Design of a Hot Object Detector for Smart Mobility Cane

by

Alireza Akbari

Electrical and Biomedical Engineering Design Project (4BI6)
Department of Electrical and Computer Engineering
McMaster University
Hamilton, Ontario, Canada

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Faculty Advisor: Dr. Thomas E. Doyle

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ABSTRACT

One of the main concerns of the visually challenged person is to locate the surrounding obstacles. A white cane is the primary device that is used to help navigation. However, it would not be the best assistive device in terms of providing information to the user. The aim of the team project is to design a device that could enhance the functionality of the white cane providing more information to the user about his/her surrounding objects. Hot object detection is one of the functionalities of the cane that can be improved. Given the way in which the cane is used, the detection is required to be done in a non-contact fashion. Thus, the principle of absorbing thermal radiation is essential to this project. A thermopile that is a “pile” of thermocouples is used to absorb the objects’ thermal radiations. This will lead into a potential difference proportional to the amount of the energy absorbed. The potential difference across the thermopile is amplified since it is in the order of micro-volts. The obtained signal is then filtered to suppress the contaminating noise coming from various sources such as 60 Hz power line and the instruments. A mathematical relationship between the potential difference and the relative temperature of the object with skin is modelled. Several tests have been conducted to verify the functionality of the design and results are presented.

Keywords: hot object detection, thermopile, noise filtering, signal amplification

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Alireza Akbari

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Nomenclature

SMC: smart mobility cane

IR: infrared detection

FOV: field of view

LPF: Low Pass Filter

Chapter 1

Introduction

1.1 Background

The main concern of visually challenged person is to have a perception of their surrounding environment to find a safe and efficient path for navigation. The white cane is a primary assistive device that has been long used to serve this purpose; however, it is not the most efficient assistive device since it provides limited information about the surroundings. The user is informed of the presence of an object when the tip of the white cane comes in contact with the object. As a result, the user is not aware of the objects such as tables, chairs and the like, which are off the ground and out of reach of the white cane. Another shortcoming of the white cane is that it does not provide more information such as the temperature of objects that might burn the user.

The challenge of advancement in the functionality of the white cane is to provide more information about the surroundings to the user. There have been a few designs out there that have tried to address this challenge and have succeeded to production stage. The current commercial white cane uses ultrasonic object sensors that inform the user about the obstacles in the surrounding area. Although this functionality help detect more objects, however, it is not giving more information about the objects such as temperature. Therefore, the user still needs to detect the hot objects that could potentially burn him/her.

The goal of the Smart Mobility Cane (SMC) team in to come up with a design that detects the obstacles and hot objects and communicates the information to the user efficiently. The focus of this report is to discuss the design of a hot-object detector for the SMC. As mentioned before, the main concern with the usage of a white cane is that it does not inform the user about objects that are not in contact with the cane. Thus, hot object detection needs to be done remotely. Thus, one way to do this is to measure thermal radiation of objects. Thermal radiation energy, which is a type of electromagnetic energy, is emitted from the surface of objects. This energy can be used to determine the temperature of the object.

For more information about the obstacle detection and user interface designs of SMC please consult with the related articles published by, and Kajatheepan Kanagaratnam, Piragath Mahalingam.

1.2 Objectives

The visually challenged person is exposed to objects that might pose a danger to him/her. One of these dangers is the hot object in the reach that might burn the user. Therefore there is a need for a technology to inform the user of such threats. This article proposes a design of a hot-object detector to fulfil the need.

1.3 General Approach to the Problem

It is important to note that the in order to determine the temperature of an object, the cane does not necessarily need to come in contact with the object. As a result, the nature of the project requires that the detection should be done in a non-contact manner. An easy approach to design a non-contact heat detector is to measure the thermal radiation that is emitted from objects. A thermopile is, which is sensitive to thermal radiation, can absorb the emitted energy by the object and produce a proportional voltage potential at the output terminal. The generated voltage potential is in the range of 10’s of microvolt is very small and contaminated with noise. The signal is then amplified to a few volts and the noise is filtered out of the signal. A comparator is used to compare the signal with a reference voltage in order to determine whether the object is hot. Figure 1.1 illustrates an overview of the design solution.

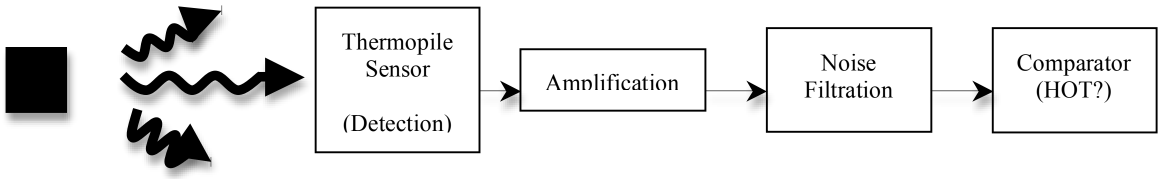


Figure 1.1: A general over view of the hot-object detector

1.4 Scope of the Project

The design will detect the hot objects such as pressing iron, stove, boiling kettle, and the like in the navigation path of the blind. The distance of the detection is restricted by the size of the object. Thus the small hot objects that are very far (more than half a metre) would not be detected unless they are very hot so their thermal radiations cause the output voltage to go past the reference voltage. Any objects about 5 degrees hotter than the average temperature of the hand (27 °C ± 2°C).

Chapter 2

Statement of Problem and Methodology of Solution

2.1 Statement of Problem

This project is to develop a hot object detector design for the SMC. Due to the nature of the application of the project design, the main challenge is to detect hot objects remotely. This could be accomplished by measuring the thermal radiation of objects that is discussed in the next section.

2.2 Methodology of Solution

2.2.1 Background

Thermal radiation is a type of electromagnetic radiation that is emitted from the surface of objects. It is produced due to the interaction of the atoms within the matter. Thermal radiation ranges from 0.1 to 100 µm. Figure 2.1 depicts the thermal radiation range with respect to the electromagnetic spectrum.

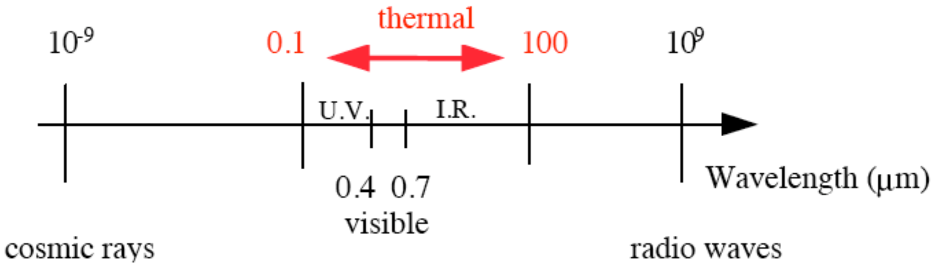


Figure 2.1: Electromagnetic Spectrum

Stefan-Boltzmann law expresses the relationship between the amount of radiated thermal energy and the temperature. The Stefan-Boltzmann law states that the energy flux density is directly proportional to the forth power of the object's absolute temperature. The mathematical relationship is given by:

$J = \sigma T$ where J denotes energy flux measured in watts per square metre, T is absolute temperature measured in kelvin, and σ is the Stefan-Boltzmann constant given by:

$\sigma = 5.670400 \times 10^{-8}\ Js^{-1}m^{-2}K^{-4}$.

Figure 2.2 shows the relationship between energy emitted and the absolute temperature of the object.

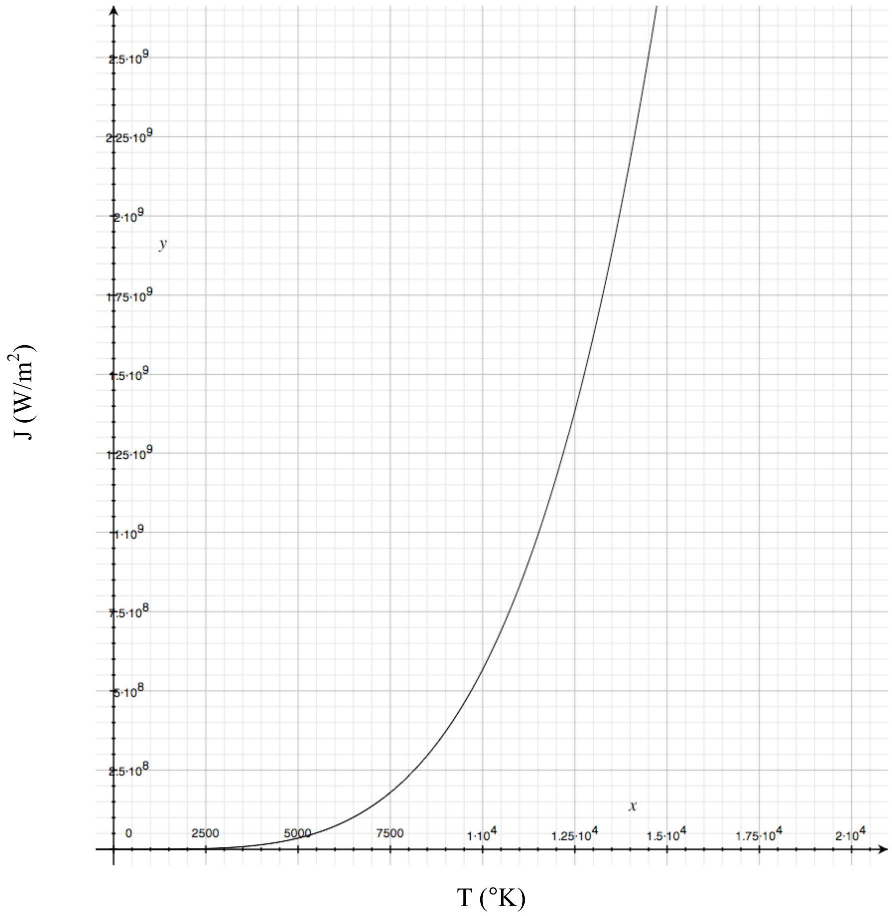


Figure 2.2: Thermal Radiation verses Absolute Temperature

The intent of this project is to find a very simple relationship between the thermal radiation and the temperature of an object. As noted in figure 3, there is a nonlinear relationship between these two quantities. However, this relationship could be simplified to a linear relationship within a certain temperature range. The expected temperature range for the design is approximately about 25 °C to 50 °C, which corresponds to 298 °K to 348 °K. This can be easily shown by zooming in to Stefan-Boltzmann graph for the temperature range of 298 °K to 348 °K. Figure 2.3 illustrates the relationship in this temperature range.

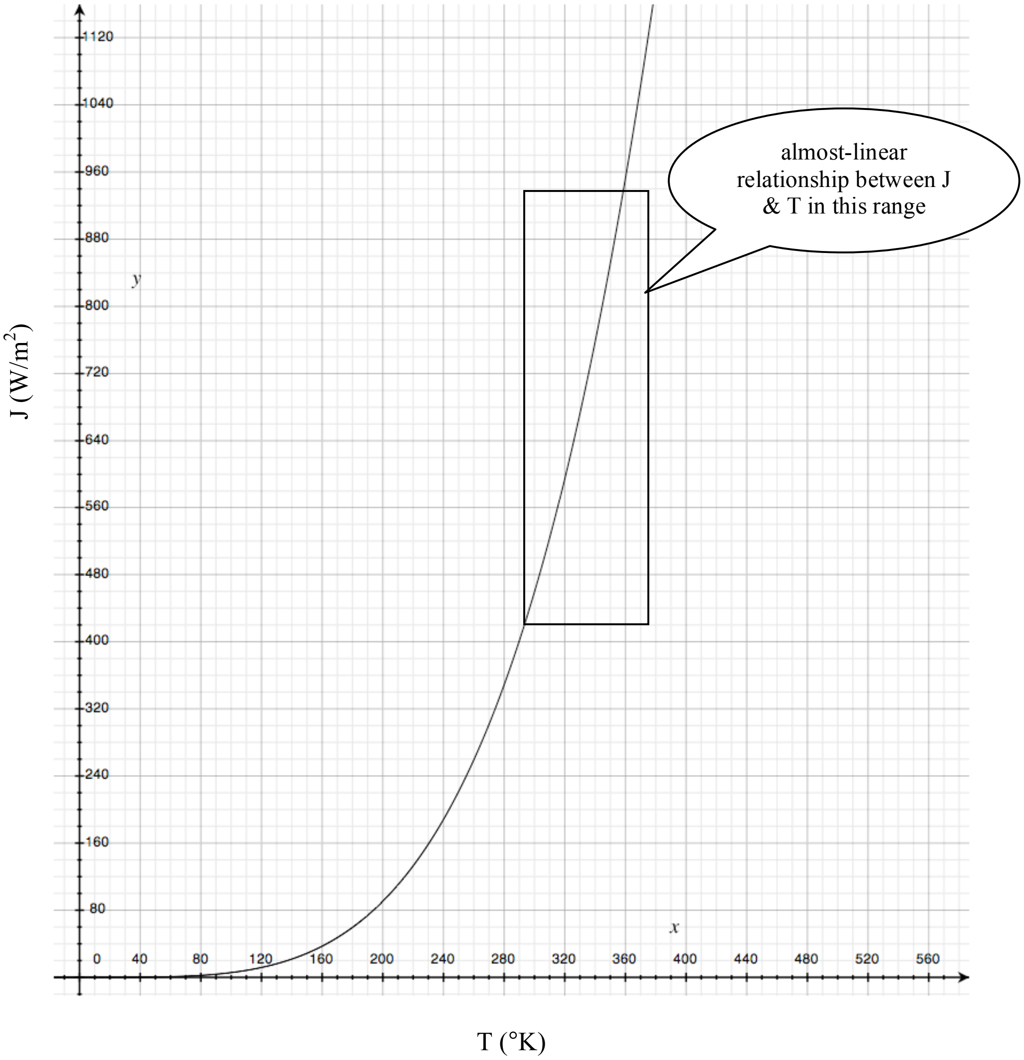


Figure 2.3: A closer look at the relationship between the thermal radiation and temperature of the object in the target range

As noted in figure 2.3, the thermal radiation and temperature relationship can be modelled as a linear relationship. Therefore, it is concluded that the amount of radiated thermal energy increases as the temperature increases.

2.2.2 Temperature Detection

The next step of the methodology is to find a way to absorb thermal radiation and determine the temperature of the emitting source. This could be done through a phenomenon called thermoelectric effect. Thermoelectric effect is the process thorough which the temperature difference is converted to the electric potential. When two ends of two different charge carrier materials are connected to each other and are exposed to a temperature difference, an electric potential is generated. This phenomenon is depicted in figure 2.4.

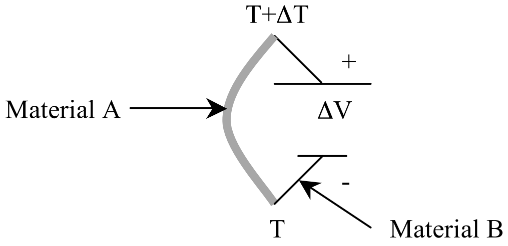


Figure 2.4: When a temperature difference is applied to the junctions of two charge carrier materials an electric potential is generated

As seen in figure 2.4, thermal radiation absorbed by one of the junctions creates ΔT, which results into ΔV at the terminal.

Thermocouples are thermoelectric devices that operate based on thermoelectric effect. They can absorb thermal energy and convert it into electric potential. Thermocouples can be arranged in series to produce enough electric potential that could be measurable. Thermocouples that are arranged in this manner are called thermopile. This project makes use of thermopile to determine the temperature of an object.

2.2.3 Temperature Measurements

Thermopiles are capable of producing voltage potential as a result of absorbing the thermal energy. The following general model expresses the relationship between the thermal radiation and the output voltage produced by a thermopile:

$$V_{out} = \alpha[(T_o{}^4) - (T_a{}^4)],$$

where V_{out} is the output voltage of the thermopile in volts, α is the sensitivity of the thermopile in V/K^4, which is device dependant, T_o is the temperature of the object in kelvin, and T_a is the ambient temperature in kelvin. The ambient temperature for this project is set to the temperature of the users hand, constant (27 °C ± 2°/300°K± 2°), using a heat sink. Figure 2.5 illustrates the graph of this equation.

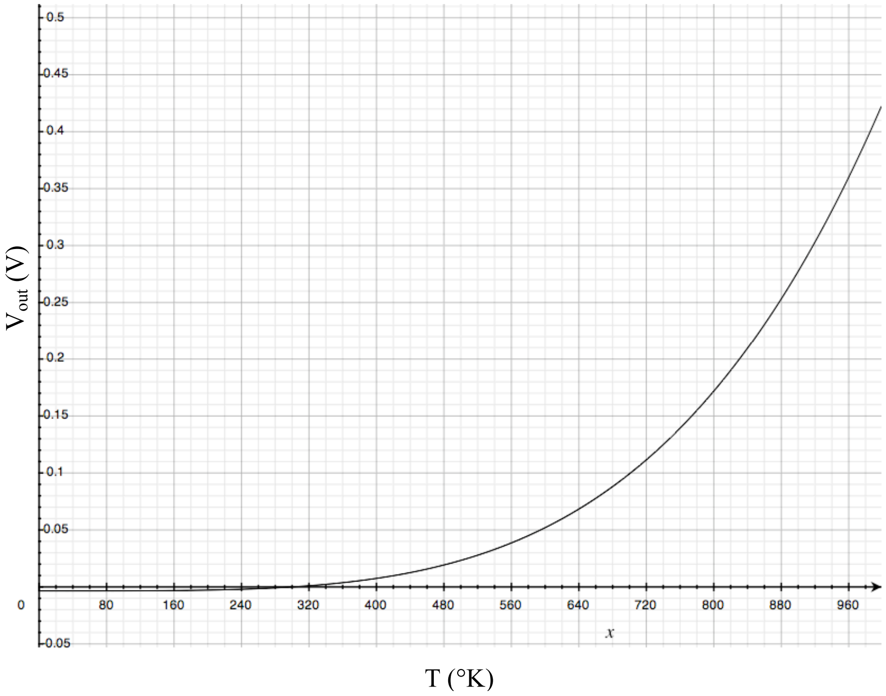
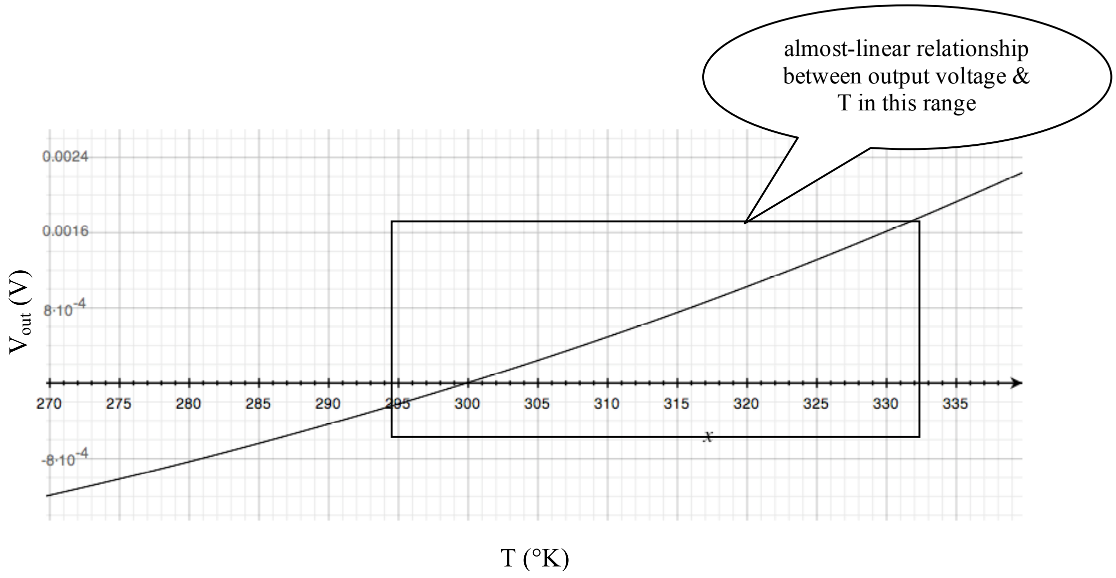


Figure 2.5: Output voltage of thermopile with respect to absolute temperature of the emitting object

As observed in figure 2.5, the relationship between output voltage and the temperature is not linear. However, the graph could be modelled as a linear graph in the intended temperature range. Figure 2.6 confirms this fact.



almost-linear relationship between output voltage & T in this range

Figure 2.6: A closer look at the output voltage of thermopile with respect to absolute temperature of the emitting object in the target temperature range

It was concluded in section 2.2.1 that the thermal radiation is linearly proportional to the temperature of the object that is $J \propto T$. According to figure 2.6, it could be inferred that the amount of thermal energy received by the thermopile leads to a linearly proportional output voltage. Therefore, from these two linear models, it is concluded that the output temperature is directly and linearly proportional to the temperature of the emitting object. Now, the project uses a linear time invariant (LTI) system for the signal processing including amplification, and noise filtration in order to produce a desirable signal. Thus, the final output voltage is directly, and linearly proportional to the temperature of the emitting object that is $V_{Signal} \propto T_{object}$. This relationship will be derived in the next chapter.

Chapter 3

Experimental and Design Procedures

3.1 Experimental Procedures

This section discusses the details of the design components including temperature detection, amplification, noise filtration, and hot-object detection.

3.1.1 Temperature Detection

MLX90247 Thermopile is an infrared (IR) sensor that uses a thermopile to measure the absolute temperature of objects. Figure 3.1[1] shows a functional diagram of this sensor.

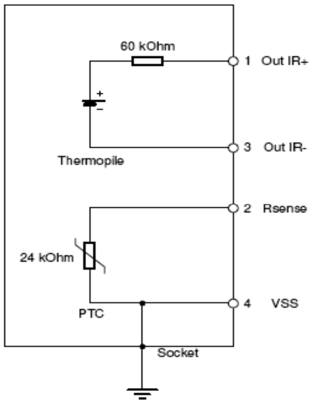
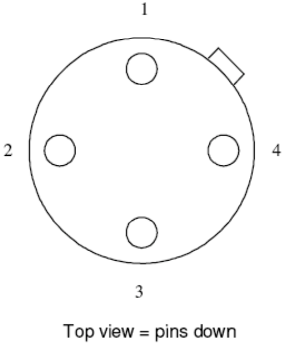
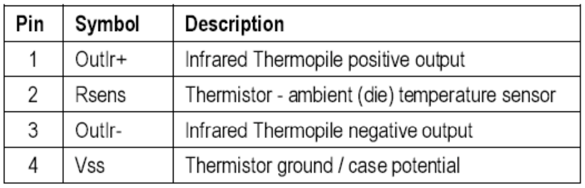


Figure 3.1: Functional diagram of MLX90247 Thermopile

Figure 3.2[1] illustrates the pin definitions and description of the thermopile.





Pin	Symbol	Description
1	OutIr+	Infrared Thermopile positive output
2	Rsens	Thermistor - ambient (die) temperature sensor
3	OutIr-	Infrared Thermopile negative output
4	Vss	Thermistor ground / case potential

Figure 3.2: Pin definitions and description of MLX90247 Thermopile

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[1] http://www.melexis.com/

Table 3.1 summarizes the thermopile specifications.

Parameter	Typical	Unit	Condition
Wavelength range	5.5 to 15	µm	
Sensitivity (α)	4.28e-13	V/K^4	Full FOV
Output Voltage	46	µV	T_a= 25 °C T_{obj}= 27 °C
Thermopile Resistance	60	kΩ	T_a= 25 °C
Time Constant	30	ms	

Table 3.1: Summary of MLX90247 Thermopile specifications

The output voltage of MLX90247 Thermopile is in the order of microvolts. This output voltage is too small and needs to be amplified in order to be able to determine the temperature. Therefore, an amplifier circuit is needed to amplify the signal.

3.1.2 Signal Amplification

An instrumentation amplifier is designed to amplify the signal. Figure 4.3 shows the block diagram of an instrumentation amplifier.

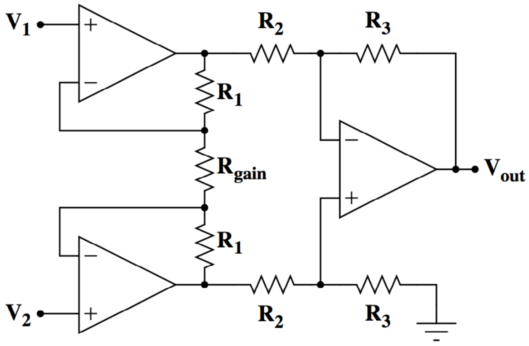
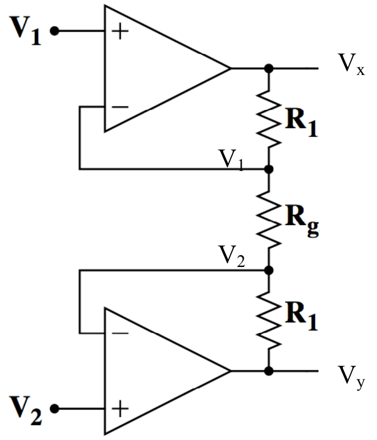


Figure 3.3: A block diagram of an instrumentation amplifier

The first two operational amplifiers on the left of figure 3.3 are providing high input impedance. This provides impedance matching between the source and the rest of the circuit. The impedance matching is important because it protects the signal source against the rest of the circuit such that there is no voltage and current enforced from the circuit on the source. They also provide some gain to the signal. The third amplifier on the right of figure 3.3 serves as a differential amplifier and also converts the tow floating signals into a referenced signal. Thus, the output voltage is the difference of the two input signal that is amplified and is not floating any more.

The gain of the instrumentation amplifier is derived in the following manner:
The circuit is broken into two parts:

Part A: Voltage divider and amplifier

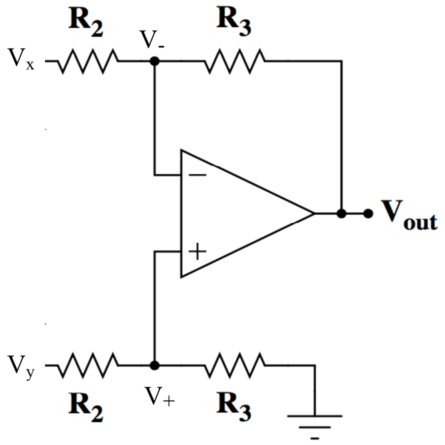


$$(V_x - V_y)/(2R_1 + R_g) = (V_1 - V_2)/(R_g)$$

$$(V_x - V_y) = (V_1 - V_2) * (2R_1 + R_g)/(R_g)$$

$$(V_x - V_y) = (V_1 - V_2) * ((2R_1/R_g) + 1) \qquad (1)$$

Part 2: Differential Amplifier



$$(V_+ - V_y)/R_2 = (V_+ - 0)/R_3$$

$$V_+ = (R_3/(R_2 + R_3)) * V_y \qquad (2)$$

$$(V_- - V_x)/R_2 = (V_- - V_{out})/(R_3)$$

$$V_{out} = V_- ((R_2 + R_3)/R_2) - (R_3/R_2) * V_x \quad (3)$$

$V_- = V_+ \rightarrow$ sub. (2) into (3)

$$V_{out} = (R_3/R_2) * (V_x - V_y) \qquad (4)$$

Now, substitute (1) into (4)

$$V_{out}/(V_1 - V_2) = (R_3/R_2) * ((2R_1/R_g) + 1) \qquad (5)$$

The gain of the instrumentation amplifier is given by equation 5.

The output signal from the instrumentation amplifier is contaminated with noise from various sources such as 60 Hz power line and instrumentation noise. The temperature of the object do not change quickly this means the useful information in the signal is in low frequency components. Therefore, a low pass filter (LPF) is needed to filter out the high frequency components that include noise.

3.1.3 Noise Filtration

It is expected that the temperature of the object dose not change quickly. As a result, the low frequency component of the signal contains the temperature information. Consequently, a second order LPF is designed that rejects all the frequencies greater than 3 Hz.

A second order LPF contains a resistor, capacitor, and inductor connected in series. In integrated circuit electronics, the use of an inductor is avoided due to the bulkiness of the inductors. Fortunately there is a circuit design that uses op-amps, resistors, and capacitor to construct a circuit that has similar characteristics to that of an inductor. Antoniou was the first to come up with the pure inductor equivalent circuit. Figure 3.4 shows a block diagram of such circuit.

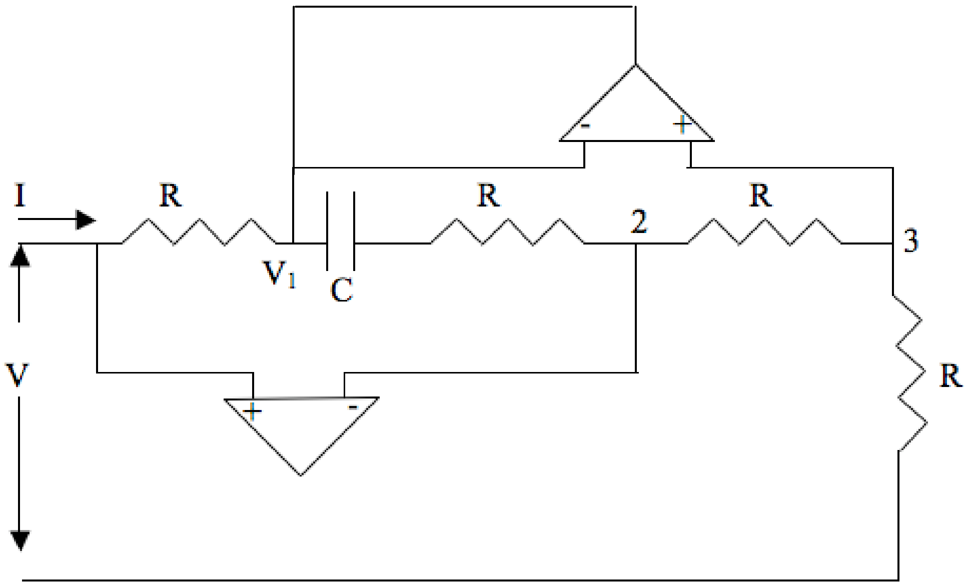


Figure 3.4: The inductor equivalent circuit

The equivalent derived as following:

$I = (V – V-)/R$ (1)

$(V1 – V)/ (1/j\omega C) = (V – V2) / R$ (2)

$(V2 – V)/R = (V – 0)/R$ → $V2 =2V$ (3)

Elimination of V1 and V2 :

From (2): $V1 = V + (V-V2)/(j\omega RC) = V + (V -2V)/(j\omega RC) = V – (1/j\omega RC) V$

Using (1): $I = (V-(1/j\omega RC)V)/R = (1/j\omega R\text{^}2C)V$

Thus: $Z = V/I = j\omega R^2C = j\omega L_{eq}$,where $L_{eq} = R^2C$

Now we can use this inductor in the following LPF circuit:

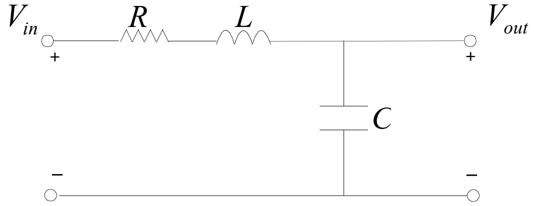


Figure 3.5: The block diagram of the LPF

The transfer function of the LPF is given by:

$$H(j\omega) \equiv \frac{V_{out}(j\omega)}{V_{in}(j\omega)} = \frac{1/j\omega C}{R + j\omega L + 1/j\omega C} = \frac{1/LC}{(j\omega)^2 + j\omega(R/L) + 1/LC}$$

$$\equiv \frac{\omega_o^2}{(j\omega)^2 + j\omega(\omega_o/Q) + \omega_o^2} = \frac{\omega_o^2}{\sqrt{(\omega_o^2 - \omega^2)^2 + \omega^2\omega_o^2/Q^2}} e^{j\phi(\omega)}$$

The relaxation oscillation frequency is given by:

$$\omega_o \equiv 1/\sqrt{LC}$$

The cutoff frequency can be determined by:

$$\left|\frac{V_{out}(j\omega_c)}{V_{in}(j\omega_c)}\right|^2 \equiv |H(j\omega_c)|^2 = \frac{1}{2}$$

Therefore: $\frac{\omega_o^4}{(\omega_o^2-\omega_c^2)^2+\omega_c^2\omega_o^2/Q^2} = \frac{1}{2} \rightarrow \omega_c = \omega_o\sqrt{\sqrt{(1-1/2Q^2)^2+1}+(1-1/2Q^2)}$

,and $f_c = f_o\sqrt{\sqrt{(1-1/2Q^2)^2+1}+(1-1/2Q^2)}$

The quality factor is given by the $Q \equiv \frac{1}{R}\sqrt{\frac{L}{C}}$, and L = L_{eq} = R^2C → Q = 1

,and as a result: $f_c = f_o\sqrt{7/4}$

3.1.4 Hot-Object Detection

Once the signal is amplified and cleared, it is fed into a comparator. The comparator compares the signal with the reference voltage, which is the threshold. If the signal is higher than the threshold the comparator outputs a 5 V signal, and zero otherwise.

Figure 3.5 depicts the block diagram of the comparator circuit:

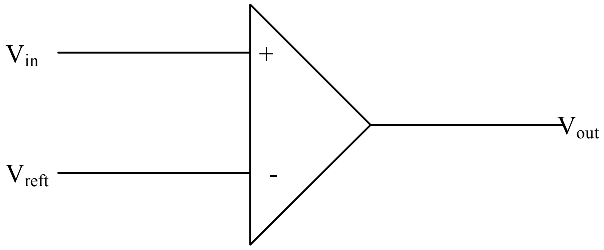


Figure 3.5: Block diagram of a comparator

$V_{out} = A(V_1 - V_2) = A(V_{in} - V_{ref})$, where A is the gain of the comparator that is a very large number ideally infinity.

3.2 Design Procedures

This section discusses the details of the apparatus components including temperature detection, amplification, noise filtration, and hot-object detection.

3.2.1 The Equipments

In order to set up the circuit the following equipments are needed:

1) +15 V, -15 V voltage supply
2) Bread board
3) 6 LM741 op-amps
4) Resistors
5) Capacitors
6) LabView with I/O board
7) Function generator
8) Oscilliscope

3.2.2 The Thermopile

The thermopile does not need a power supply. Pin 4 of the thermopile is grounded and pins 1 and 3 are the positive and negative output respectively.

3.2.2 Amplification

The instrumentation amplifier consists of 3 op-amps and 7 resistors. The gain of the instrumentation amplifier is given by:
Gain = $(R_3 / R_2) *((2R_1/ R_g)+1)$.

The output of the detector is in the range of microvolts and needs to be raised to a few volts. Thus, choosing R1 = R3 = 100K, R2 = 10K, and Rg = 1 K will produce a 2010.

The op-amps are connected to +10 V and -10 V of the voltage supply.
A copy of the LM741 op-amp data sheet can be found in the appendix of this report if more information is needed.

At this stage, feeding a sinusoid of 20 mV PP and 10 Hz from a function generator can verify the functionality of the amplifier. The output signal is saturated because of the high gain of the circuit.

3.2.3 Noise filtration

The LPF module parameters should be selected in such a way that it produces a cut-off frequency about 3 Hz.

The equation relating the cut-off frequency and oscillation frequency of the circuit is already determined to be $f_c = f_o\sqrt{7/4}$ from section 3.1.3. The oscillation frequency is given by: $\omega_o = 2\pi f_o \equiv 1/\sqrt{LC}$ → $f_o \equiv 1/(2\pi\sqrt{LC})$

$f_c = 3$ Hz → $f_o = f_c\sqrt{4/7} = 2.3$ Hz

In order to meet above criteria, 1 KΩ resistors and 76 μF capacitors are used to set up the filter.

In order to test the functionality of the circuit, two sinusoids of different frequencies (1 Hz, and 15 Hz) are fed into to filter and the output is monitored on the scope. It is observed that the sinusoid with 1 Hz frequency is passed while the other one is suppressed.

3.2.4 Comparator

The comparator consists of only an op-amp (LM741). It is connected to a +5 V and ground (0).

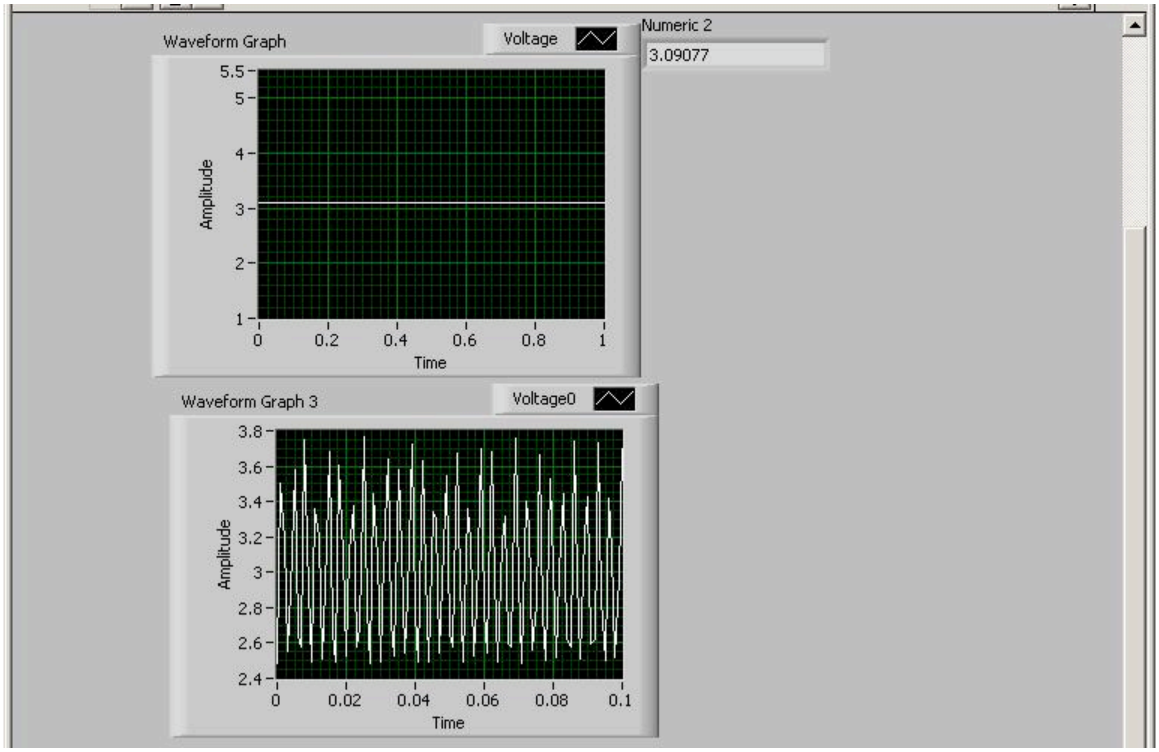
In order to determine the reference voltage of the comparator, some tests has been done to determine the signal produced due to the objects that their a temperature is higher than 35 °C. It is found that the circuit produces voltages over 3.6 V for objects with higher temperature than 35 °C. Thus the reference voltage is 3.6 V. The comparator will output 5 V when the signal is greater than the reference and zero otherwise.

Chapter 4

Results and Discussion

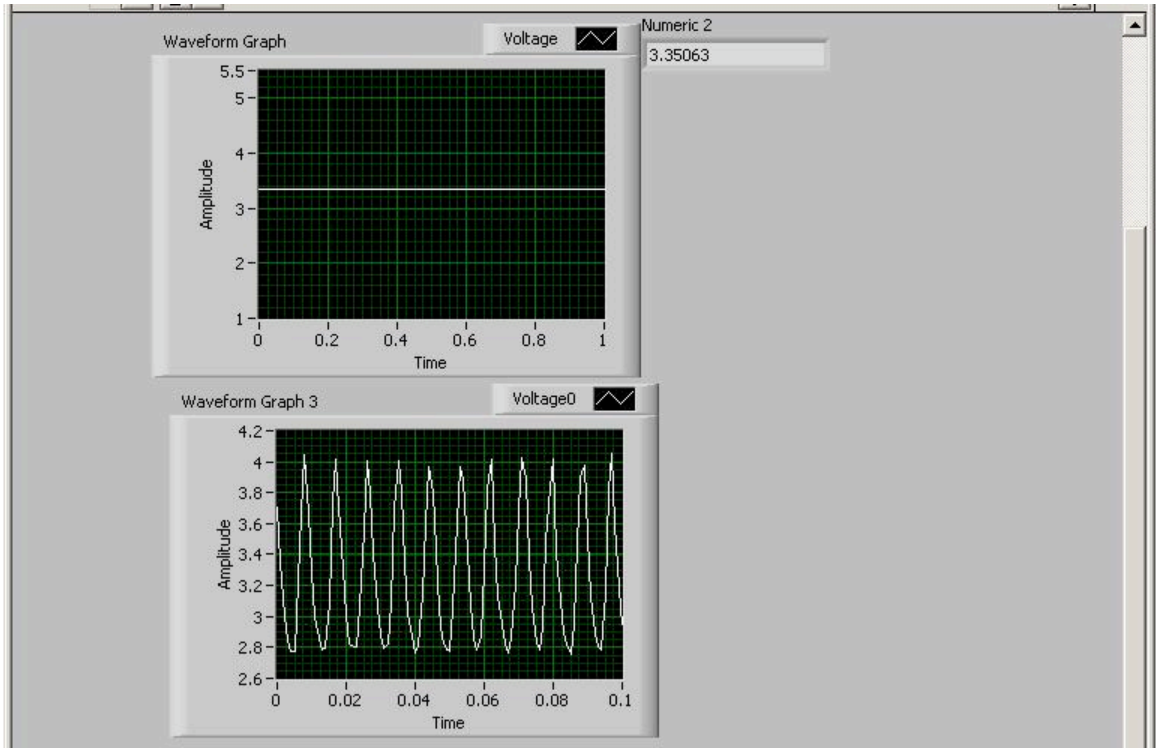
4.1 Results

The circuit is tested with object with different temperatures. The objects used are pressing iron, bottle of hot water. Both objects were left to gradually cool down to temperature of the room and tests were conducted at various temperatures. The following figures illustrate the results.



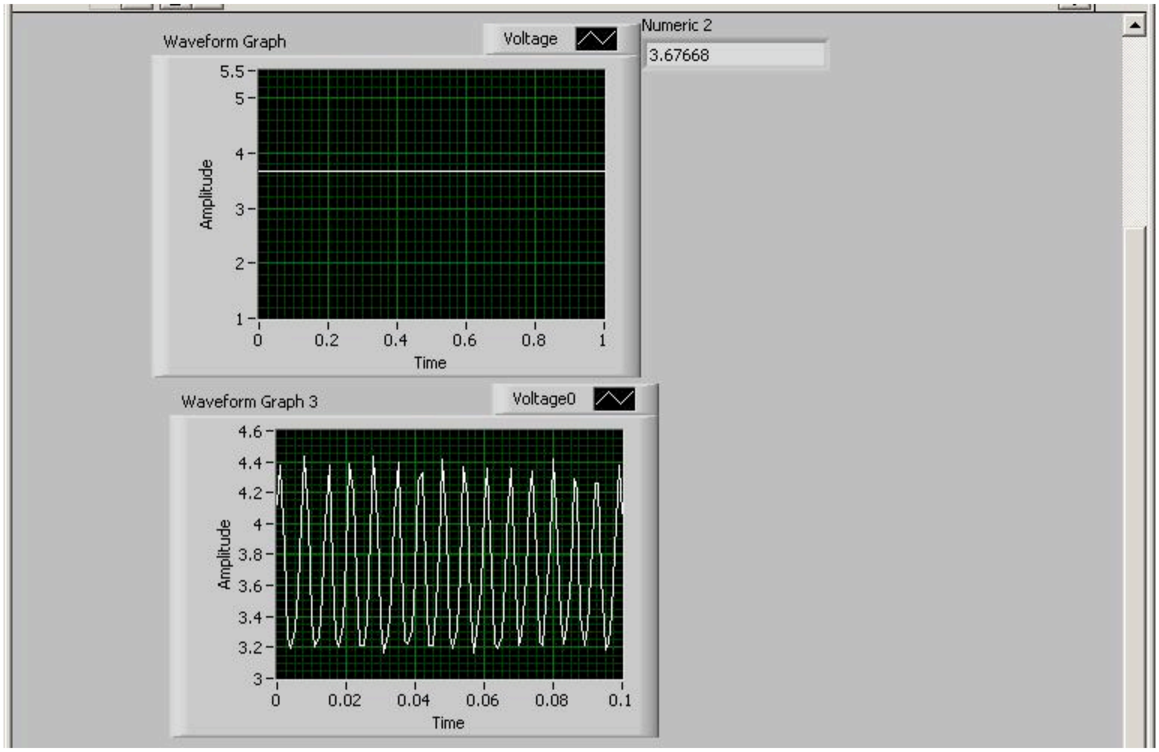
Numeric 2: 3.09077

Figure 4.1: The filtered (top) and unfiltered (bottom) signal from object @ 27 °C



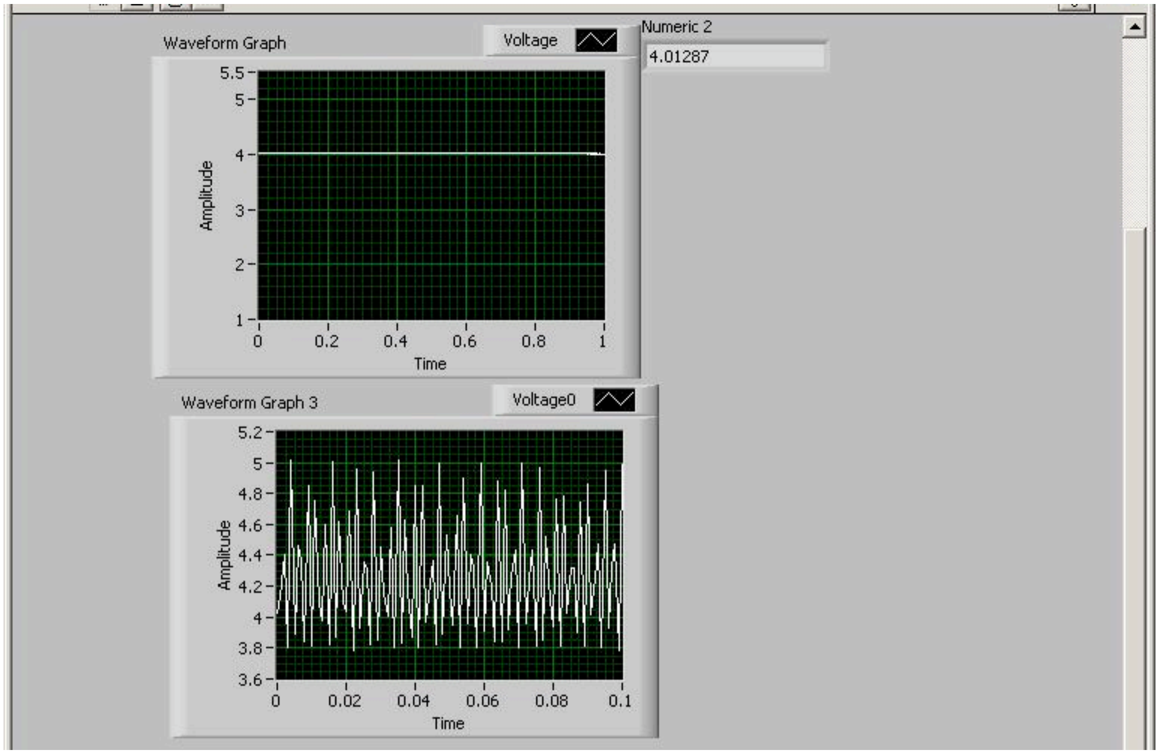
3.35063

Figure 4.2: The filtered (top) and unfiltered (bottom) signal from object @ 30 °C



3.67668

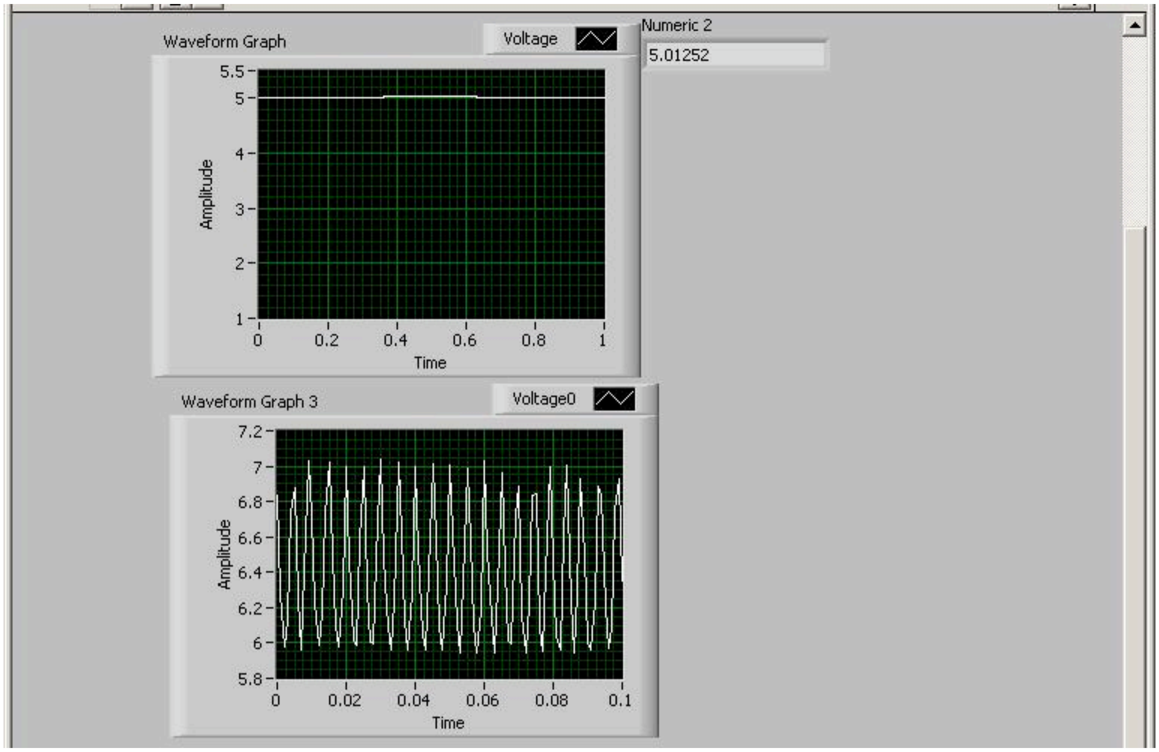
Figure 4.3: The filtered (top) and unfiltered (bottom) signal from object @ 35 °C



Numeric 2

4.01287

Figure 4.4: The filtered (top) and unfiltered (bottom) signal from object @ 40 °C



Numeric 2

5.01252

Figure 4.5: The filtered (top) and unfiltered (bottom) signal from object @ 45 °C

Figure 4.6 shows the linear relationship that is the result of the tests done for an object at different temperatures.

Temperature	Voltage
0	1.13244
4	1.42665
13	2.10888
27	3.01743
30	3.35878
35	3.66964
40	4.18798
45	5.00419

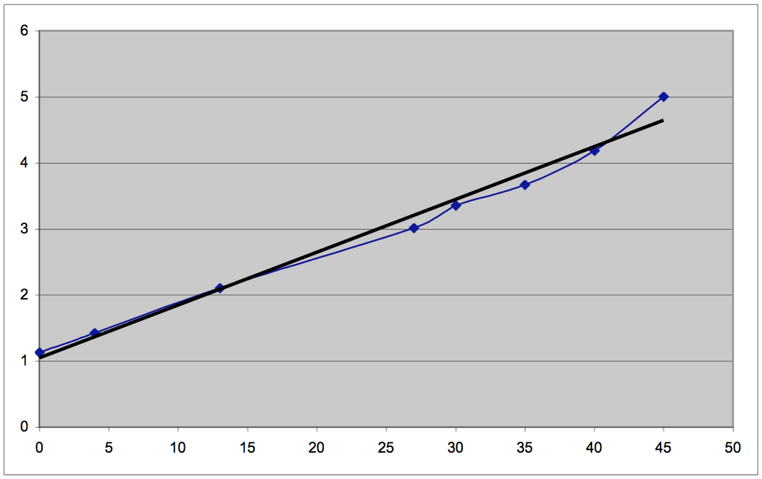


Figure 4.6: Output voltage of the designed circuit vs. the temperature of the object

4.2 Discussions

The results seem to be consistent each time there is a test conducted. It is important to note that the object must fully cover the FOV of the thermopile pile in order to get accurate results. This brings up the concern about the size of the object and the its distance from the thermopile.

The FOV of the thermopile is 88°. Figure 4.6 illustrates the FOV of thermopile, distance of the object, and the radius.

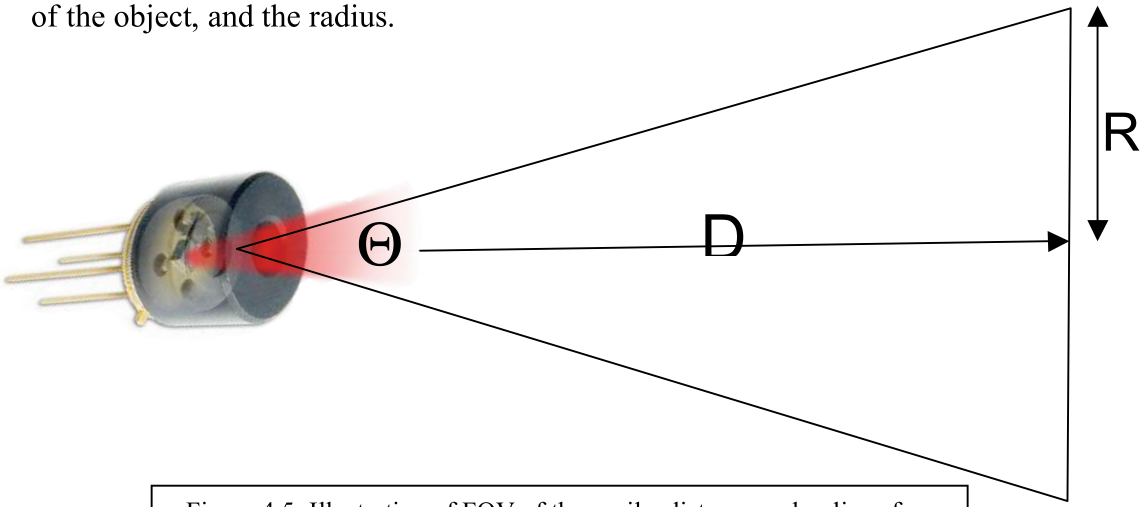


Figure 4.5: Illustration of FOV of thermoile, distance and radius of an object

The following calculations determine the relationship between the distance of an object and the size of the object.

$2*\Theta=\sim 90$ deg.

$\tan 45 = R/D \rightarrow R = D$

The calculation shows that in order to fully cover the FOV, the distance of an object cannot be greater than the radius of the object. This means that smaller objects should be closer to the sensor. For instance, an object of radius 10 cm is detectable when it is which 10 cm distance from the thermopile. This is creates an issue with the safety of this design. On the other hand, a pressing iron with radius 10 cm was detected from a 50 cm distance. This was due to the high temperature of the iron at its least operating temperature that is 110 °C. This is due to the fact that thermal energy received from the iron produced a signal of about 3.5 V at the input of the comparator. Since this signal is greater than the reference voltage, the comparator outputs a 5 V signal meaning a hot object is detected. Thus, it is possible to detect hot objects at temperatures above 100 °C even if the object is as small as 10 cm in radius.

Chapter 5

Conclusions and Recommendations

5.1 Conclusions

A non-contact hot object detector circuit is designed. The design makes use of thermal radiation emitted from objects and uses a developed linear relationship to determine the temperature.

The design proves that it is possible to detect the temperature of the object. However, the limitation of the design in detection of the temperature of the small objects introduces a safety issue.

5.2 Recommendations

The limitation of the design can be improved by selecting a thermopile with a narrower FOV. A narrower FOV would allow the detection of smaller objects in larger distances from the thermopile.

On the other hand, it is noticed that the use of a thermopile with a wide FOV serves as a motion detector. If the FOV is too wide, then the objects cannot fully cover the FOV; as a result, as the object gets closer to the detector, more thermal radiation is detected and the output voltage goes higher. The speed of the object then can be determined from the rate of change of the output voltage.

References

[1] Sedra, Adel S., Smith, Kenneth Carless. “Microelectronic circuits”, New York: Oxford University Press, 2004.

[2] Jaeger, Richard C, Blalock, Travis N. “Microelectronic circuit design”, New York : McGraw-Hill Higher Education, c2004.

[3] James B. Campbell, *Introduction to Remote Sensing*. The Guilford Press New York, 1996.

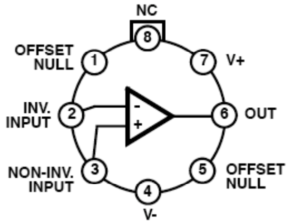
[4] W.G. Rees, *Physical Principles of Remote Sensing*. Cambridge University Press, 2001.

Index

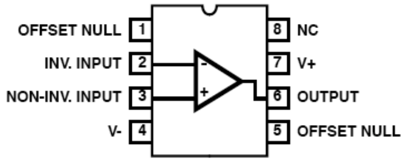
LM741

Pinouts

CA741, CA741C (CAN)
TOP VIEW



CA741, CA741C, LM741, LM741C (PDIP)
TOP VIEW



Electrical Specifications Typical Values Intended Only for Design Guidance, $V_{SUPPLY} = \pm15V$

PARAMETER	SYMBOL	TEST CONDITIONS	TYPICAL VALUE (ALL TYPES)	UNITS
Input Capacitance	C_I		1.4	pF
Offset Voltage Adjustment Range			±15	mV
Output Resistance	R_O		75	Ω
Output Short Circuit Current			25	mA
Transient Response		Unity Gain, $V_I = 20mV$, $R_L = 2k\Omega$, $C_L \leq 100pF$		
Rise Time	t_r		0.3	µs
Overshoot	O.S.		5.0	%
Slew Rate (Closed Loop)	SR	$R_L \geq 2k\Omega$	0.5	V/µs
Gain Bandwidth Product	GBWP	$R_L = 12k\Omega$	0.9	MHz

Electrical Specifications For Equipment Design, $V_{SUPPLY} = \pm15V$

PARAMETER	TEST CONDITIONS	TEMP (^oC)	(NOTE 4) CA741, CA1558, LM741			(NOTE 4) CA741C, CA1458, LM741C, LM1458			UNITS
			MIN	TYP	MAX	MIN	TYP	MAX	
Input Offset Voltage	$R_S \leq 10k\Omega$	25	-	1	5	-	2	6	mV
		Full	-	1	6	-	-	7.5	mV
Input Common Mode Voltage Range		25	-	-	-	±12	±13	-	V
		Full	±12	±13	-	-	-	-	V
Common Mode Rejection Ratio	$R_S \leq 10k\Omega$	25	-	-	-	70	90	-	dB
		Full	70	90	-	-	-	-	dB
Power Supply Rejection Ratio	$R_S \leq 10k\Omega$	25	-	-	-	-	30	150	µV/V
		Full	-	30	150	-	-	-	µV/V
Input Resistance		25	0.3	2	-	0.3	2	-	MΩ

Electrical Specifications For Equipment Design, $V_{SUPPLY} = \pm15V$ **(Continued)**

PARAMETER	TEST CONDITIONS	TEMP (°C)	(NOTE 4) **CA741, CA1558, LM741**			(NOTE 4) **CA741C, CA1458, LM741C, LM1458**			UNITS
			MIN	TYP	MAX	MIN	TYP	MAX	
Input Bias Current		25	-	80	500	-	80	500	nA
		Full	-	-	-	-	-	800	nA
		-55	-	300	1500	-	-	-	nA
		125	-	30	500	-	-	-	nA
Input Offset Current		25	-	20	200	-	20	200	nA
		Full	-	-	-	-	-	300	nA
		-55	-	85	500	-	-	-	nA
		125	-	7	200	-	-	-	nA
Large Signal Voltage Gain	$R_L \geq 2k\Omega$, $V_O = \pm10V$	25	50,000	200,000	-	20,000	200,000	-	V/V
		Full	25,000	-	-	15,000	-	-	V/V
Output Voltage Swing	$R_L \geq 10k\Omega$	25	-	-	-	±12	±14	-	V
		Full	±12	±14	-	-	-	-	V
	$R_L \geq 2k\Omega$	25	-	-	-	±10	±13	-	V
		Full	±10	±13	-	±10	±13	-	V
Supply Current		25	-	1.7	2.8	-	1.7	2.8	mA
		-55	-	2	3.3	-	-	-	mA
		125	-	1.5	2.5	-	-	-	mA
Device Power Dissipation		25	-	50	85	-	50	85	mW
		-55	-	60	100	-	-	-	mW
		125	-	45	75	-	-	-	mW

NOTE:

4. Values apply for each section of the dual amplifiers.

Test Circuits

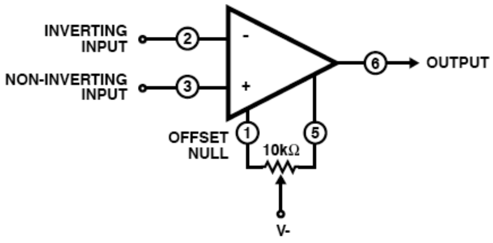


FIGURE 1. OFFSET VOLTAGE NULL CIRCUIT FOR CA741C, CA741, LM741C, AND LM741

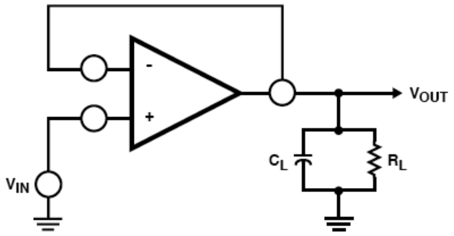
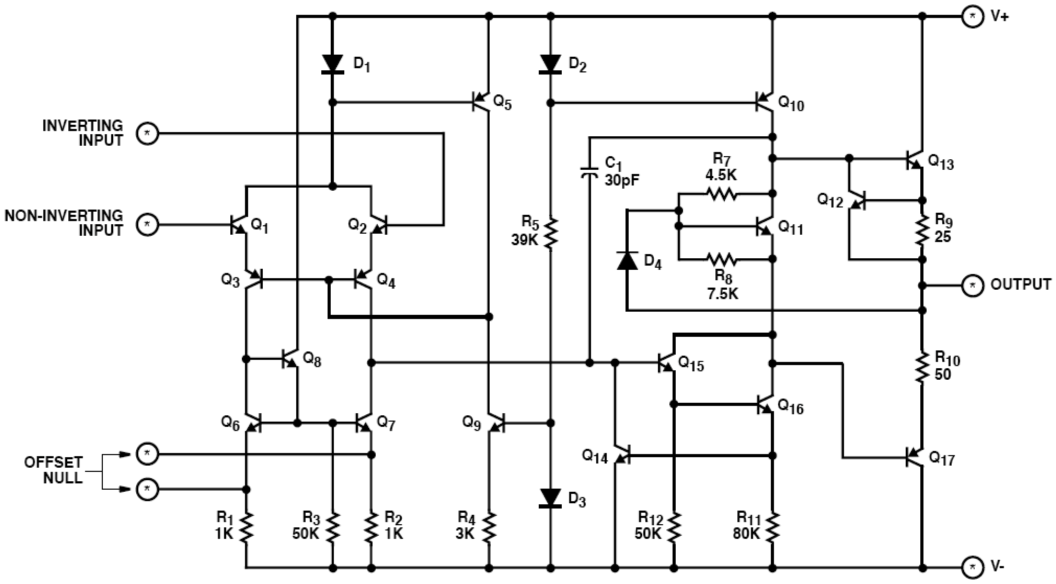


FIGURE 2. TRANSIENT RESPONSE TEST CIRCUIT FOR ALL TYPES

Schematic Diagram (Notes 5, 6)

CA741C, CA741, LM741C, LM741 AND FOR EACH AMPLIFIER OF THE CA1458, CA1558, AND LM1458



NOTES:

5. See Pinouts for Terminal Numbers of Respective Types.
6. All Resistance Values are in Ohms.

Typical Performance Curves

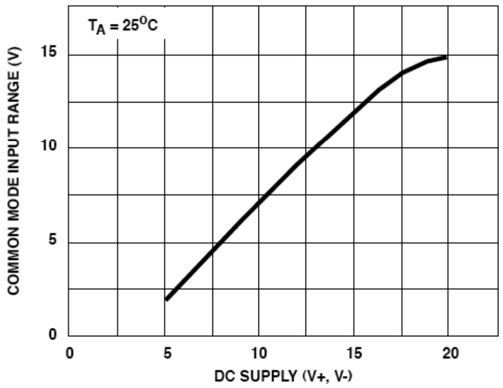


FIGURE 3. COMMON MODE INPUT VOLTAGE RANGE vs SUPPLY VOLTAGE FOR ALL TYPES

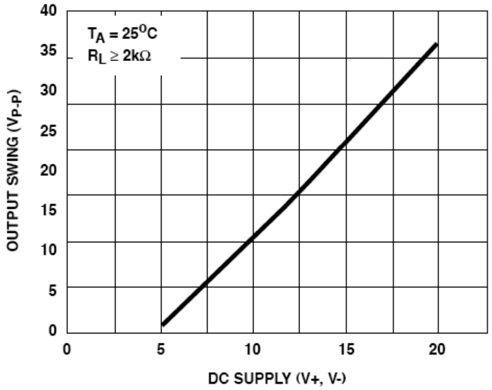


FIGURE 4. OUTPUT VOLTAGE vs SUPPLY VOLTAGE FOR ALL TYPES

Typical Performance Curves (Continued)

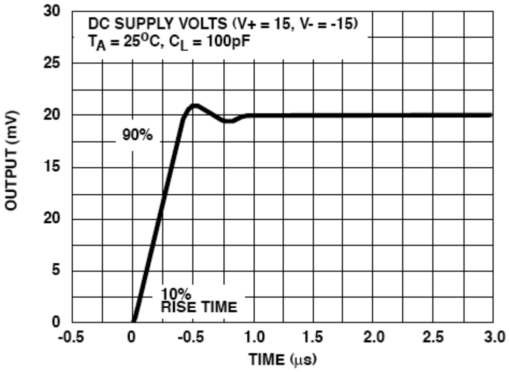
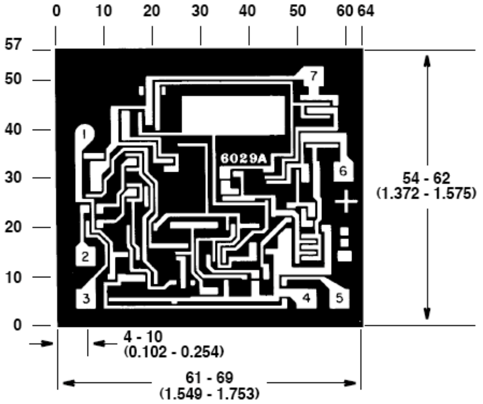


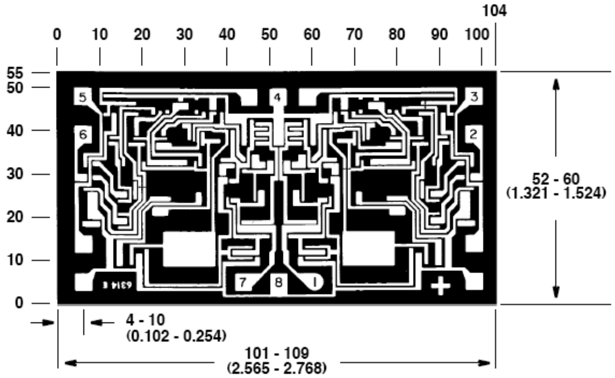
FIGURE 5. TRANSIENT RESPONSE FOR CA741C AND CA741

Metallization Mask Layout

CA741CH



CA1458H



NOTE: Dimensions in parentheses are in millimeters and are derived from the basic inch dimensions as indicated. Grid graduations are in mils (10^{-3} inch).

5. MLX90247 Specifications

Operating temperature range: Ta = -40 to 85 ˚C unless otherwise noted

Parameter	**Typical**	**Units**	**Condition**
Sensitive Area	1.2 x 1.2	mm^2	
Wavelength range	5.5 … 15	μm	
DC membrane responsitivity	12	V / W	Ta = 25˚C Tbb = 60˚C
Sensitivity (Alpha)	$4.28^{\pm 25\%} \times 10^{-13}$	V/K^4	Full FOV
Thermopile output voltage	$46^{\pm 25\%}$	μV	Ta = 26˚C Tbb = 27˚C, Full FOV
Window aperture size	3.5	mm	
Field of view	88	Deg	50% thermopile signal
Spectral sensitivity	> 70 < 1	% %	7.5μm < λ < 13.5μm 0 < λ < 5μm
Thermopile Resistance	60	kΩ	Ta = 25˚C
Noise	32	nV / √Hz	RMS, Ta = 25˚C
NEP	2.6	nW / √Hz	RMS, Ta = 25˚C
Time constant	30	ms	
Thermopile resistance tempco	0.1	% / ˚C	
PTC value R(25°C)	$24^{\pm 30\%}$	kΩ	Ta = 25˚C
PTC TC_1	$6500^{\pm 20\%}$	ppm/˚C	
PTC TC_2	16	$ppm/˚C^2$	
Withstand ESD voltage	+ 800 - 7000	V V	

NOTE: The thermistor resistance can be calculated using following expresion:

$$R(T) = R(25^o C)\left[1 + TC_1(T - 25^o C) + TC_2(T - 25^o C)^2\right]$$

Thermopile output voltage is:
Vir = Alpha .[$(T_o^4) - (T_a^4)$]
where To is the measured object temperature, both To and Ta are in Kelvins

Vita

Alireza Akbari, Electrical and Biomedical Engineering.