume of product (L).

Applying equation (3.3), the mass of air is:

$m = 0.001225 * 9.24 = 0.0113$ [kg]

Applying equation (3.2), the difference temperature is:

$\Delta T = (30) - (13) = 17$ [°C]

The desired cooling time is:

$\Delta t = 10 * 60 = 600$[sec]

Applying equations (3.1), the Q_{active} for the refrigerator is:

$$Q_{active} = \frac{0.0113 * (1) * (17)}{600} = 5.46\ [W]$$

3.5.1.2 Infiltration

In general, the refrigerator is opened and closed many times during its work to insert and remove the medicine and other products to be preserved from the damage. The infiltration load is one of the major loads in the refrigerator it should therefore be taken into consideration the infiltration is the air enters a refrigerated space through cracks and opening of the door, this is caused by pressure difference between the external and internal surface and it depends upon difference between the outside and inside air.

$$Q_{inf} = m_f * C_p * (T_o - T_i) \quad (3.4)$$

Where:

Q_{inf}: Heat losses by air change [W].

m_f: Mass product of infiltrated air [kg/sec].

C_p: Specific heat capacity of the air [1 kJ/kg.°C].

T_0: Outside air temperature [30°C].

T_i: Inside air temperature [13°C].

V_f = Number of air change * Volume of refrigeration space (3.5)

Number of changes = 1 [time/hour], see Table A-2.

$$m_f = \rho V_f \quad (3.6)$$

Where:

ρ: Air density [0.001225 kg/L], at temperature 30 °C, see figure A-4 in appendix A.

V_f: Volumetric flow rate of infiltration air [m^3/sec].

Applying equation (3.5), the volumetric flow rate is:

$$V_f = \frac{1 * 9.24}{3600} = 2.56 * 10^{-3} [L/sec]$$

Applying equation (3.6), the mass flow rate of air is:

$$m_f = 0.001225 * 2.56 * 10^{-3} = 3.136 * 10^{-6}$$

Applying equations (3.4), the Q_{inf} for the refrigerator:

$$Q_{inf} = 3.136 * 10^{-6} * 1 * (303 - 286) = 0.0533 \text{ [W]}$$

3.5.1.3 Passive Heat load

The passive heat load is the heat losses due to convection and conduction of the enclosed thermoelectric cabinet, see figure 3.5.

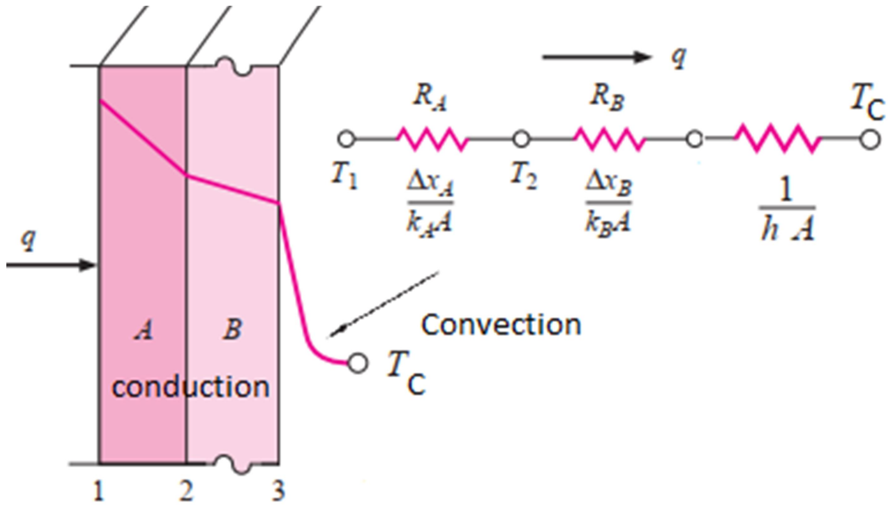

Figure 3.5: sketch for heat transfer, series thermal resistance.[9]

$$Q_{passive} = \frac{A\Delta T}{(\frac{\Delta X_A}{k_1}+\frac{\Delta X_B}{k_2}+\frac{1}{h})} \tag{3.7}$$

Where:

A: Heat transfer surface area for all walls of the cabinet (length * width) [m^2].

ΔT: Temperature difference (Tout – Tin) [°C].

ΔX_A: Thickness of the mineral wool [1 cm].

ΔX_B: Thickness of the fiberglass [0.2 cm]

k_1: Thermal conductivity of Mineral wool [0.035 W/m.°C].

k_2: Thermal convective of Fiberglass [0.04 W/m.°C].

h: Convection heat transfer coefficient.

The interior of the refrigerator is similar to that of a rectangular shape. The area of refrigerator is, see figure 3.3:

$\text{Side 1} = 0.11 * 0.3 = 0.033\ m^2$

$\text{Side 2} = 0.11 * 0.3 = 0.033\ m^2$

$\text{Side 3} = 0.11 * 0.28 = 0.0308\ m^2$

$\text{Roof} = 0.28 * 0.3 = 0.084\ m^2$

$\text{Floor} = 0.28 * 0.3 = 0.084\ m^2$

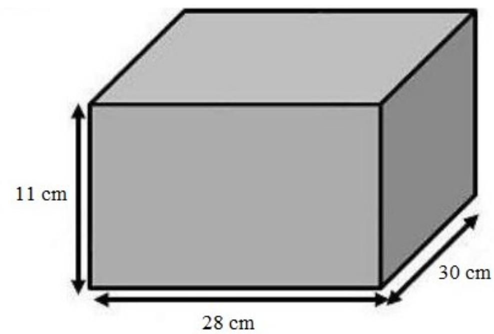

Figure3.6: Rectangular shape

$\text{the total area} = 2 * (0.033) + 2 * (0.0308) + 2 * (0.084) = 0.2956\ [m^2]$

Applying equation (3.7), the $Q_{passive}$ for refrigerator is:

$$Q_{passive} = \frac{0.2956 * (30 - 13)}{(\frac{0.01}{0.035} + \frac{0.002}{0.04} + \frac{1}{20})} = 13.05\ [W]$$

3.5.1.4 Total cooling load

The total cooling load of this modeling is summing of heat load from active, passive, and infiltration.

$$Q_{Totla} = Q_{active} + Q_{passive} + Q_{infiltration} \quad (3.8)$$

Applying equation (3.8), the total cooling load:

$$Q_{Total} = 5.46 + 0.05 + 13.05 = 18.56 \text{ [W]}$$

3.6 Efficacy of the system

The efficiency of the module and it is always desirable to maximize it whenever possible. It can calculate by:

$$\eta = \frac{\text{Power out}}{\text{Power in}} = \frac{Q_C}{I * V} \quad (3.9)$$

Applying equation (3.9), the η:

$$\eta = \frac{18.56}{12 * 25} = 0.06$$

Where:

I: input current [A].

V: input voltage [V].

3.8 Heat sink (Fins)

Selection of a heat sink is crucial to the overall operation of a thermoelectric system. The heat sink should be used to facilitate the transfer of heat from the surface of the thermoelectric. This could be achieved by free convection and forced convection.

1. Free conversion:

In a natural convection air cooled the air comes in contact with the warm fin, it absorbs heat from the TEC and thus the temperature of the air increases. The warm air being lighter, rises up and the cold air from below rises to take away to take away the heat from the fin. This cycle continues in natural convection air cooled fin, since the rate of heat transfer in natural convection is lower, therefore they require a larger surface as compared to forced convection, this is not appropriate for the project, see figure 3.6.

2. Forced convection:

In forced convection there are two methods which can be employed to facilitate the transfer of heat from the surface of the thermoelectric, by air-cooled and water-cooled.

In forced convection air cooled, the fan is used to force the air over the TEC fin to increase its heat transfer capacity. But in forced convection water-cooled is used pipe and pump to facilitate the transfer of heat making it difficult to handle, low flexibility and more expensive. For solar TEC, it will be used forced convection air-cooled, as in figure (2.3). Despite its efficiency is low compared with the water-cooled, but the size of the project is small so that it will not be affected by this efficiency, see figure 3.7.

Figure 3.7: heatsink

Figure 3.8: Heatsink with fan

3.9 Power generation

In general, the module has been manufactured and designed to cool or heat things after the power is applied, but fortunately this module can be used in reverse, where electricity can be generated by applying a temperature difference between the two faces, although power output and generation efficiency are very low, but it is a good ways to take advantage of wasted energy in the engine exhaust outlet and radiator engine cooling. Thermoelectric generator similar in its work to a traditional thermocouple, see figure 3.8.[10]

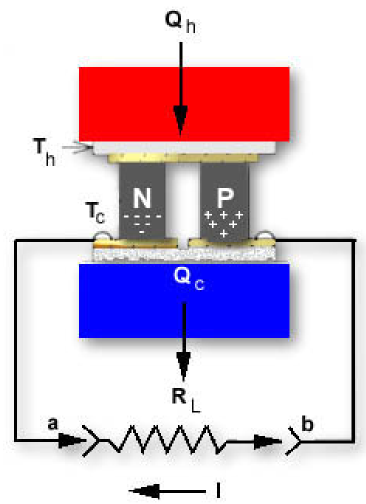

Figure 3.9: Single thermoelectric couple where $T_h > T_c$

It is possible, but unlikely, that the precise conditions will exist within a given generator application whereby one module will provide the exact output power desired. As a result, most thermoelectric generators contain a number of individual modules which may be electrically connected in either series, parallel, or series/parallel arrangement. A typical generator configuration is illustrated in Figure 3.9.

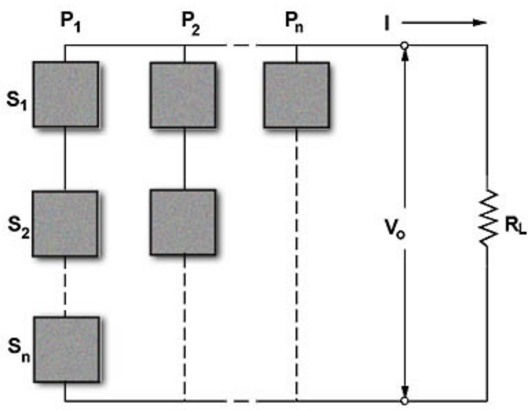

Figure 3.10: Typical Thermoelectric Generator with a Series-Parallel Arrangement of Modules

3.9.1 Output Power

The output power for the TEG is calculated from the datasheet, that give this information, see table 3.2.[11]

Table 3.2: Relationship between temperature difference and output voltage [11]

Hot Side Temperature (°C)	Output Voltage (volt)	Output wattage (W)
50	0.2	0.35
70	0.39	1.27
90	0.59	2.63
110	0.78	4.35
130	0.98	6.34
150	1.17	8.56
170	1.37	10.96
190	1.56	13.52
When T_C = 30°C		

From figure 3.11, can calculate total output voltage from 10 pieces of TEGs that give enough voltage for charging battery and that is connected in series. The hot side temperature of TEGs is 90°C, and cooled side temperature is 30°C that lead to get voltage is 0.59 [V].

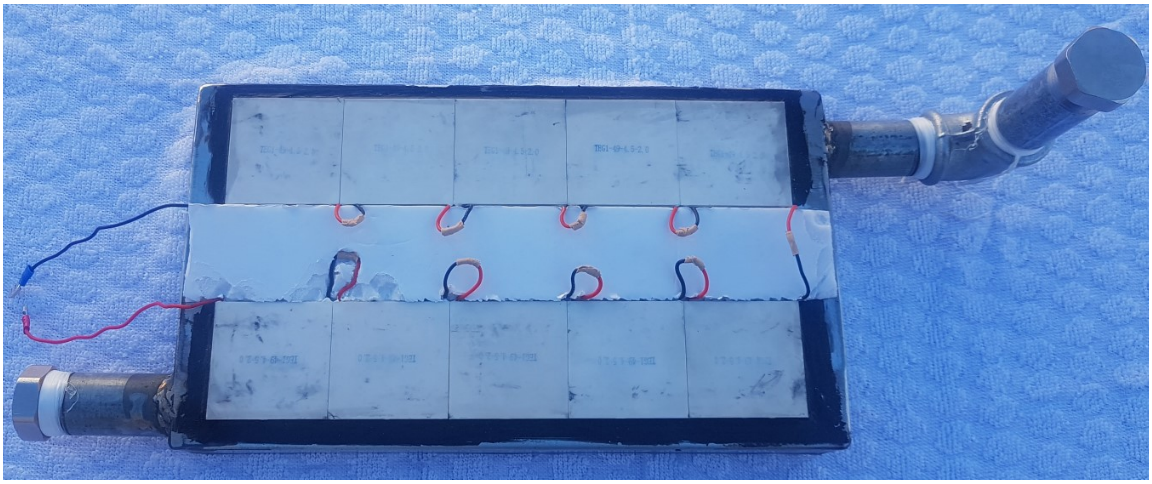

Fig3.11: Combined radiator and TEGs waste heat recovery system.

$$\text{Totla output volatge} = \text{Number of TEGs} * \text{Output voltage} \quad (3.10)$$

$$V_T = 10 * 0.59 = 5.9 \text{ [V]}$$

$$\text{Output current} = \frac{\text{Output power}}{\text{Output voltage}} \quad (3.11)$$

$$\mathrm{I} = \frac{2.63}{0.59} = 4.45 \text{ [A]}$$

For this data, the voltage is 5.9[V] and current is 4.45[A]. To charge battery the required volt is 13[V] and use the boost converter to boost the volt from 5.9W to 13[V].

3.10 Application of Thermoelectric Generators

- For increasing the fuel efficiency of cars, thermoelectric generators are used. These generator use heat produced when the vehicle is running.
- Play music system.
- Electricity from tea cup.
- Solar cells.

3.11 Electrical Components

There are many electrical components which are used in this project to protect and operate a refrigerator. The components are:

1. Temperature control switch module

temperature controller is a device that is used to control temperature. It does this by first measuring the temperature inside the cabinet and compares it to the desired value, see figure 3.12.

Fig3.12: Temperature control switch module

2. Boost Converter

A boost converter (step-up converter) is a DC-to-DC power converter that steps up voltage (while stepping down current) from its input (supply) to its output (load), see figure 3.13.

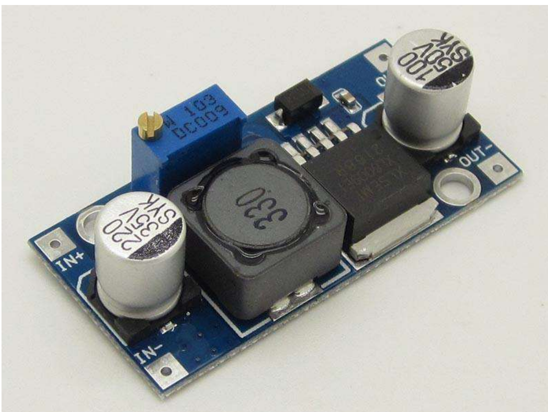

Fig3.13: Boost Converter

3. Lead acid battery

A battery is a device that is able to store electrical energy in the form of chemical energy, and convert that energy into electricity, see figure 3.14.

Fig3.14: Lead acid battery

Chapter 4
Tests and Results

4.1 Introduction

This chapter shows the experimental that were tested in the project, discuss these experiments, and identify the results and compare them with what was expected.

4.2 Test and Results

Several experiments have been conducted in this project on the glove compartment, this experience and their results will be explained below.

4.2.1 Test and Results for thermoelectric generator

This curve shows the relationship between radiator temperature (°C) and voltage (V).

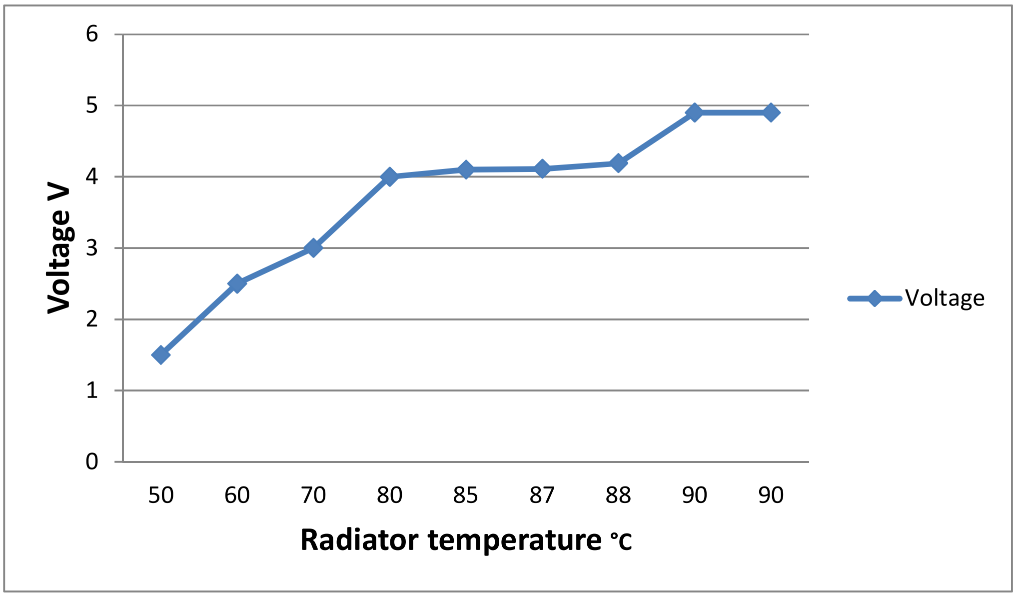

Fig4.1: Relationship between radiator temperature and voltage

4.2.2 Test and Results for refrigerator “glove compartment”

An experiment was conducted to determine the rate of heat transfer through the walls of the cabinet. The experiment was conducted within a specified period of time, as shown in the diagram in Figure 4.2.

This curve shows the relationship between the temperature °C and time in minute for 9.2 litter at (10-13)°C.

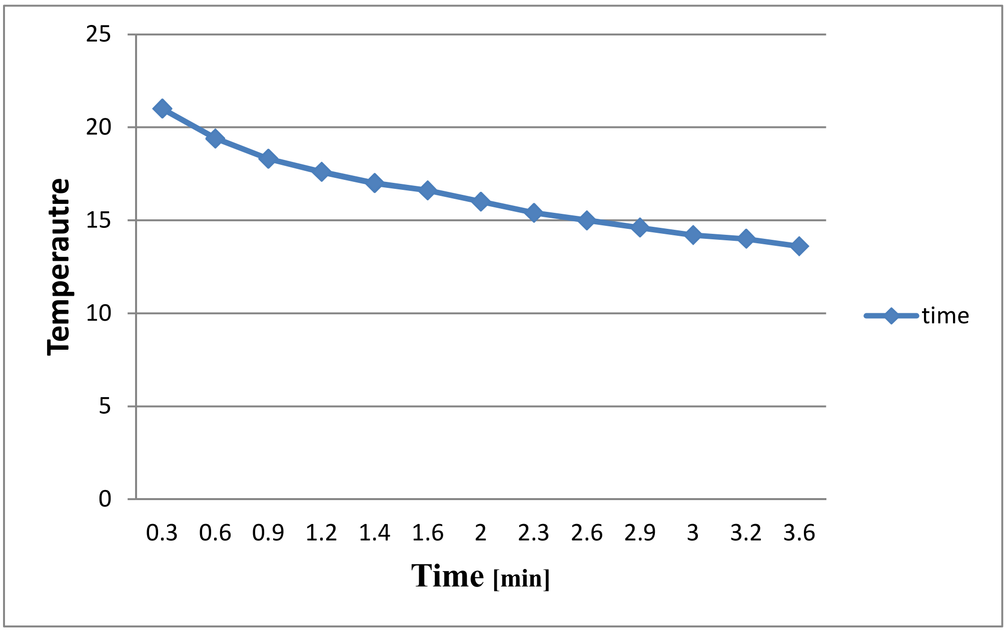

Fig4.2: Relationship between temperature and time

4.3 Conclusion

The project is divided into two main parts, the first part is the generator from engine cooling system in the vehicle, that's convert some of the waste heat energy into electric energy that used to charge the battery. Second part is building a solid-state refrigerator, that derive the electric from first part. Thermoelectric refrigerator was tested for the cooling purpose and designed based on the principle of a thermoelectric module to create a cooling load. The cooling load of thermoelectric module was utilized for refrigerator purpose whereas the rejected heat from the hot side of the module was eliminated using heatsinks. In order to utilize the wasted energy from engine cooling, thermoelectric generator was integrated to power the thermoelectric cooler. Furthermore, the thermoelectric generator provides a very environmentally friendly.

The project primarily targets people who need to preserve their medication from damage, especially diabetics, by providing them with a suitable place in the car, which is the glove compartment, and it also targets people who like to have their products always fresh during long trips.

The final results were not among the expected results due to the use of poor-quality parts, and because of the difficulty of providing high quality parts to give the required results.

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Appendix A

Table A-1: Maximum and minimum temperature for Hebron city depending on the Palestinian reference.[7]

Month	Max Temp (◦C)	Min Temp (◦C)
January	10.3	3
February	11.5	4.7
March	14.6	6.5
April	19.6	9.9
May	23.6	13.2
June	25.9	15.8
July	27.2	17
August	31	18
September	26	15
October	23.2	14
November	17.5	9.9
December	12.1	5.6

Table A-2: Air change per hour.[12]

Kind of room building	Air change [time/h]
Room with no windows or exterior door	0.5
Room with windows or exterior door on one side only	1
Room with windows or exterior door on two side only	1.5
Room with windows or exterior door on three side only	2
Entrance halls	2
Factories, machine shops	1 - 1.5
Recreation room, assembly rooms, gymnasium	1.5
Home, apartment, offices	1 - 2
Class room, dining room, lounges, toilets, hospital room, kitchen, laundries, ballrooms, bathrooms	1 - 2
Stores, public buildings	2 - 3
Toilets, auditorium	3

Figure A-3: Water –Temperature and Density [13]

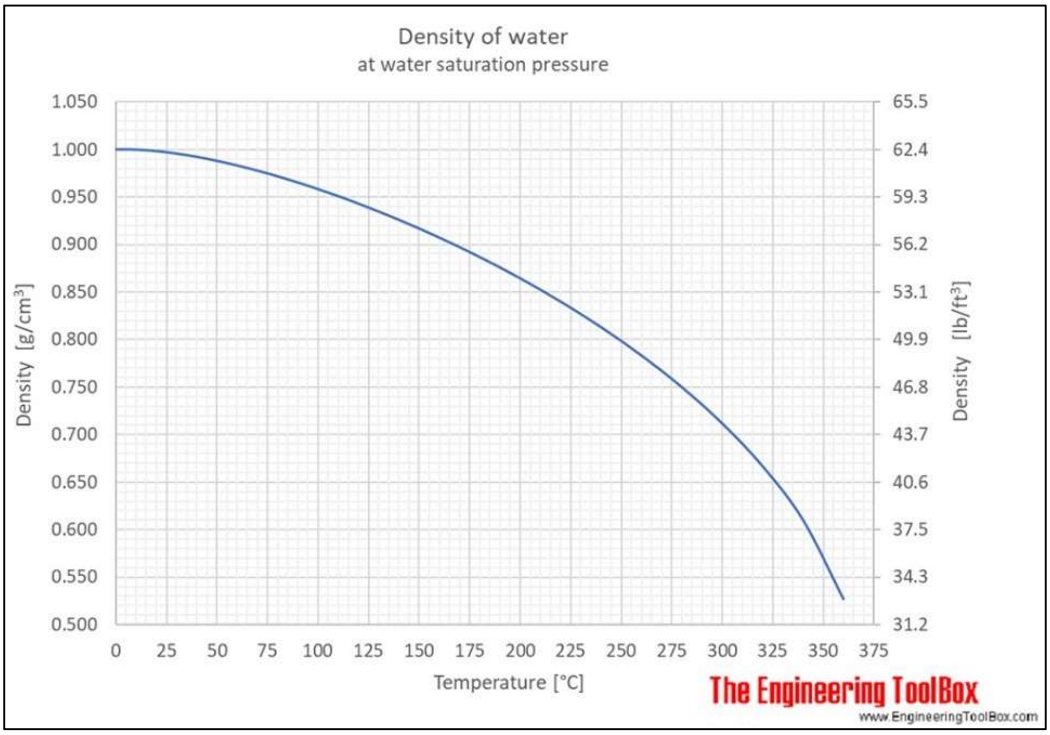
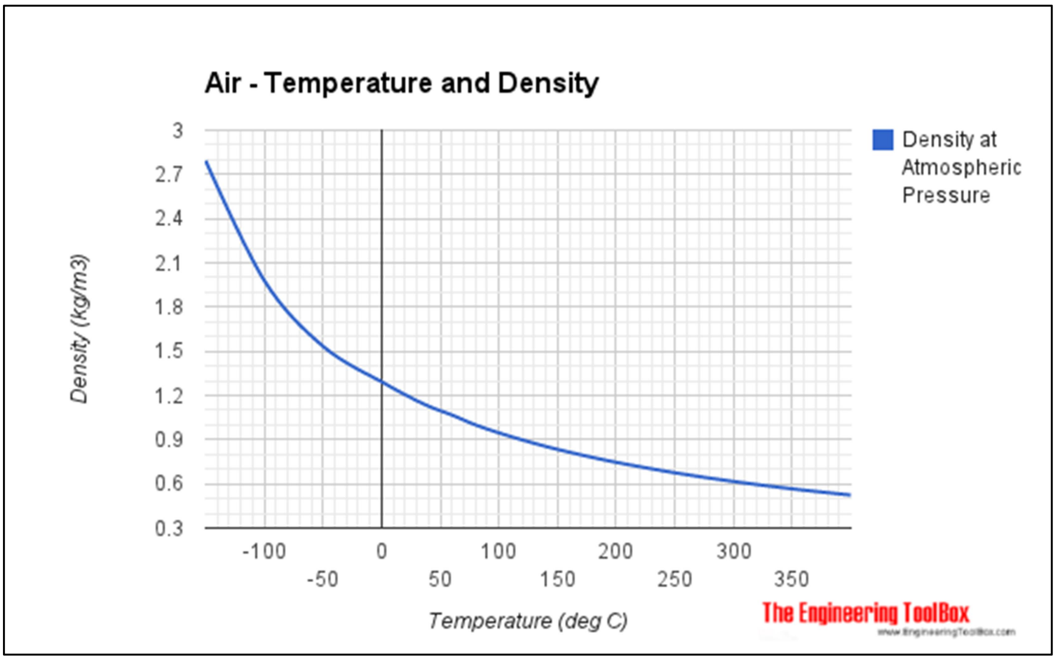


Figure A-4 : Air -Temperature and Density[13]



Appendix B

‘Thermoelectric Cooler’

Specification of Thermoelectric Module

TEC1-12706

Description

The 127 couples, 40 mm × 40 mm size single stage module is made of selected high performance ingot to achieve superior cooling performance and greater delta T up to 70 °C, designed for superior cooling and heating up to 100 ℃ requirement. If higher operation or processing temperature is required, please specify, we can design and manufacture the custom made module according to your special requirements.

Features

- High effective cooling and efficiency.
- No moving parts, no noise, and solid-state
- Compact structure, small in size, light in weight
- Environmental friendly, RoHS compliant
- Precise temperature control
- Exceptionally reliable in quality, high performance

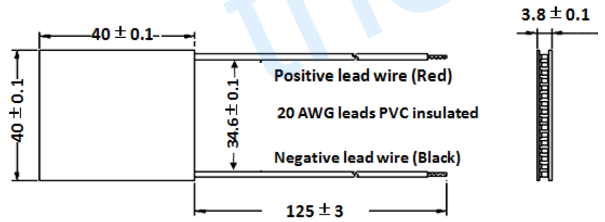
Application

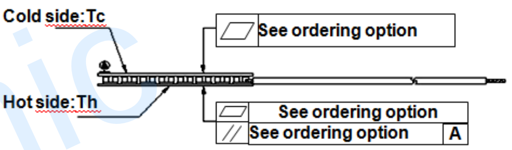
- Food and beverage service refrigerator
- Portable cooler box for cars
- Liquid cooling
- Temperature stabilizer
- Photonic and medical systems

Peformance Specification Sheet

Th(℃)	27	50	Hot side temperature at environment: dry air, N_2
DT_{max}(℃)	70	79	Temperature Difference between cold and hot side of the module when cooling capacity is zero at cold side
U_{max}(Voltage)	16.0	17.2	Voltage applied to the module at DT_{max}
I_{max}(amps)	6.1	6.1	DC current through the modules at DT_{max}
QC_{max}(Watts)	61.4	66.7	Cooling capacity at cold side of the module under DT=0 ℃
AC resistance(ohms)	2.0	2.2	The module resistance is tested under AC
Tolerance (%)	± 10		For thermal and electricity parameters

Geometric Characteristics Dimensions in millimeters





Sealing Option

A. Solder:

1. T100: BiSn (Tmelt = 138 °C)

B. Sealant:

1. NS: No sealing (Standard)
2. SS: Silicone sealant
3. EPS: Epoxy sealant
4. Customer specify sealing other than above

C. Ceramics:

1. Alumina (Al_2O_3, white 96%)
2. Aluminum Nitride (AlN)

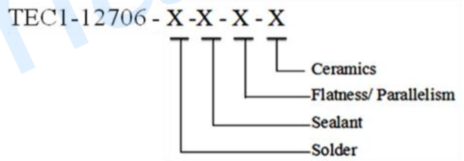
D. Ceramics Surface Options:

1. Blank ceramics (not metallized)
2. Metallized (Au plating)

Ordering Option

Suffix	Thickness (mm)	Flatness/ Parallelism (mm)	Lead wire length(mm) Standard/Optional length
TF	0:3.8±0.1	0:0.035/0.035	125±3/Specify
TF	1:3.8±0.05	1:0.025/0.025	125±3/Specify
TF	2:3.8±0.025	2:0.015/0.015	125±3/Specify
Eg. TF01: Thickness 3.8 ± 0.1 (mm) and Flatness 0.025 / 0.025 (mm)			

Naming for the Module



TEC1-12706–T100 -NS –TF01 -AlO

T100: BiSn (Tmelt=138°C)

NS: No sealing

AlO: Alumina white 96%

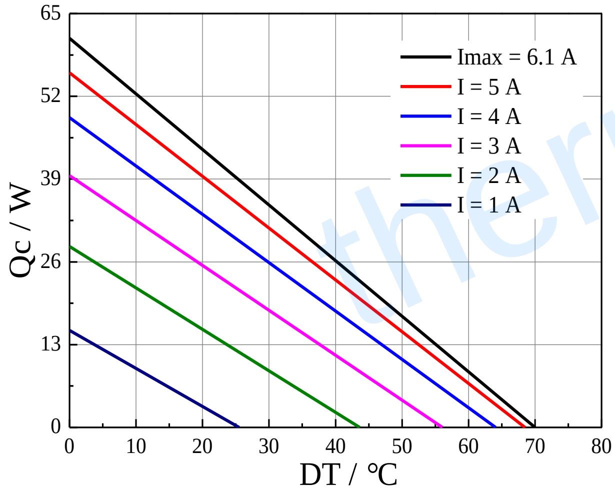
TF01: Thickness ±0.1 (mm) and Flatness/Parallelism 0.025/0.025(mm)

Tel: +86-791-88198288 Fax: +86-791-88198308 Email: sales@thermonamic.com.cn Web Site: www.thermonamic.com.cn

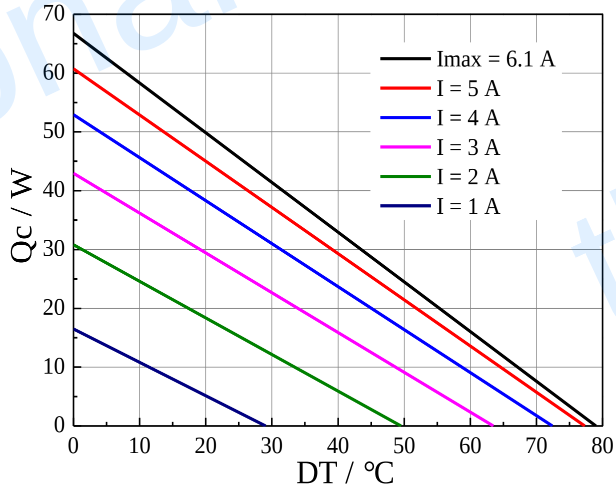
Specification of Thermoelectric Module

TEC1-12706

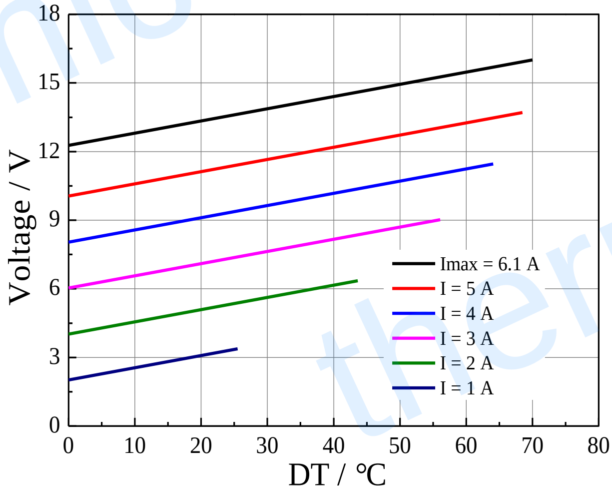
Performance Curves at Th=27 ℃

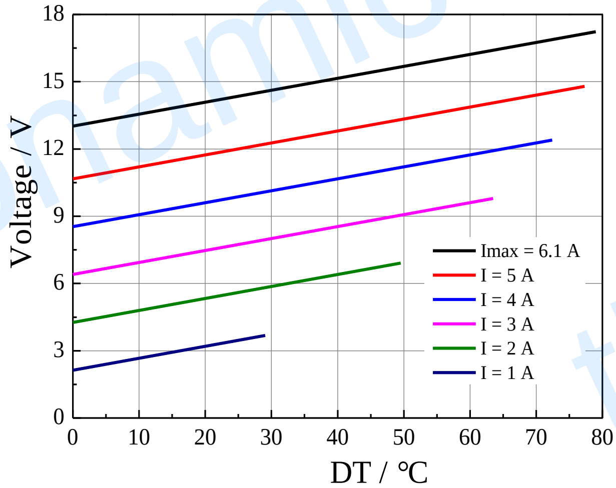


Performance Curves at Th=50 ℃

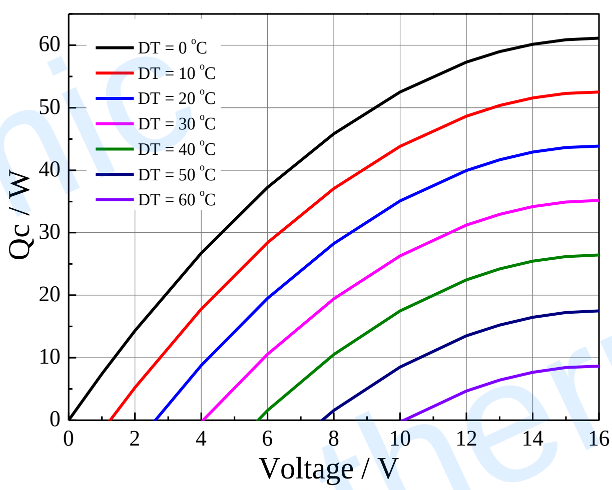


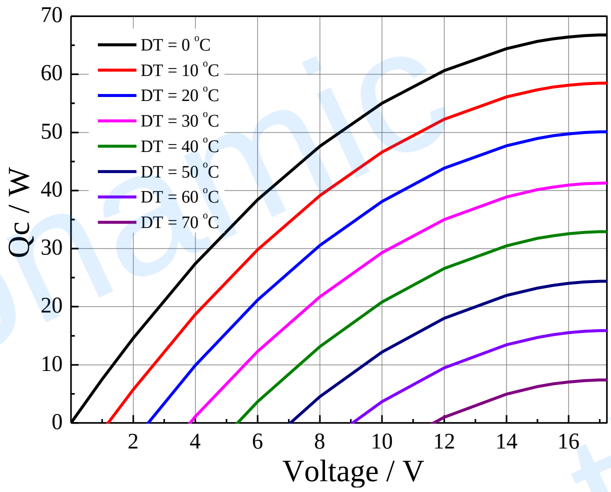
Standard Performance Graph Qc= f(DT)





Standard Performance Graph V= f(ΔT)



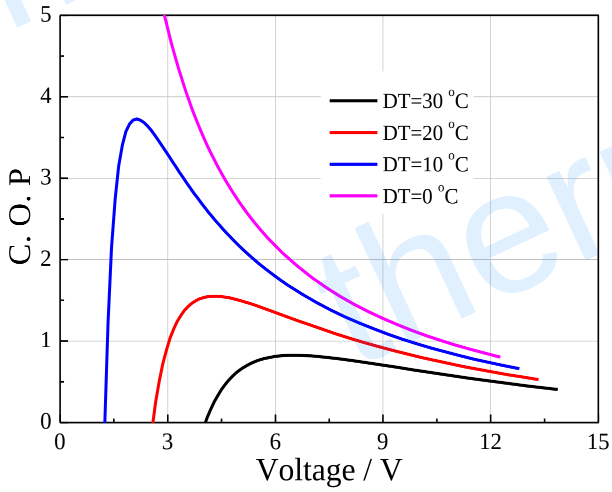


Standard Performance Graph Qc= f(V)

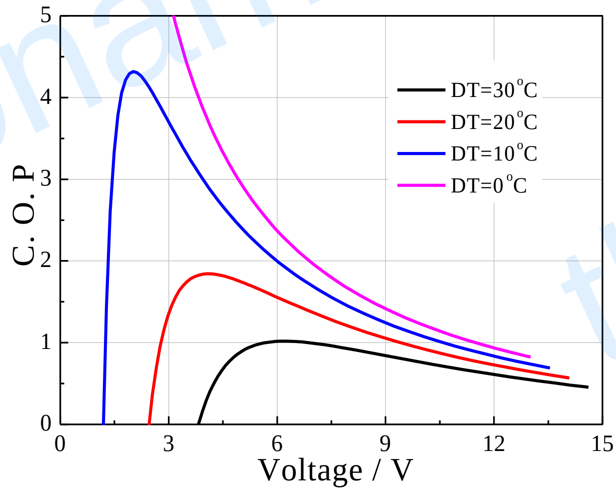
Specification of Thermoelectric Module

TEC1-12706

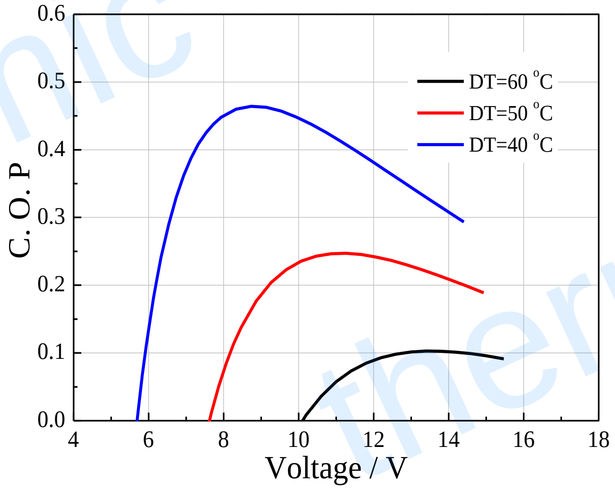
Performance Curves at Th=27 ℃

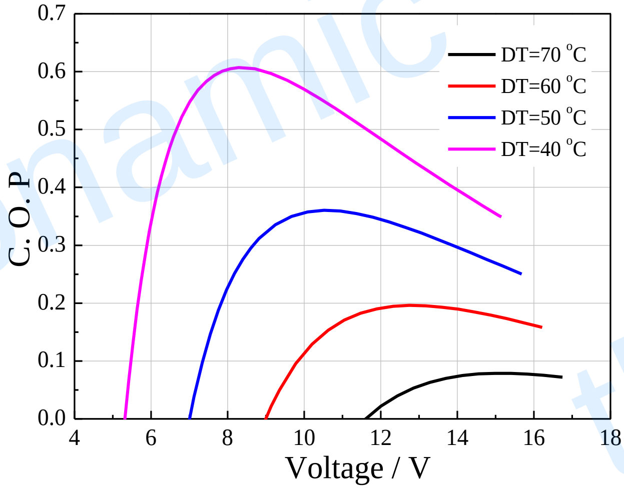


Performance Curves at Th=50 ℃



Standard Performance Graph COP = f(V) of ΔT ranged from 0 to 30 ˚C





Standard Performance Graph COP = f(V) of ΔT ranged from 40 to 60/70 ˚C

Remark: The coefficient of performance (COP) is the cooling power Qc/Input power (V × I).

Operation Cautions

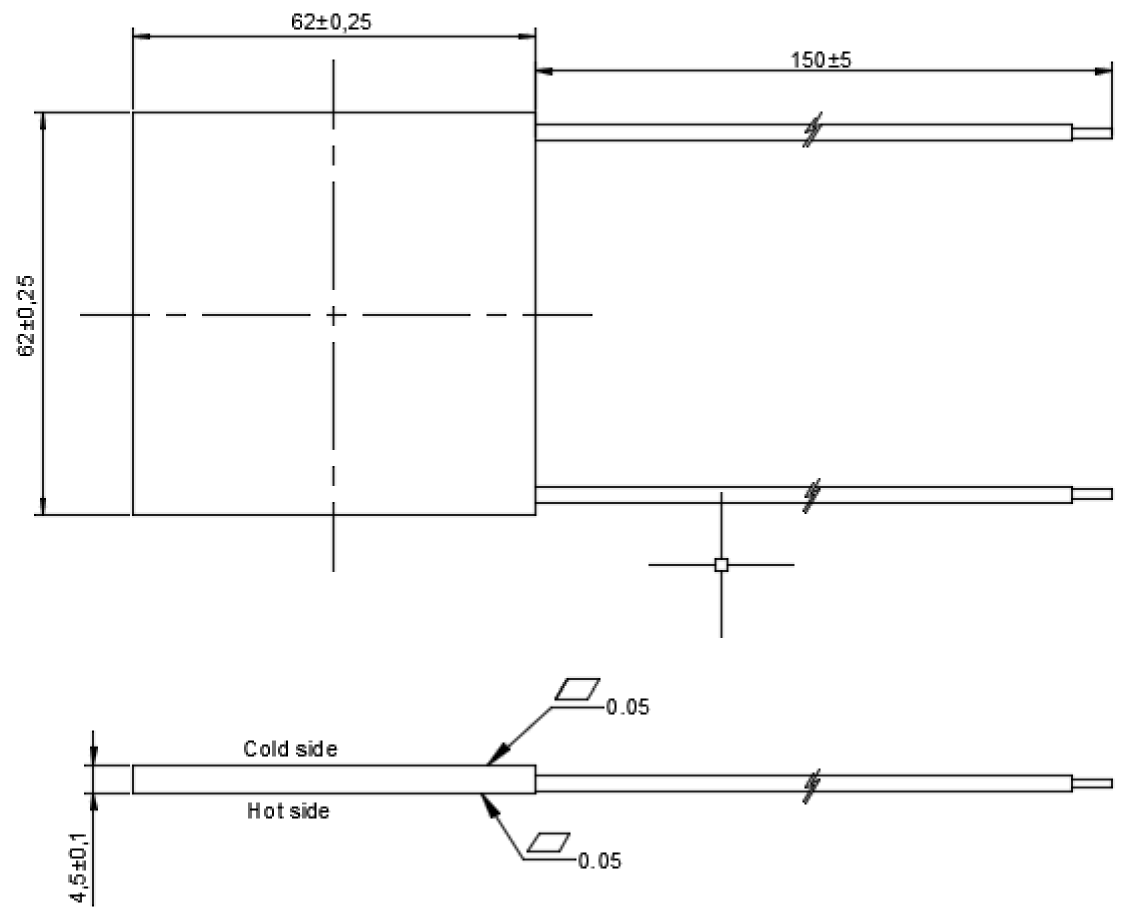
- Cold side of the module sticked on the object being cooled
- Hot side of the module mounted on a heat radiator
- Storage module below 100 ℃
- Operation below I_{max} or V_{max}
- Work under DC

Appendix C

‘Thermoelectric Generator’

TEG1-49-4.5-2.0 Thermoelectric Generator

Ⅰ.Module Drawing:



Ⅱ.Materials

1.Ceramic plate： 96%Al_2O_3 white color

2.Seal: Sealed with 704 RTV

3.Thermolectric material: Bismuth Telluride

Ⅲ. Module Specification

TEG1-49-4.5-2.0					
Th= ℃	Open Voltage (V)	Output voltage(V)	Internal R (Ω)	Load R (Ω)	Output wattage (W)
50	0.39	0.20	0.10	0.10	0.35
70	0.78	0.39	0.12	0.12	1.27
90	1.17	0.59	0.13	0.13	2.63
110	1.56	0.78	0.14	0.14	4.35
130	1.95	0.98	0.15	0.15	6.34
150	2.34	1.17	0.16	0.16	8.56
170	2.73	1.37	0.17	0.17	10.96
190	3.12	1.56	0.18	0.18	13.52

When Tc=30℃

Working temperature :-40~ 200℃

IV. The correct installation/assemble method.

1.There is cooling fin in one side of the thermoelectric generator module, and the other side install heat resource, the planeness of the install surface can' t over 0.03mm,the surface need to be deburred and clean the dirty.

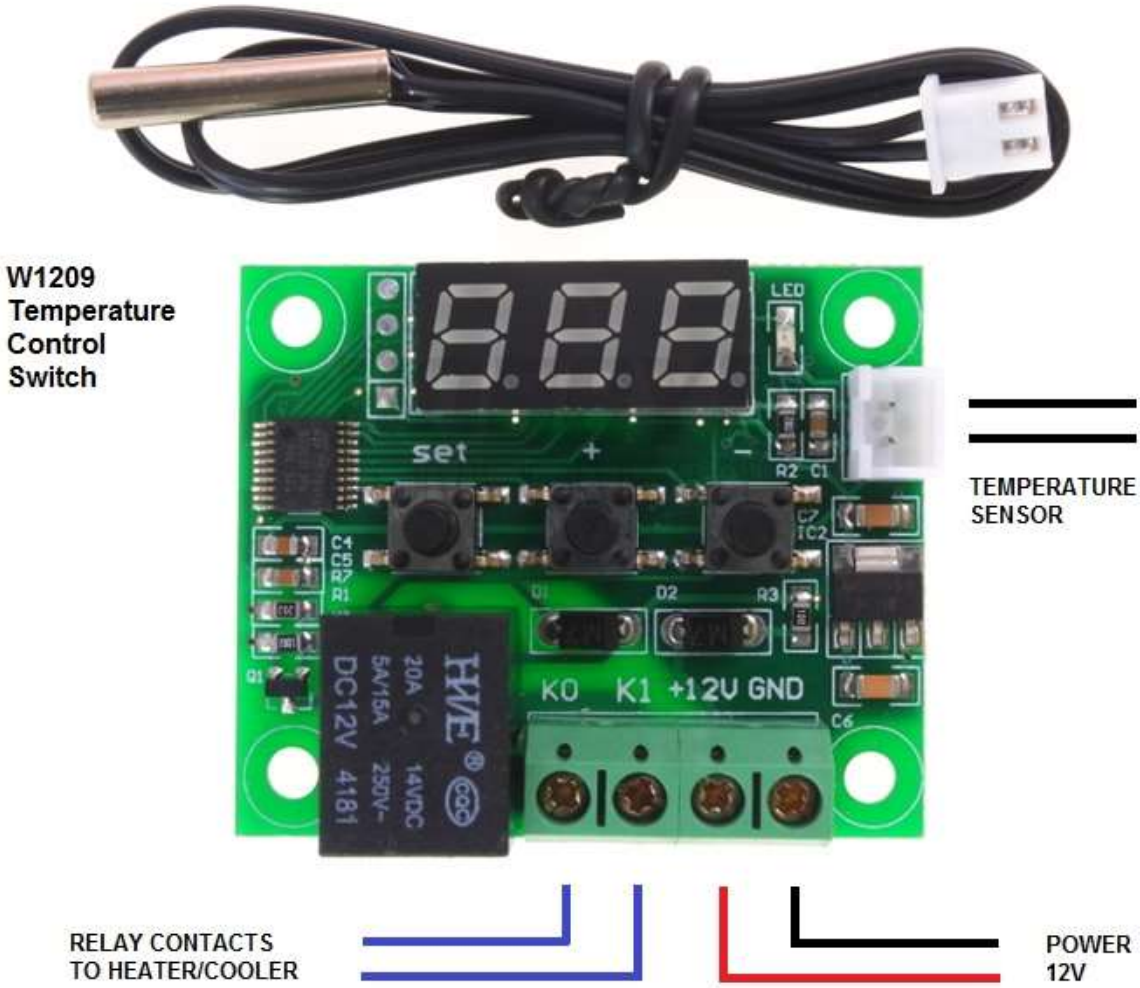
2.The module, cooling fin and heat resource should contact with each other very well, the touch surface need cover with heat-conducting glue.

3.Locate the module, apply the force evenly, make sure not over-force, avoid crushing the module.

Appendix D

‘Temperature Control switch module’

W1209 Temperature Control Switch



DESCRIPTION:

The W1209 is an incredibly low cost yet highly functional thermostat controller. With this module you can intelligently control power to most types of electrical device based on the temperature sensed by the included high accuracy NTC temperature sensor. Although this module has an embedded microcontroller no programming knowledge is required. 3 tactile switches allow for configuring various parameters including on & off trigger temperatures. The on board relay can switch up to a maximum of 240V AC at 5A or 14V DC at 10A. The current temperature is displayed in degrees Centigrade via its 3 digit seven segment display and the current relay state by an on board LED.

SPECIFICATION:

Temperature Control Range: -50 ~ 110 C
Resolution at -9.9 to 99.9: 0.1 C
Resolution at all other temperatures: 1 C
Measurement Accuracy: 0.1 C
Control Accuracy: 0.1 C
Refresh Rate: 0.5 Seconds
Input Power (DC): 12V
Measuring Inputs: NTC (10K 0.5%)
Waterproof Sensor: 0.5M
Output: 1 Channel Relay Output, Capacity: 10A

Power Consumption
Static Current: <=35mA
Current: <=65mA

Environmental Requirements
Temperature: -10 ~ 60 C
Humidity: 20-85%

Dimensions
48mm x 40mm x 14mm

Settings Chart
Long press the "SET" button to activate the menu.

Code Description Range Default Value
P0 Heat C/H C
P1 Backlash Set 0.1-15 2
P2 Upper Limit 110 110
P3 Lower Limit -50 -50
P4 Correction -7.0 ~ 7.0 0
P5 Delay Start Time 0-10 mins 0
P6 High Temperature Alarm 0-110 OFF

Long pressing +- will reset all values to their default

Displaying the current temperature:
The thermostat will display the current temperature in oC by default. When in any other mode making no input for approximately 5 seconds will cause the thermostat to return to this default display.

Setting the trigger temperature:
To set the trigger temperature press the button marked 'SET'. The seven segment display will flash. You can now set a trigger temperature (in oC) using the '+' and '-' buttons in 0.1 degree increments. If no buttons are pressed for approximately 2 seconds the trigger temperature will be stored and the display will return back to the current temperature.

Setting the parameters:
To set any parameter first long press the 'SET' button for at least 5 seconds. The seven segment display should now display 'P0'. This represents parameter P0. Pressing the '+' or '-' buttons will cycle though the various parameters (P0 to P6). Pressing the 'SET' button whilst any of there parameters are displayed will allow you to change the value for that parameter using the '+' and '-' buttons (see below). When finished setting a parameter press the set button to exit that option. If no buttons are pressed for approximately 5 seconds the thermostat will exit the parameter options and will return back to the default temperature display.

Setting the cooling or heating parameter P0:
The parameter P0 has two settings, C and H. When set to C (default) the relay will energise when the temperature is reached. Use this setting if connecting to an air-conditioning system. When set to H the relay will de-energise when the temperature is reached. Use this setting if controlling a heating device.

Setting the hysteresis parameter P1:
This sets how much change in temperature must occur before the relay will change state. For example if set to the default 2oC and the the trigger temperature has been set to 25oC, it will not de-energise until the temperature falls back below below 23oC. Setting this hysteresis helps stop the thermostat from continually triggering when the temperature drifts around the trip temperature.

Setting the upper limit of the thermostat parameter P2:
This parameter limits the maximum trigger temperature that can be set. It can be used as a safety to stop an excessively high trigger temperature from accidentally being set by the user.

Setting the lower limit of the thermostat parameter P3:
This parameter limits the minimum trigger temperature that can be set. It can be used as a safety to stop an excessively low trigger temperature from accidentally being set by the user.

Setting temperature offset correction parameter P4:
Should you find there is a difference between the displayed temperature and the actual temperature (for instance if the temperature probe is on a long run of cable) you can make minor corrections to the temperature reading with this parameter.

Setting the trigger delay parameter P5:
This parameter allows for delaying switching of the relay when the trigger temperature has be reached. The parameter can be set in one minute increments up to a maximum of 10 minutes.

Setting the high temperature alarm parameter P6:
Setting a value for this parameter will cause the relay to switch off when the the temperature reaches this setting. The seven segment display will also show '---' to indicate an alarm condition. The relay will not re-energise until the temperature falls below this value. The default setting is OFF.

Appendix E

‘Boost Converter’

400KHz 60V 4A Switching Current Boost / Buck-Boost / Inverting DC/DC Converter

Features

- Wide 5V to 32V Input Voltage Range
- Positive or Negative Output Voltage Programming with a Single Feedback Pin
- Current Mode Control Provides Excellent Transient Response
- 1.25V reference adjustable version
- Fixed 400KHz Switching Frequency
- Maximum 4A Switching Current
- SW PIN Built in Over Voltage Protection
- Excellent line and load regulation
- EN PIN TTL shutdown capability
- Internal Optimize Power MOSFET
- High efficiency up to 94%
- Built in Frequency Compensation
- Built in Soft-Start Function
- Built in Thermal Shutdown Function
- Built in Current Limit Function
- Available in TO263-5L package

Applications

- EPC / Notebook Car Adapter
- Automotive and Industrial Boost / Buck-Boost / Inverting Converters
- Portable Electronic Equipment

General Description

The XL6009 regulator is a wide input range, current mode, DC/DC converter which is capable of generating either positive or negative output voltages. It can be configured as either a boost, flyback, SEPIC or inverting converter. The XL6009 built in N-channel power MOSFET and fixed frequency oscillator, current-mode architecture results in stable operation over a wide range of supply and output voltages.

The XL6009 regulator is special design for portable electronic equipment applications.

Figure1. Package Type of XL6009

Pin Configurations

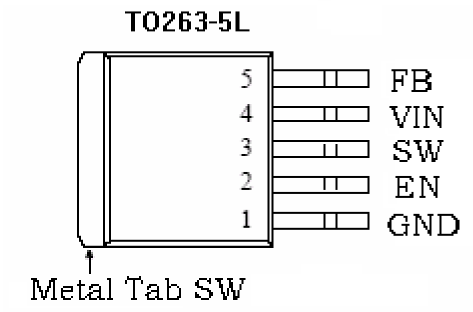


Figure2. Pin Configuration of XL6009 (Top View)

Table 1 Pin Description

Pin Number	Pin Name	Description
1	GND	Ground Pin.
2	EN	Enable Pin. Drive EN pin low to turn off the device, drive it high to turn it on. Floating is default high.
3	SW	Power Switch Output Pin (SW).
4	VIN	Supply Voltage Input Pin. XL6009 operates from a 5V to 32V DC voltage. Bypass Vin to GND with a suitably large capacitor to eliminate noise on the input.
5	FB	Feedback Pin (FB). Through an external resistor divider network, FB senses the output voltage and regulates it. The feedback threshold voltage is 1.25V.

Function Block

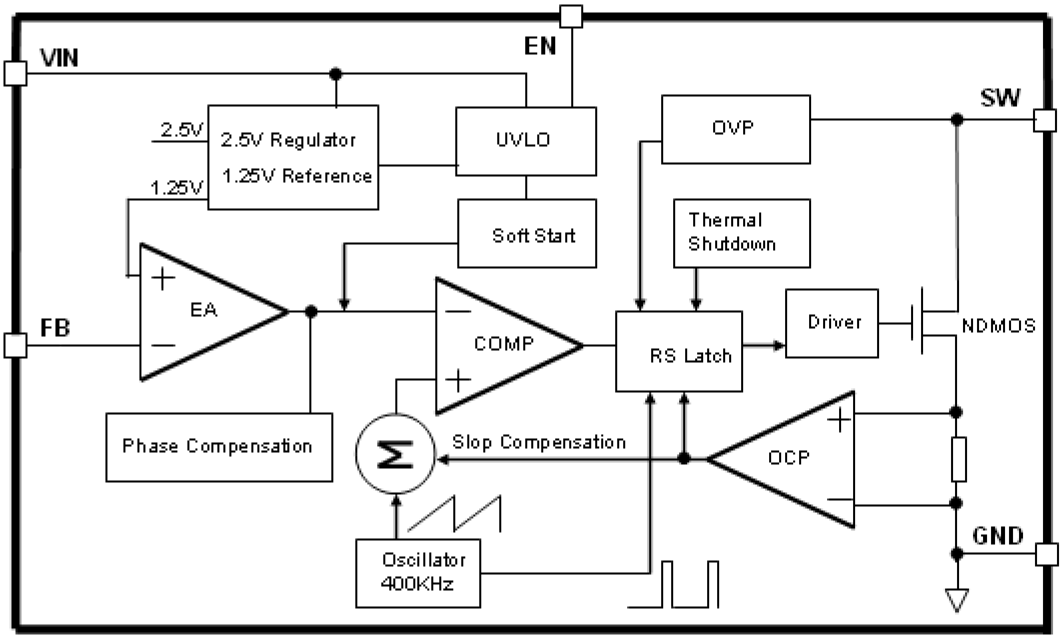


Figure3. Function Block Diagram of XL6009

Typical Application Circuit

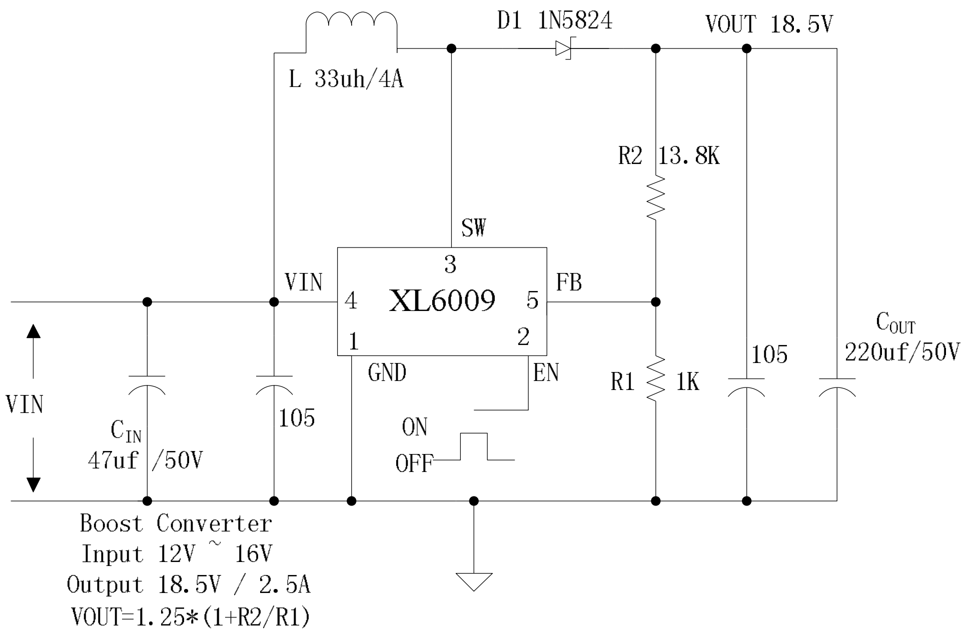


Figure4. XL6009 Typical Application Circuit (Boost Converter)

Ordering Information

Package	Temperature Range	Part Number	Marking ID	Packing Type
		Lead Free	Lead Free	
		XL6009E1	XL6009E1	Tube
		XL6009TRE1	XL6009E1	Tape & Reel

XLSEMI Pb-free products, as designated with “E1” suffix in the par number, are RoHS compliant.

Absolute Maximum Ratings（Note1）

Parameter	Symbol	Value	Unit
Input Voltage	Vin	-0.3 to 36	V
Feedback Pin Voltage	V_{FB}	-0.3 to Vin	V
EN Pin Voltage	V_{EN}	-0.3 to Vin	V
Output Switch Pin Voltage	V_{Output}	-0.3 to 60	V
Power Dissipation	P_D	Internally limited	mW
Thermal Resistance (TO263-5L) (Junction to Ambient, No Heatsink, Free Air)	R_{JA}	30	ºC/W
Operating Junction Temperature	T_J	-40 to 125	ºC
Storage Temperature	T_{STG}	-65 to 150	ºC
Lead Temperature (Soldering, 10 sec)	T_{LEAD}	260	ºC
ESD (HBM)		>2000	V

Note1: Stresses greater than those listed under Maximum Ratings may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operation is not implied. Exposure to absolute maximum rating conditions for extended periods may affect reliability.

XL6009 Electrical Characteristics

T_a = 25℃;unless otherwise specified.

Symbol	Parameter	Test Condition	Min.	Typ.	Max.	Unit
System parameters test circuit figure4						
VFB	Feedback Voltage	Vin = 12V to 16V, Vout=18V Iload=0.1A to 2A	1.213	1.25	1.287	V
Efficiency	ŋ	Vin=12V ,Vout=18.5V Iout=2A	-	92	-	%

Electrical Characteristics (DC Parameters)

Vin = 12V, GND=0V, Vin & GND parallel connect a 220uf/50V capacitor; Iout=0.5A, T_a = 25℃; the others floating unless otherwise specified.

Parameters	Symbol	Test Condition	Min.	Typ.	Max.	Unit
Input operation voltage	Vin		5		32	V
Shutdown Supply Current	I_{STBY}	V_{EN}=0V		70	100	uA
Quiescent Supply Current	I_q	V_{EN} =2V, V_{FB} =Vin		2.5	5	mA
Oscillator Frequency	Fosc		320	400	480	Khz
Switch Current Limit	I_L	V_{FB} =0		4		A
Output Power NMOS	Rdson	Vin=12V, I_{SW}=4A		110	120	mohm
EN Pin Threshold	V_{EN}	High (Regulator ON) Low (Regulator OFF)		1.4 0.8		V
EN Pin Input Leakage Current	I_H	V_{EN} =2V (ON)		3	10	uA
	I_L	V_{EN} =0V (OFF)		3	10	uA
Max. Duty Cycle	D_{MAX}	V_{FB}=0V		90		%

Schottky Diode Selection Table

Current	Surface Mount	Through Hole	VR (The same as system maximum input voltage)				
			20V	30V	40V	50V	60V
1A		√	1N5817	1N5818	1N5819		
3A		√	1N5820	1N5821	1N5822		
		√	MBR320	MBR330	MBR340	MBR350	MBR360
	√		SK32	SK33	SK34	SK35	SK36
	√			30WQ03	30WQ04	30WQ05	
		√		31DQ03	31DQ04	31DQ05	
		√	SR302	SR303	SR304	SR305	SR306
5A		√	1N5823	1N5824	1N5825		
		√	SR502	SR503	SR504	SR505	SR506
		√	SB520	SB530	SB540	SB550	SB560
	√			50WQ03	50WQ04	50WQ05	

Typical System Application for EPC/Notebook Car Adapter – Boost (Output 18.5V/2.5A)

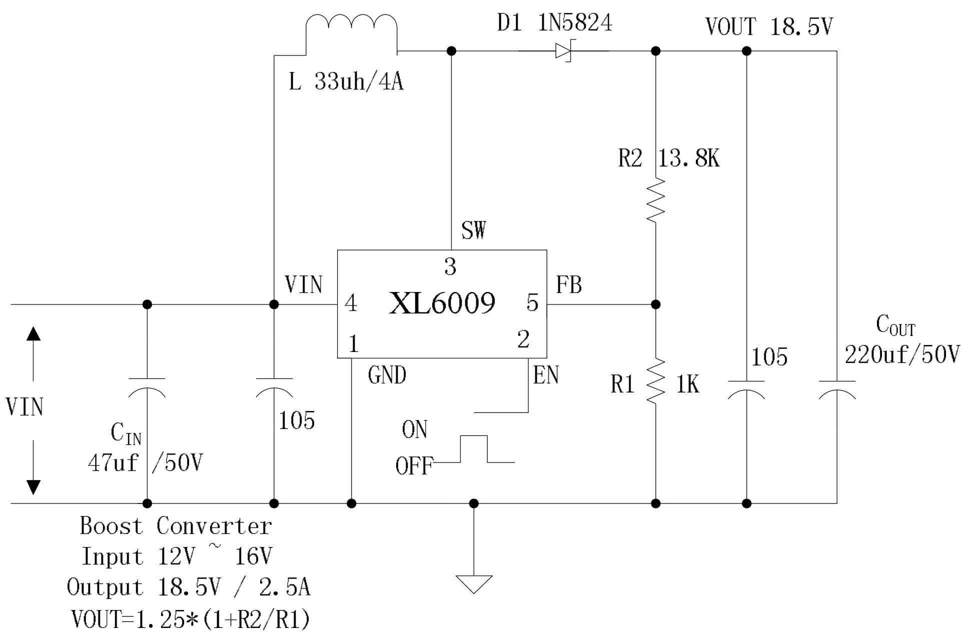


Figure5. XL6009 Typical System Application (Boost Converter)

Typical System Application for Portable Notebook Car Adapter
– SEPIC Buck-Boost Topology (Input 10V~30V, Output 12V/2A)

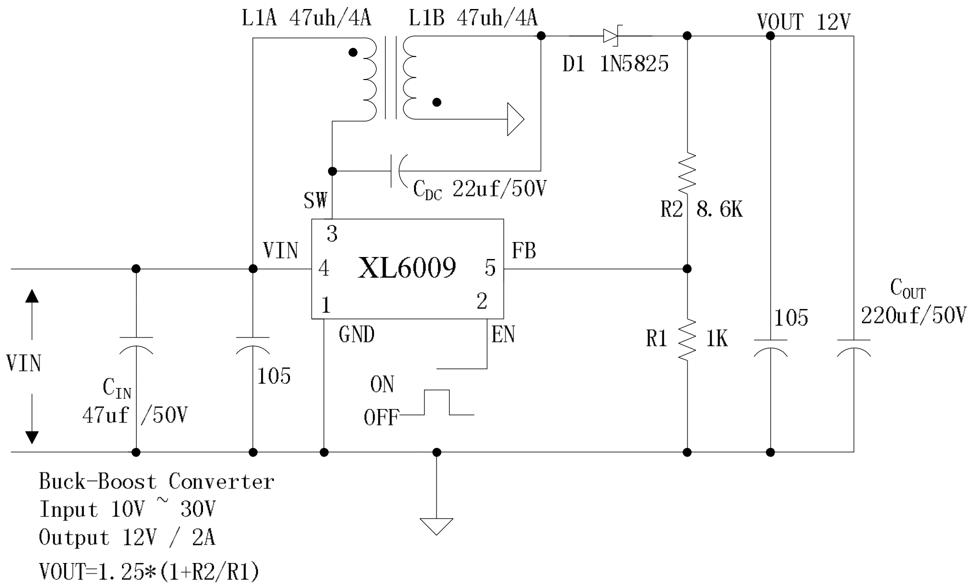


Figure6. XL6009 Typical System Application (SEPIC Buck-Boost Converter)

Typical System Application for Inverting Converter
– SEPIC Inverting Topology (Input 10V~30V, Output + -12V/1A)

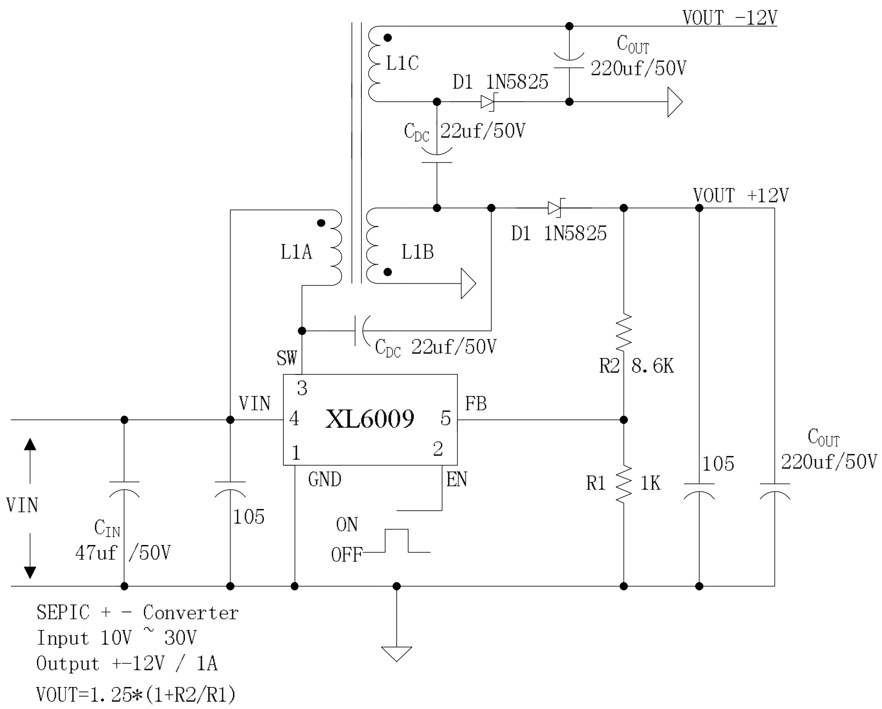
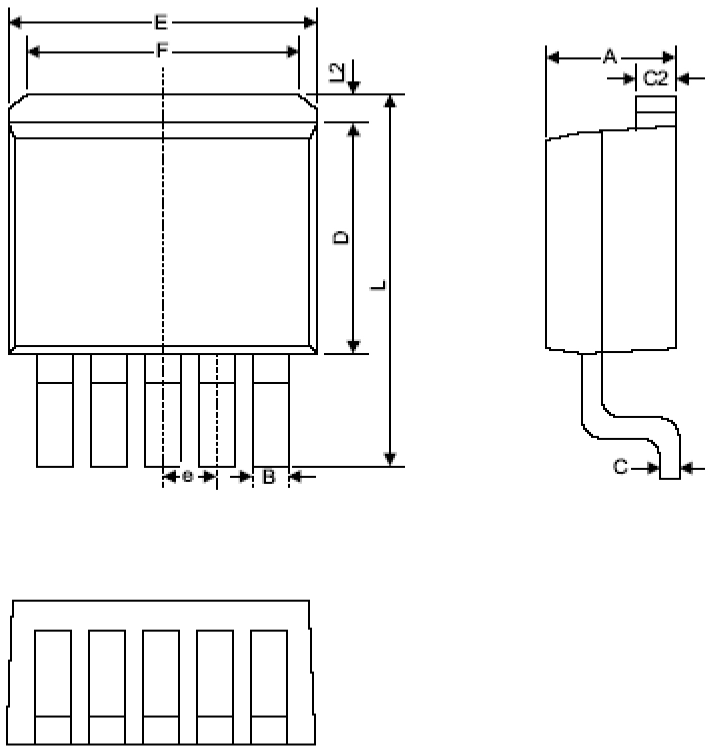


Figure7. XL6009 Typical System Application (SEPIC Inverting Converter)

Package Information

TO263-5L



Symbol	Dimensions In Millimeters		Dimensions In Inches	
	Min	Max	Min	Max
A	4.440	4.650	0.175	0.183
B	0.710	0.970	0.028	0.038
C	0.360	0.640	0.014	0.025
C2	1.255	1.285	0.049	0.051
D	8.390	8.890	0.330	0.350
E	9.960	10.360	0.392	0.408
e	1.550	1.850	0.061	0.073
F	6.360	7.360	0.250	0.290
L	13.950	14.750	0.549	0.581
L2	1.120	1.420	0.044	0.056