VEHICLE OVERHEAT PREVENTION SYSTEM: COOLING FAN FAILURE ALERT SYSTEM

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TAN KOK HOE

A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons.) Electrical and Electronic

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Universiti Tunku Abdul Rahman

May 2016

DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"VEHICLE OVERHEAT PREVENTION SYSTEM: COOLING FAN FAILURE ALERT SYSTEM"** was prepared by **TAN KOK HOE** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons.) Electrical and Electronic at Universiti Tunku Abdul Rahman.

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Supervisor : Dr. Chew Kuew Wai

Date : __________________________

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ABSTRACT

There are many causes which led to vehicle overheat and one of the common causes is the cooling fan failure. In this project, the failure of the cooling fan system will be throughout investigated. Most of the time, the failure of the cooling fan is unknown by the vehicle driver and when the failure is detected, it might be too late and cost a lot to repair. Heat generated by the engine needed to be dissipated and if fail to do so, the engine might be seriously damaged due to overheating. Therefore, the cooling fan in vehicle cooling system is a crucial part which helps to dissipate the engine heat. With this failure alert system, which serves as a prevention system, the vehicle driver can take a necessary step before more damage are made to the engine due to overheating The objective of this project is to develop and built a system which will alert the vehicle driver when there is a failure on any component of the cooling fan system. Research is done on engine cooling system and cooling fan in order to develop the vehicle overheating prevention system. A few sensor are used to monitor the health of the cooling fan system which will be processed by a controller and appropriate action will be taken accordingly. The health of the cooling fan system such as temperature and RPM of the cooling fan will be displayed to the vehicle driver. Component failure indicator will be illuminated with beeping sound when there is any failure. A prototype is built to test the functionality of this system. All the possible failure of the component of the cooling fan system such as relay, coolant temperature sensor, and fan are tested using appropriated methods and the system is working perfectly. This project is successfully done.

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LIST OF SYMBOLS / ABBREVIATIONS

V	Voltage, volt
A	Current, ampere
R	Resistance, ohm
psi	Pounds per square inch
LED	Light Emitting Diode
PMDC	Permanent Magnet DC
CTS	Coolant Temperature Sensor
RPM	Rotation per Minutes
IC	Integrated Circuit
ADC	Analog to Digital Converter
PWM	Pulse Width Modulation
PIC	Peripheral Interface Controller

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

Most of the time, car driver did not know what has caused their vehicle to overheat suddenly in the middle of traffics jam or driving along the hills. Some of the car drivers might stop at the roadside and waited for the vehicle to cold down and check on the water level of the radiator water tank. After that, the car driver continues their journey without knowing actually the cooling fan had failed. Some of the car drivers might not even notice the dashboard of their vehicle showing a “hot” on meter or indicator which their vehicle is actually overheating and then broke down in the middle of the road. The engine may be seriously damaged due to engine overheat and will cost a lot in repairing it.

There are many factors which lead to vehicle overheat such as cooling system leak, leaky head gasket, leaky water pump, slipping water pump, lower radiator hose collapsing, plugging or dirty radiator, overworking of the engine and electric cooling fan failure. However, the vehicle overheat prevention system which to be developed and built are based on the failure of the electric cooling fan. There are many prevention methods to avoid vehicle overheat but there is no such integrated solution yet to be installed in any vehicle to detect failure of cooling fans.

Hence, by developing cooling fan failure alert system helps to provide health of the cooling fan system and initiate warning on the panel with sound when it fails. This system also alert car driver whenever there is abnormal of the cooling fan and others related parts such as slow fan speed, temperature sensor failure, and relay failure. This system gives a prevention measure for the car driver on the cooling fan failure before it cause serious damage to the engine.

1.2 Aim and Objective

The purpose of this research is to;

- Investigate the possible failure of the cooling fan system.
- Determine the characteristic of the electric cooling fan.
- Determine different specification of the electric cooling fan.
- Design and built a system which alerts the car driver on types of failure which will lead to cooling fan failure.

CHAPTER 2

LITERATURE REVIEW

2.1 Internal Combustion Engine

Internal Combustion engine is a heat engine which used fuel as chemical energy to convert into mechanical energy and output as a rotating output shaft (Pulkrabek, 1997). Fuel chemical energy is converted into thermal energy by combustion method with the mixture of air. The thermal energy is use to drive the piston in the engine thus convert thermal energy into mechanical energy which is the output of the engine to drive a system such as a vehicle. There are various types of classification of internal combustion engine. Table 2.1 shows the classification of the engine. Figure 2.1 shows the engine classification by cylinder arrangement.

Table 2.1: Engine classification (Pulkrabek, 1997)

	Classification	Type
1	Type of ignition	Spark ignition
		Compression ignition
2	Engine Cycle	two-stroke cycle
		four-stroke cycle
3	Valve location	Overhead valve (I head Engine)
		Flat head (L Head Engine)
4	Basic Design	Reciprocating
		Rotary
5	Position and Number of Cylinders of Reciprocating Engines (Figure 2.1)	a) Single Cylinder
		b) In-Line (positioned Straight line)
		c) V Engine
		d) Opposed Cylinder Engine

		e) W Engine
		f) Opposed Piston Engine
		g) Radial Engine
6	Air Intake Process	Naturally Aspirated
		Supercharged
		Turbocharged
		Crankcase Compressed
7	Method of Fuel Input for Spark Ignited Engines	Carbureted
		Multipoint Port Fuel Injection.
		Throttle Body Fuel Injection
8	Fuel Used	Gasoline
		Diesel Oil or Fuel Oil
		Gas, Natural Gas, Methane
		LPG.
		Alcohol-Ethyl, Methyl
		Dual Fuel (gasoline-alcohol)
9	Application	Automobile, Truck, Bus.
		Locomotive
		Stationary
		Marine
		Aircraft
10	Type of Cooling	Air Cooled
		Liquid Cooled, Water Cooled

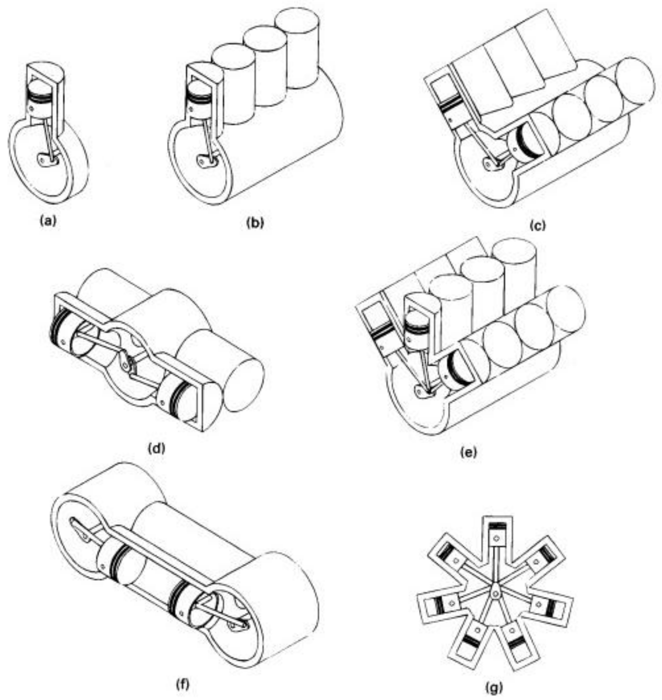

Figure 2.1: Engine classification by cylinder arrangement (Pulkrabek, 1997)

The most common use internal combustion engines in the vehicle today are four-stroke cycle engines, spark ignited and water cooled. A four-stroke cycle engine is also known as Otto cycle, in honor of Nikolaus Otto, who invented it in 1967 (Marshall Brain, 2015). The working principle of the four-stroke cycle engine is explained below.

In the first stroke, the intake process takes place. The intake valve is open and the exhaust valve is closed. The input air is mixed with the desired amount of fuel and channel into the combustion chamber. The piston moving downward to allow suction of the mixture of fuel and air into the combustion chamber. After that, the second stroke takes place, which is compression process. In this process, the mixture of air and fuel are compressed by the piston moving upward, thus raising the temperature and pressure in the combustion chamber. Both intake and exhaust valve are closed at this process. When the piston moved to the peak of the stroke, the spark parks is fired and ignited the fuel mixture. Explosions in the cylinder are more powerful due to compression. The stroke one and two of the four-stroke cycle engine is shown in Figure 2.2.

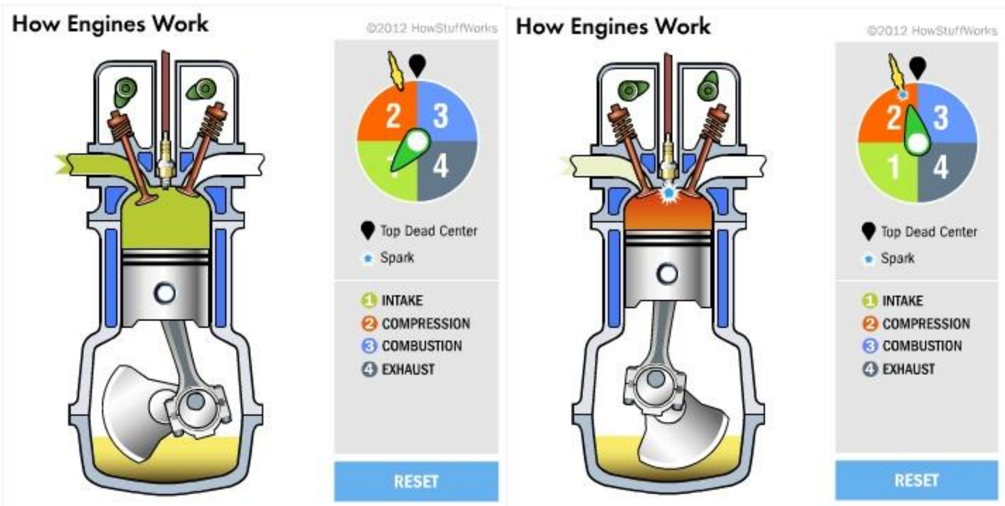

Figure 2.2: Intake and Compression stroke (Marshall Brain, 2015)

Then, the third stroke takes place. The ignited fuel creates combustion gases and the high pressure pushed the piston downward. This process is known as combustion or work as is create work output to move the engine. Both the intake and exhaust valve are closed at this time. The volume of cylinder increases as the piston move downward thus decreases the pressure. The final process or forth stroke is exhaust where the combustion gases are released through the exhaust valve when the piston moving upward. The exhaust valve is open and the intake valve is closed. Cylinder temperature and pressure are still relatively high. The different in pressure at the exhaust system makes the hot exhaust gas in the cylinder to be pushed out. The process of the four-stroke cycle is started again after that. The stroke three and four of the four-stroke cycle engine is shown in Figure 2.3.

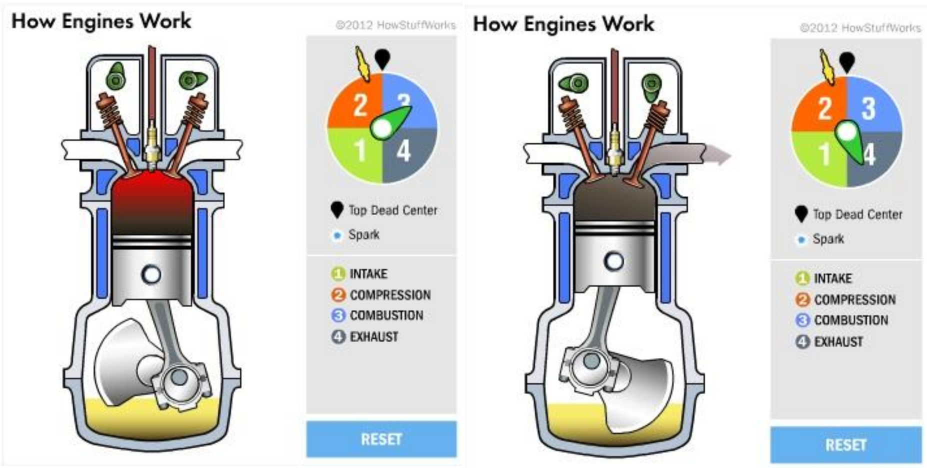

Figure 2.3: Combustion and Exhaust stroke (Marshall Brain, 2015)

During all this process, heat is generated. Some of the heat generated by combustion is used to drive the piston and then the heat of the combustion is released through the exhaust valve. However, the remaining heat is absorbed by the engine body, and therefore increasing the temperature of the engine. There are different points of operating temperature in the four-stroke cycle engine. Figure 2.4 shows the typical temperature of an engine cylinder on steady state condition.

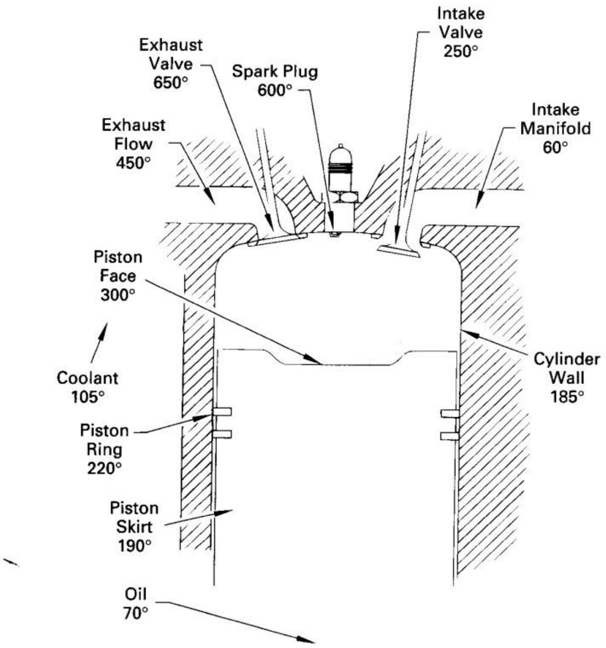

Figure 2.4: Typical temperature in the combustion chamber at steady state condition. (Pulkrabek, 1997)

From Figure 2.4, there are points where it is the hottest which is spark plug, exhaust flow, and piston face. However, this place is difficult to cool by the coolant water jacket. When an engine is started up, the temperature of all the components in the engine start to raise thus all components are subject to thermal expansion. Each component in the engine has a different magnitude of expansion depending on the material and temperature of the part. The heat transfer through cylinder wall in the combustion chamber is given by the equation 2.1. Figure 2.5 shows the heat transfer through the combustion chamber.

$$q = Q/A = \left(T_g - T_c\right)/\left[\left(1/h_g\right) + (\Delta x/k) + (1/h_c)\right] \tag{2.1}$$

Where: T_g = gas temperature in the combustion chamber

T_c = coolant temperature

h_g = convection heat transfer coefficient on the gas side

h_c = convection heat transfer coefficient on the coolant side

Δx = thickness of the combustion chamber wall

k = thermal conductivity of the cylinder wall

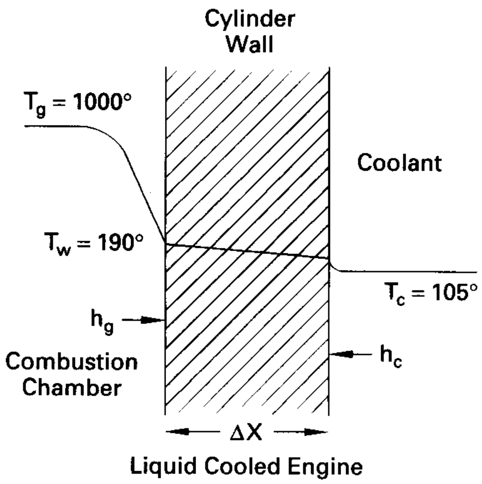

Figure 2.5: Heat transfer through the combustion chamber. (Pulkrabek, 1997)

The cylinder wall temperature should stay at between 180 ˚C to 200 ˚C for optimum performance and avoid breakdown of lubricating oil. Thus dissipating the heat out of the engine is important to avoid damage. Therefore, a water jacket surrounding the combustion chamber in the engine is needed, so that coolant water can flow through and dissipate the heat generated by the engine. Figure 2.6 shows the typical cooling system found in all vehicles.

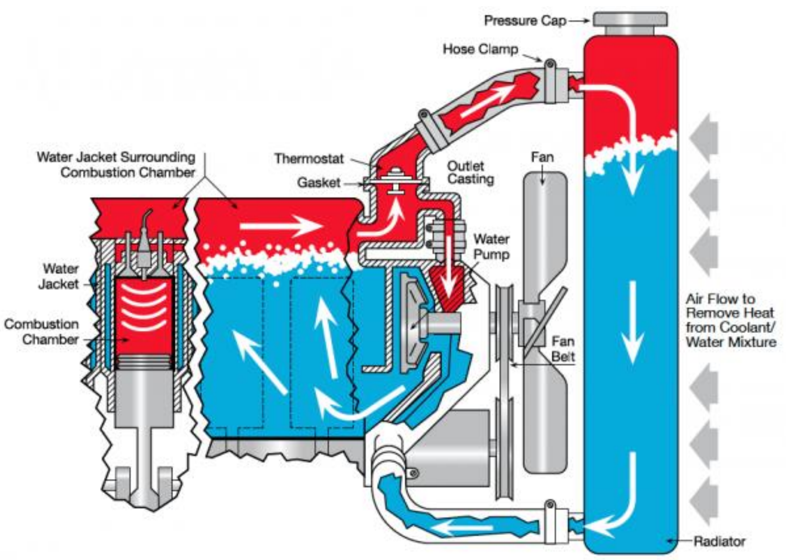

Figure 2.6: Typical cooling system of vehicle (truck news.com, 2015)

Loss of power or performance occurs when the engine is overheating. Not only that, overheating an engine may cause serious damage to the engine if step not taken to cool down the engine. When the engine starts to overheat, the piston starts to expand. As engine temperature continues to rise, damage on cylinder and piston may occur as there is no room for expansion for both of it. Therefore, they scrape each other. Not only that, the valve may start to stick and damage which make it not functioning well. Blown head gasket, overhead cam break and seize may also happen when overheating of the engine is prolonged.

Other than engines, stress is also created at the cooling system where water boiled and white smoke can be seen coming out when the engine is overheating. Hoses of the cooling system may burst and damage the radiator.

2.2 Vehicle Cooling System

Vehicle cooling system did not evolve much since the creation of internal combustion engine. Early vehicle cooling system uses thermosyphon system where the circulations of coolant rely on convection method. The hot coolant will move up to the top of the engine and circulate to the radiator. After the coolant is cold down through the radiator, cold coolant is recirculated to the engine. No water pump is required in this thermosyphon system. A fan is attached to the engine belt and turns when the engine is started. These systems prone to overheating when the engine is overwork.

With the increasing power of the engine and more heat is produced. Water pump is introduced into the cooling system to increase the efficiency of the cooling system. Older vehicles used mechanical fans to cool down the coolant at the radiator. Mechanical fans are break into two types which is clutch fans and flex fans. In the clutch fan, a clutch is used to engage and disengage the fan at the different engine speed or temperature (David Fuller, 2012). However the fan never stops spinning due to the clutch is never fully disengage. For flex fan, the fan always rotates at full speed make them more efficient. Flex fan typically lighter and features flatten out blades which make it greater in efficiency. Mechanical fans are rarely used in the modern vehicle because mechanical fans have parasitic horsepower loss (David Fuller, 2012).

In the modern vehicle cooling system, it consists of water pump, radiator, thermostat, coolant temperature sensor (CTS), coolant, and electric cooling fan. Water pump, usually driven by the engine belt through a pulley, and it is the heart of the cooling system where it pumps the coolant. Radiator or also known as heat exchanger is used to transfer out heats of the heated coolant to the atmosphere. Thermostat is a valve which controls the flow of the coolant base on the temperature. CTS is a device to monitor the temperature of the engine and the data is used to control the electric cooling fan. Most of the CTS used in vehicles are Negative Temperature Coefficient type where resistance decreases when the temperature increases (Autoelectrics, 2015).

Inside an engine, it consists of a safe passage through or water jacket which the coolant can flow through without mixing the engine oil or leakage to the cylinder. The coolant is pumped by the water pump so that it circulates throughout the system. When the engine is started, the engine is cold and so for the coolant. Therefore, the bypass valve of the thermostat was open and the coolant bypassed the radiators and circulates back to the engine through the bypass hose. As the engine heated up, the coolant temperature increases and the bypass valve will start to close and main valve started to open. The thermostat bypass valve usually started to close at the temperature of 90 ˚C to 110 ˚C (aa1car, 2015).

The hot coolant from the engine flow to the radiator and the cold coolant from the radiator circulate back to the engine. In most cars, CTS is located near to the thermostat housing. If the high temperature was sense, it will trigger the electric cooling fan to blow out the heat at the radiator to the atmosphere so that cold coolant is circulated back to the engine.

As temperature increases, the closed system coolant liquid builds up pressure. Therefore, a radiator pressure cap is used to control the pressure of the system. When a pressure of 15 psi is reached it will push the pressure valve spring and the excess coolant will flow to the expansion tank. When the coolant cools down, the vacuum inside the system will be sucked back the coolant from the expansion tank. Figure 2.7 shows the entire component in the vehicle cooling system.

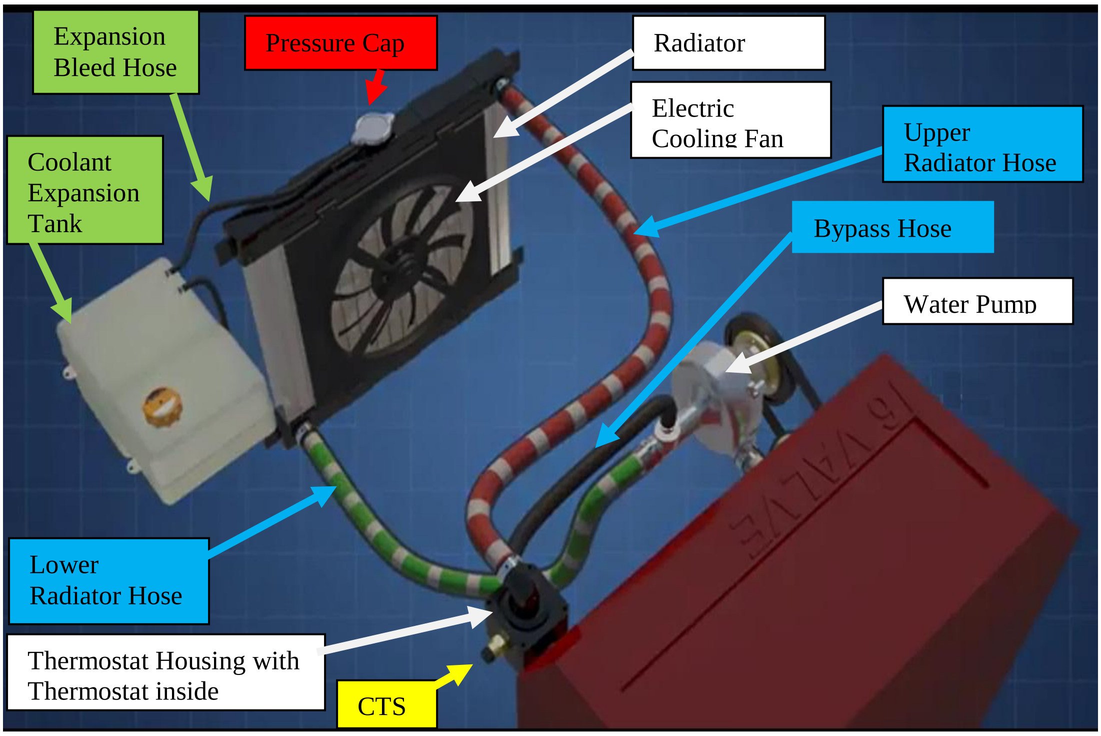

Figure 2.7: Vehicle cooling system (How Engine Cooling System Works. 2015)

2.3 Electric Cooling Fan Circuit

In a simple electric cooling fan control circuit, it consists of a fuse, relay, CTS, and electric cooling fans. The operation of the circuit is simple. When the CTS sense the temperature above the limits, it will trigger or close circuit so that the relay will trigger and allow current to flow through, thus the electric cooling fan is running. Figure 2.8 shows the electrical circuit of the electric cooling fan.

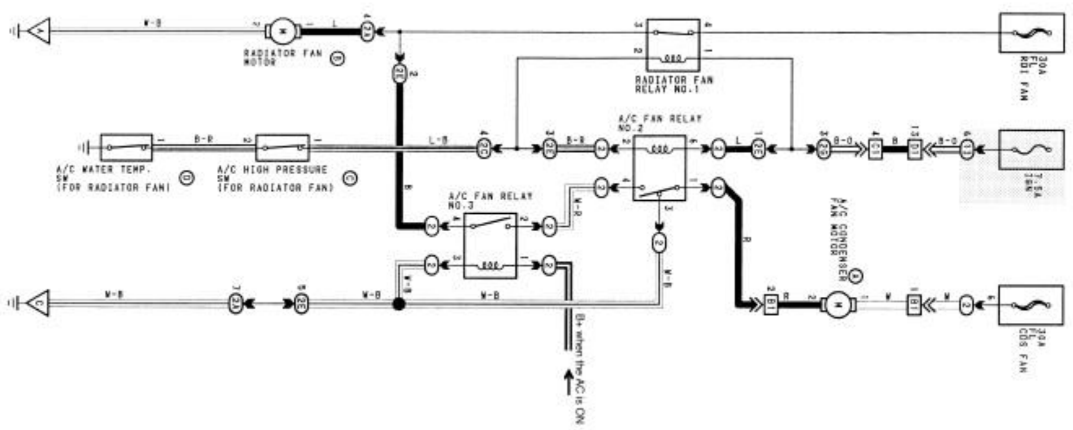

Figure 2.8: Electric cooling fan wiring (Kevin R. Sullivan, 2015)

There are many possible of failures in these systems. Failures such as blow fuse, bad relay, and bad CTS could happen. Apart of that, electric cooling fans ageing and dead lead to the overheating of the engine as the circulated coolant did not cold down. Component such as relay, CTS, and electric cooling fans need to be replaced over time as it will fail.

2.4 DC Electric Fan

Most vehicle electric cooling fans used brushed DC electric fans. This type of fans typically does not last long as there is carbon brush wear and tear applies as time go. This is why electric cooling fan at the radiator will fail after a few years usage. Brushed DC electric cooling fans consist of a brushed DC motor. The construction of this brushed DC motor is simple, and consists of stator, armature (rotor), a commutator and brushes.

The stator in an electric cooling fan is a permanent magnet rather than an electromagnetics winding. One or more winding is wound around the highly permeable steel layers which form the rotor. When electricity is applied, it generated a magnetic field which cut the magnetics field of the magnet causing the rotor to turn. A commutator or a split ring is placed at the end of the axle of the rotor. Commutator acts like a switch which switches over the direction of current flow in the winding as it rotates. The spring loaded carbon brush is contacted with the commutator to supply electricity to the winding.

Due to the absent of excitation winding, PMDC motor is cheaper and smaller in size. As there is no excitation winding, no power is consumed in this part thus improve the efficiency of the motor. PMDC motor has good speed control capabilities however the permanent magnet properties will lose over time which causes the performance of the motor to decline.

The torque-speed characteristics of the PMDC motor tend to have a much linear characteristic than other types of DC motors (SDT Drive Technology, 2015). PMDC output power is limited due to the characteristics of permanent magnet, thus, the usage of PMDC are normally in motion instrumentation such as fans. At normal operating condition, PMDC motor rotates at the designed speed, however as the torque applied to the motor, the speed decreases. At very high torque the speed of the motor will be stalled. As the torque increases, the current increases steadily. Figure 2.9 shows the Torque- Speed characteristics graph with current.

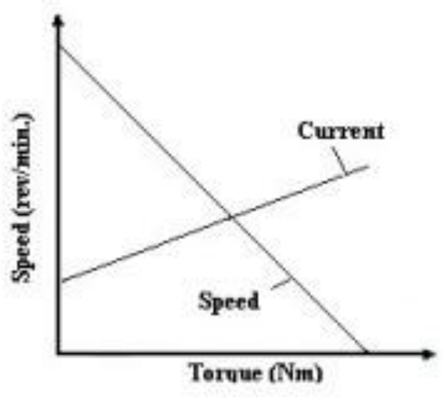

Figure 2.9: Torque-Speed characteristics graph with current (SDT Drive Technology, 2015)

DC electric fan airflow is measured in cubic feet per minutes (CFM). The airflow needed to cold the coolant at the radiator is depends on the engine horsepower and the heat generated. DC electric fan come in different size, mounting, RPM and CFM depending on the manufacturer. Therefore, current draw by the DC electric motor is different depending on the specification. Furthermore, these electric fans have single or dual fans configuration.

2.5 Problem Statement

Existing systems of the vehicle cooling system tend to fail due to relay failure, CTS failure, and cooling fan failure. This will cause the vehicle to overheat and if no prevention measures are taken, it will cause serious damage to the engine. Heat generated by the engine must be cold down via the cooling system. Without a proper alert system to indicate the failure of the cooling fan which leads to overheating will cost a lot to repair.

As an engine is the heart of the vehicle, preventing the engine from overheating is a must. Therefore, cooling fan alert system will be built to help solve the vehicle overheating issues. An Arduino microcontroller will be used as data processing coupled with some input such as voltage and current of the cooling fan, RPM of the cooling fan and temperature of the coolant. The output of this system is to alert vehicle owner when any abnormality of the cooling fan and parts are detected. Thus, early inspection can be done to prevent the vehicle from overheat.

CHAPTER 3

METHODOLOGY

3.1 Overview

Basically, the overall of this project is to design a cooling fan failure alert system to prevent the vehicle from overheats. There will be a simple display such as RPM of fan, temperature of the coolant and health of the system. Not only that, there will be indicators on failures of the cooling fan with sound, thus giving more alert to the driver. This system gives driver early indication before and when the cooling fan fails. In this chapter, the method and implementation will be developed. The flow of the works to be implemented is shown in Figure 3.1.

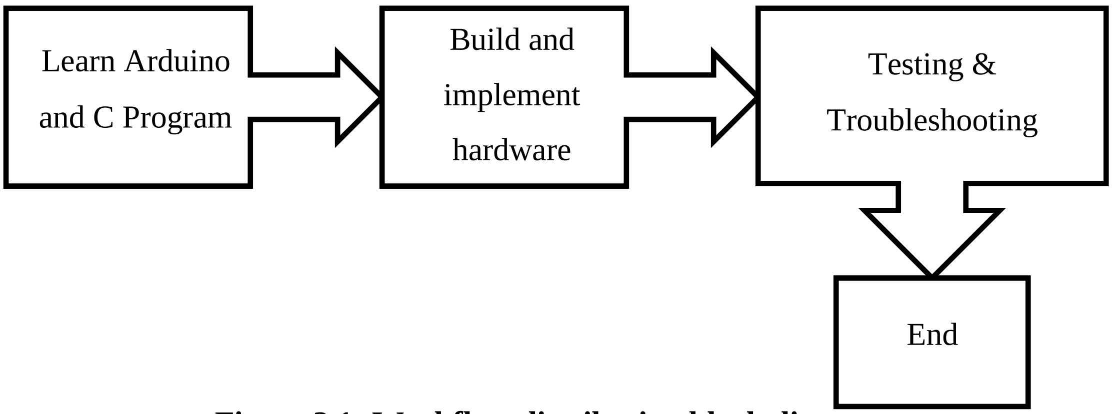

Figure 3.1: Workflow distribution block diagram.

3.2 Design of Cooling Fan Alert System

In the cooling fan alert system, there will be three parts which are data collection, data processing and signal output. The electric cooling fan used in this project is from typical sedan vehicle. The specification of this typical electric cooling fan is used to helps data processing of the system based on the input. Among the data will be collected are CTS output, cooling fans speed, and cooling fan voltage and current. This data collected will be channel to Arduino through digital and analog input and will be process to trigger appropriate output. Finally, the Arduino will give output through digital port to display and relay circuit.

The working of this system is simple. The temperature of the coolant will be known through the signal from the CTS. The cooling fans will be trigger when the temperature is above 100 ˚C or when CTS is failed and stop when the temperature is below 90 ˚C. A high or low signal will be sent to the relay circuit to trigger the cooling fan. After the cooling fan is triggered, the RPM, voltage and current of the cooling fans are monitors. Any abnormal on the RPM, voltage and current of the cooling fan, alerts will be displayed to the vehicle driver to indicate the type of failure. Through monitoring the input of all the sensors, the types of failure can be detected.

To detect the failure of the relay, voltage is measured at the output of the relay contactor when the relay circuit is triggered. If there is no voltage flow through the output of the relay, the relay part fails or damaged. There are two methods to detect fan failure. First of all is by detecting the current flow through the cooling fan where if the current is two times higher than the nominal current then the cooling fan is stuck or motor of the cooling fan is damaged. Secondly is by detecting the RPM of the cooling fan where if the RPM of the cooling fan is below half of the typical RPM then the cooling fan is going to dead.

The state of the temperature of cold, warm and hot are defined in below 30 °C, between 30 °C to 120 °C, and above 120 °C respectively. There are also two methods to detect the failure of CTS. Firstly is by determining the temperature of the CTS after the engine started for 2 minutes where the temperature should reach above

50 °C. If the temperature does not reach above 50 °C, CTS is consider failed and need replacement. The second method is by determining the input voltage from the voltage divider circuit of CTS where it should not give a maximum 5 V. If it happens to give a maximum voltage of 5 V then the CTS is totally dead where there is no more resistance from the CTS itself. Figure 3.2 shows the flow of the cooling fan alert system.

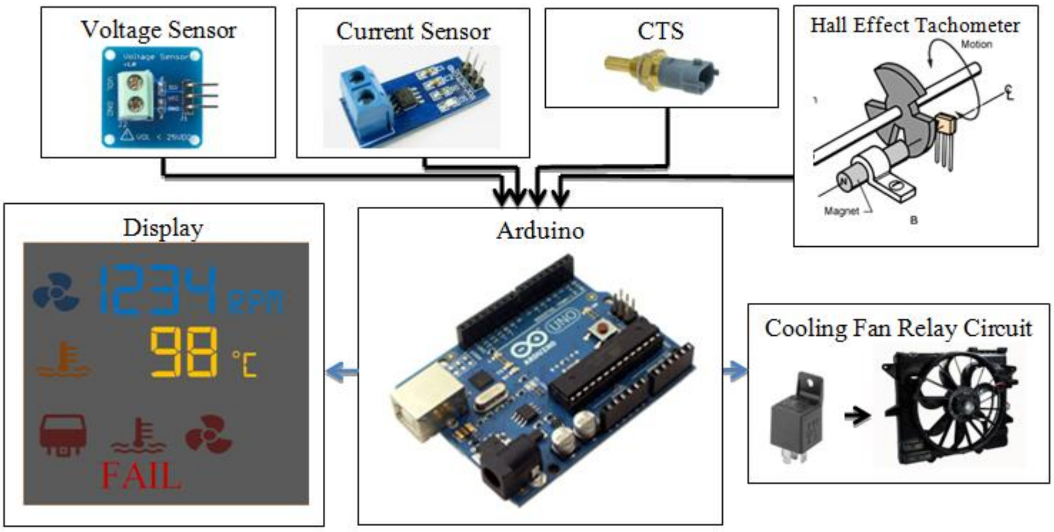

Figure 3.2: Flow of cooling fan alert system.

Proper implementation of the hardware in the cooling fan failure alert system is important to ensure the quality and reliability of the system. The hardware is separated into few parts for easy assembly. There will be voltage detector circuit, Hall Effect current sensor circuit, Hall Effect tachometer circuit, cooling fan relay trigger circuit, and Arduino microcontroller.

3.2.1 Voltage Divider Circuit

To measure the voltage of the cooling fan, a simple voltage divider circuit is used which consist of two resistors in series so that the output of the voltage divider is at the range of the Arduino analog inputs which is 5 V. The circuit is shown in Figure 3.3.

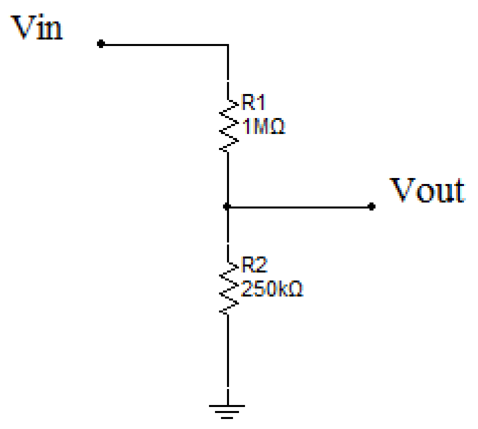

Figure 3.3: Voltage divider circuit

$$V_{out} = V_{in}\left(\frac{R_2}{R_1 + R_2}\right) \tag{3.1}$$

$$I = \frac{V_{in}}{(R_1 + R_2)} \tag{3.2}$$

Where,

V_{in} = voltage input to voltage divider circuit,

V_{out} = voltage divider circuit output to Arduino,

I = current flowing through the circuit,

Equation 3.1and 3.2 shows the output voltage calculation and the current flowing through the circuit calculation respectively. High impedance is required when measuring voltage, therefore, the circuit has an input impedance of 1.25 MΩ. Not only that, the current follow through to the analog input port of Arduino must be small, typically less than 20 mA. This circuit can measure voltage up to 24 V and the output of the circuit to Arduino at this voltage is 4.8 V, thus does not exist the limit of the Arduino port. The input voltage, V_{in}, increased by one volt, the output voltage, V_{out}, increased by 0.2 V.

3.2.2 Hall Effect Current Sensor

To sense high current flowing through the conductor of the cooling fan, a suitable current sensor must be chosen to ensure precise measurement. Allegro ACS712ELCTR-30A-T fully integrated, hall-effect-based linear current sensor IC is chosen as it is meet the requirement (Allegro, 2015). This current sensor can measure AC and DC current up to ±30 A. This IC used copper as conduction path which has internal resistance of 1.2 mΩ near the surface of the die and a precise, low-offset, linear Hall Sensor circuit which has nearly zero magnetic hysteresis (Allegro, 2015). Since this sensor will be placed in the engine compartment, it is crucial for this sensor to work at high temperature. The operating temperature of this sensor is range from -40 ˚C to 150 ˚C which is suitable. Figure 3.4, 3.5 and 3.6 shows the pin-out diagram, ACS712ELCTR-30A-T IC and typical application circuit respectively.

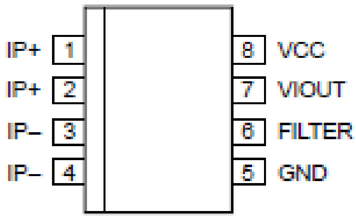

Figure 3.4: Pin-out diagram of ACS712ELCTR-30A-T

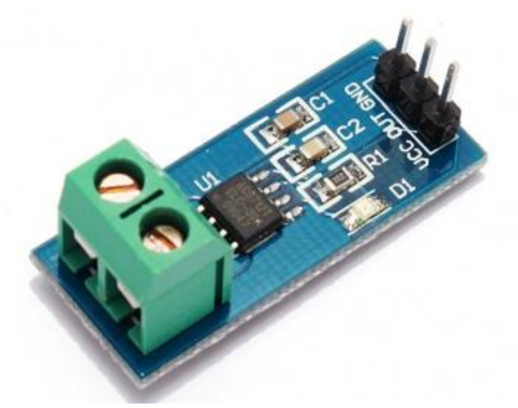

Figure 3.5: ACS712ELCTR-30A-T IC

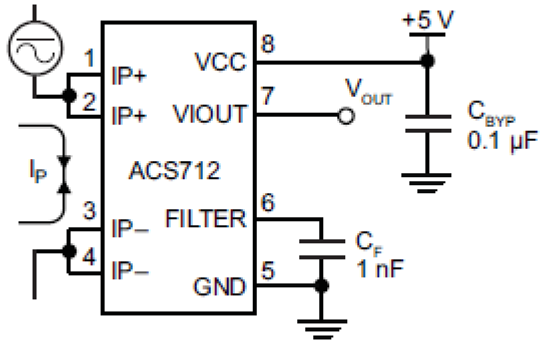

Figure 3.6: Typical application circuit of ACS712ELCTR-30A-T

3.2.3 Hall Effect Tachometer

To measure the RPM of the cooling fan, a Hall Effect sensor IC is used. Engines compartment is a dirty and harsh environment, therefore, a suitable sensor must be used to avoid failure due to dust or high temperature. Allegro A1220LUA-T Chopper Stabilized Precision Hall Effect Latches sensor is chosen for this application. It has wide voltage operating range from 3.0 V to 24 V, high temperature rating (-40 °C to 150 °C) and a flat TO-92 package which makes it easily fit into pack place.

The operating of this IC is simple, when a South Pole magnet is placed to the front of the sensor, it will turn the signal from high to low. The low output will retain until a North Pole magnet is placed near the sensor, where it will turn the low signal to high signal. The generated pulse can serve as a PWM signal which then sent to Arduino to calculate the speed or RPM of the cooling fan. Figure 3.7 and 3.8 shows the operating of the A1220LUA-T sensor and typical three-wire application circuit respectively.

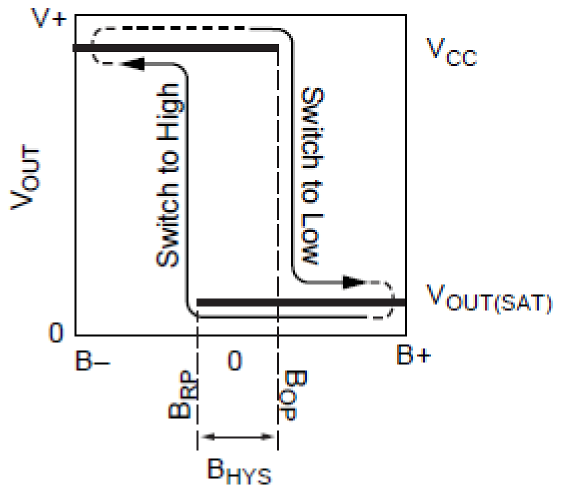

Figure 3.7: Operating of A1220LUA-T (B+ direction indicates increasing south polarity magnetic field strength and B- direction decreasing south polarity field strength with increasing north polarity)

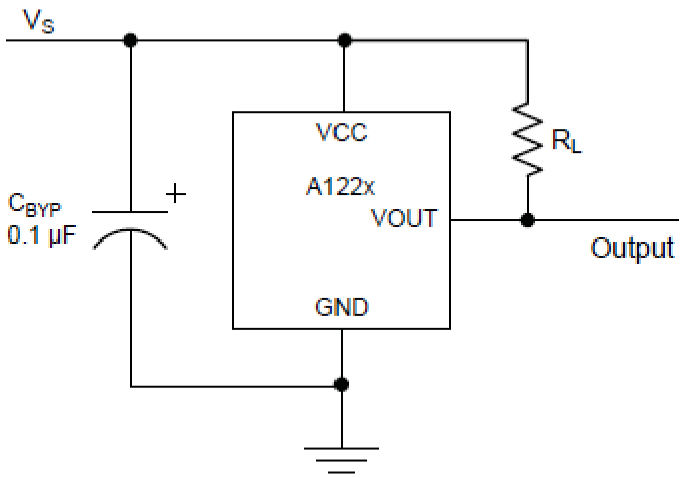

Figure 3.8: Typical three-wire application circuit of A1220LUA-T

3.2.4 Coolant Temperature Sensor (CTS)

Coolant temperature sensor (CTS) is used to measure the temperature of the coolant. Negative Temperature Coefficient type of CTS is use which resistance drop when temperature increasing. The output voltage of the CTS is used to measure the temperature. The resistance of the CTS varies with temperature. Figure 3.9 and 3.10 shows the CTS circuit and CTS respectively.

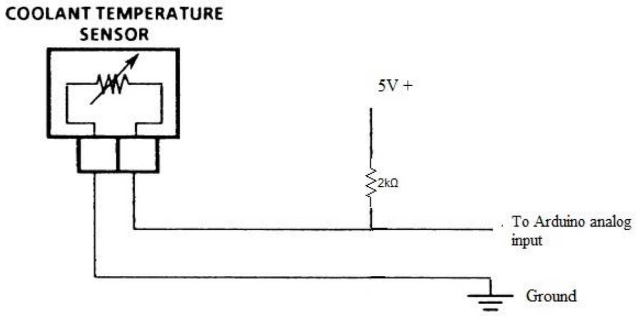

Figure 3.9: CTS circuit.

Figure 3.10: CTS (autozone, 2015)

3.2.5 Cooling Fan Relay Trigger Circuit

A simple circuit is designed to trigger the relay of the cooling fan. When a high signal is provided by the Arduino, the relay will be triggered and the cooling fan is turn on. Figure 3.11 shows the relay trigger circuit. Number 86 and 85 is connected to 12 V and ground respectively where this coil of the relay. Number 30 is the common where 12 V will be connected and the output to the cooling fan will be connected to number 87. The typical automotive relay connection is shown in Figure 3.12.

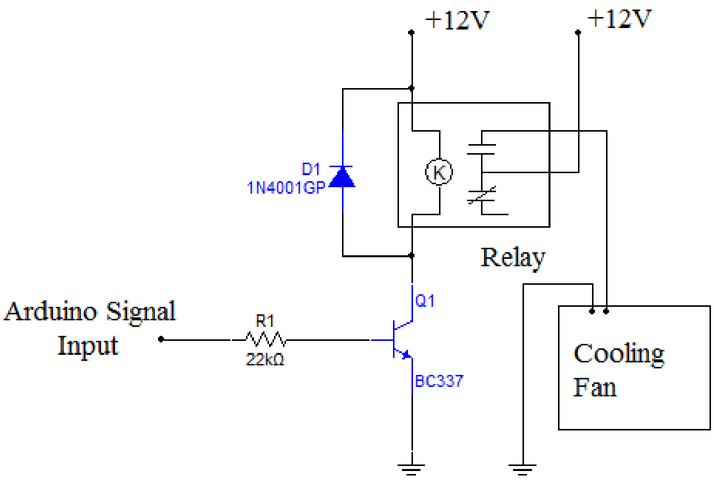

Figure 3.11: Relay trigger circuit

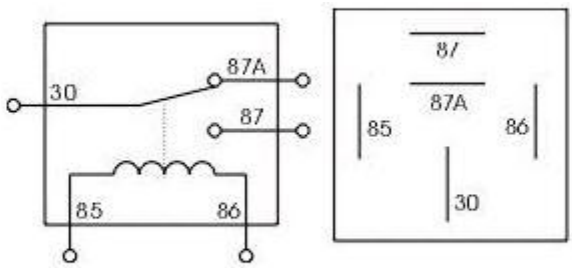

Figure 3.12: Automotive relay connection

3.2.6 Display Design

The design of the display is simple. It displays the RPM of the cooling fan when running, temperature of the coolant and some failure indicator. The RPM and temperature of the coolant are displayed using LED 7-segment display while failure indicator used LED indicator with icons. The fan icon and RPM display will be in blue colour. The fan icon will illuminate when the cooling fan is trigger and fan icon is blank when the cooling fan is off. The coolant temperature icon will change colour according to temperature and LED is off when CTS failed. There will be three different colours which are blue, yellow and red indicate cold, warm and hot respectively. When there is a failure of any of the part such as relay, CTS or cooling fan, the icon of the part will light up in red colour and a "FAIL" word below it to indicate failure. The Figure 3.13 shows the design of the display.

MAX7221 Serially Interfaced, 8-Digit LED Displays Drivers IC is used to drive the two 4-Digit 7-segment LED display. This IC only requires 3-wire serial interface connection to the Arduino. The circuit of the display is shown in Figure 3.14.

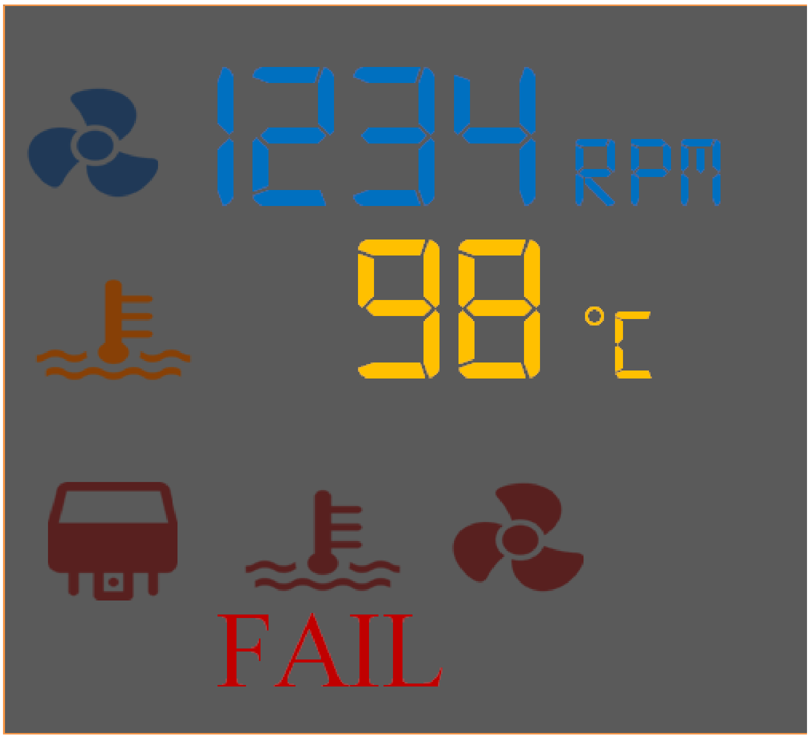

Figure 3.13: Cooling fan failure alert system display

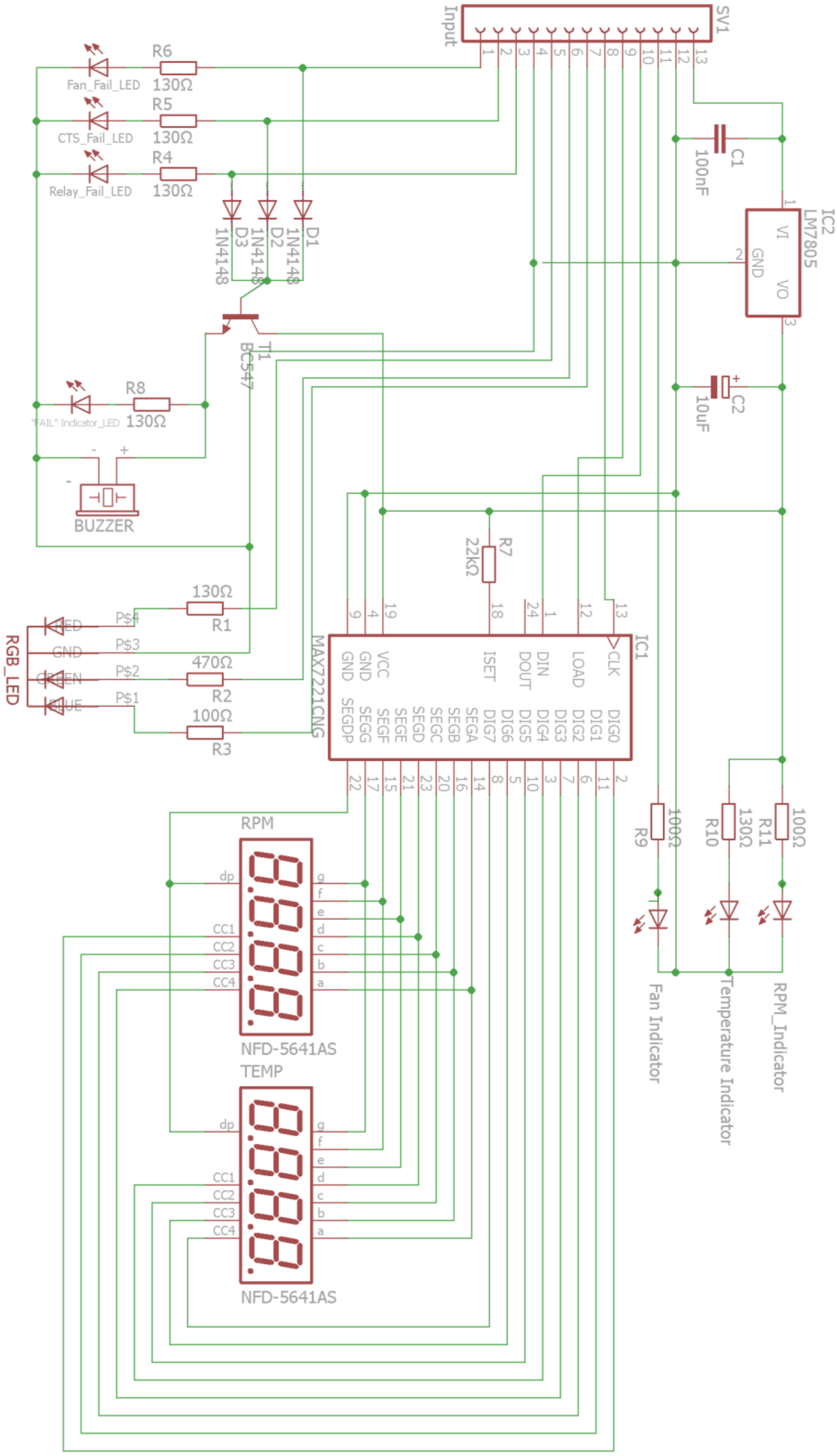

Figure 3.14: Display circuit diagram

CHAPTER 4

RESULT AND DISCUSSION

4.1 Prototype

A prototype of the cooling fan failure alert system has been built in order to test the functionality of the system. The prototype was built using a 3-layer plywood as a base and 3 stick wood joining together to form a rectangular frame. The frame is then mounted onto the base. The prototype is shown in Figure 4.1.

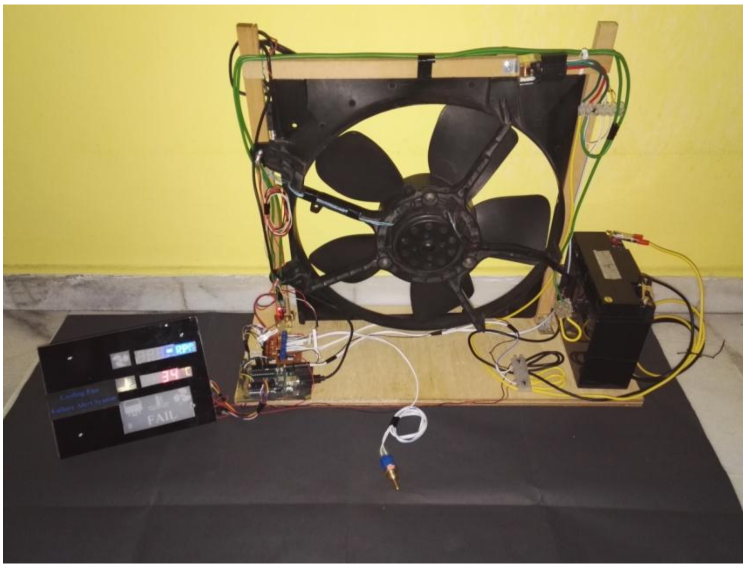

Figure 4.1: Cooling fan failure alert system prototype

The voltage divider circuit, relay trigger circuit, Hall Effect sensor circuit and CTS circuit are combined into a Veroboard. The circuit board and Arduino unit are screw onto the base of the prototype. The circuit board and Arduino unit is shown in Figure 4.2 and Figure 4.3 respectively.

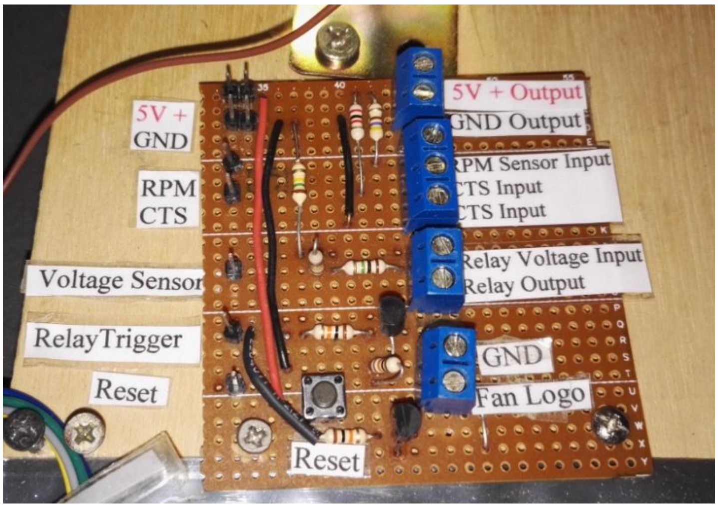

Figure 4.2: Circuit board

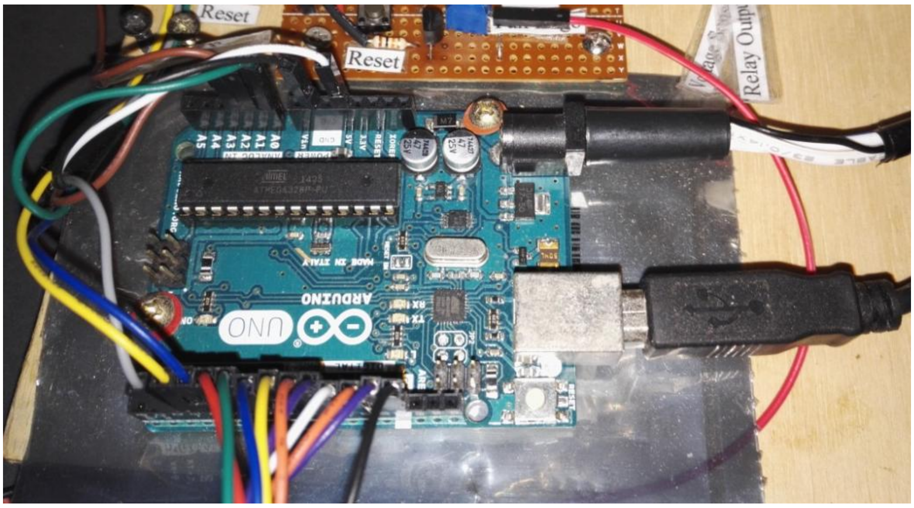

Figure 4.3: Arduino unit

4.2 Input

4.2.1 Voltage Sensor

The voltage divider circuit used for the voltage sensing is shown in Figure 3.3. The input voltage is step down to between 0 V to 5 V before feeding into Arduino. To ensure the Arduino ADC working correctly, the voltage of the Arduino is ensured at 5 V. The voltage at Arduino is so importance because the Arduino ADC using the 5 V to do the conversion, therefore the high voltage drop will cause the conversion to be inaccurate. This will result in the calculated voltage base on the raw data of the ADC to be wrong or large gap between the original values. Table 4.1 shows the results obtain from multimeter and voltage sensor. The calculated voltage from Arduino ADC is real time compared to the multimeter which taking an average. However, after the reading of the calculated voltage is averaged, the error is ±1 % which is acceptable. Figure 4.4 and 4.5 shows Arduino calculated voltage and multimeter measured voltage respectively.

Table 4.1: Voltage reading comparison result

	Voltage Reading (V)	
Reading Attempt	**Multimeter**	**Calculated Voltage Sensor (Arduino)**
1	11.63	11.71
2	11.63	11.73
3	11.63	11.75
4	11.63	11.75
5	11.63	11.75
6	11.63	11.78
7	11.63	11.63
8	11.63	11.75
Average	**11.63**	**11.73**

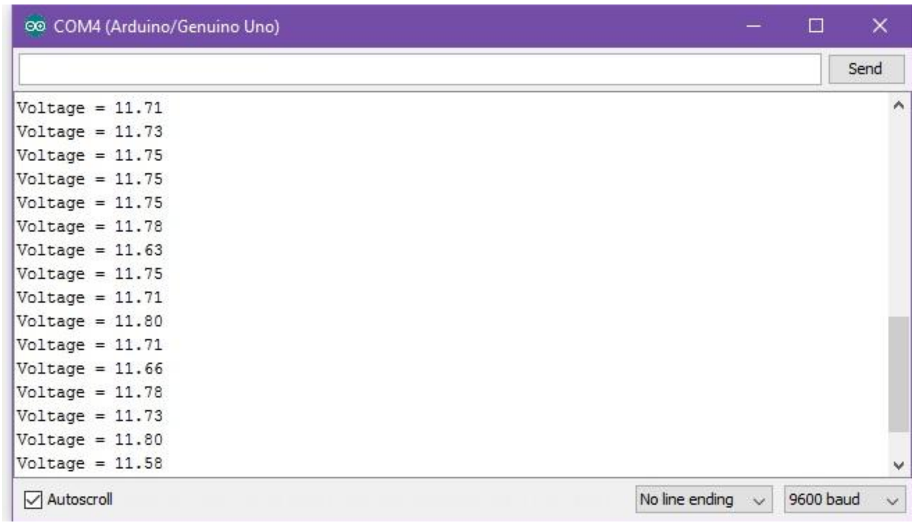

Figure 4.4: Arduino calculated voltage

Figure 4.5: Multimeter measured voltage

4.2.2 Current Sensor

Referring to Figure 3.6, current sensor circuit, the high current is measured through series connected circuit of the ACS712ELCTR-30A-T IC. The output is fed to Arduino to calculate the actual current flow through. The measurement of current through this IC will have an error of ±1.5 % and subject to the surrounding temperature which will affect the accuracy. Table 4.2 shows the results obtain from the multimeter and current sensor. The calculated current from Arduino ADC is real time compared to the multimeter which taking an average. The current reading at the Arduino is fluctuating up to 1.5 A in between reading. This is because the electric motor is drawing different current to maintain the speed of the fans at different points. Hence, fluctuating in current is normal in this case. However, after the reading of the calculated voltage is averaged, the error is ±2 %. Figure 4.6 and 4.7 shows Arduino calculated current and multimeter measured current respectively.

Table 4.2: Current reading comparison result

	Current Reading (A)	
Reading Attempt	**Multimeter**	**Calculated Voltage Sensor (Arduino)**
1	6.08	6.95
2	6.08	5.99
3	6.08	6.81
4	6.08	5.77
5	6.08	6.21
6	6.08	5.77
7	6.08	6.51
8	6.08	5.40
Average	**6.08**	**6.18**

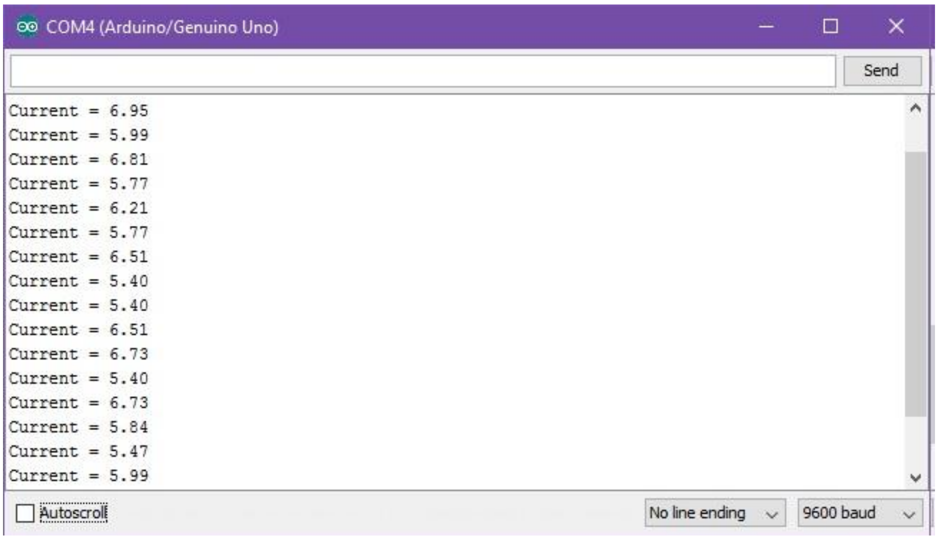

Figure 4.6: Arduino calculated current

Figure 4.7: Multimeter measured current

The starting current of the electric motor is twice as high as the nominal current which averages at 12 A and only lasted for about 1 second before gradually drop to nominal operating current. This is because the electric motors need high current to overcome the torque. Lastly, the stall current of this electric motor is four times higher than the nominal current which is at around 24 A. Large current is drawn by the stall electric motor to turn the fan itself. From this result, it is seen that the current increases as the torque required to turn the electric cooling fan are increases. Different electric motor will have different electrical characteristics such as starting current and nominal operating current. Therefore, this result is intended for the electric motor used in the prototype. Figure 4.8 and 4.9 shows the multimeter measured starting current and Arduino calculated stall current respectively.

Figure 4.8: Multimeter measured starting current

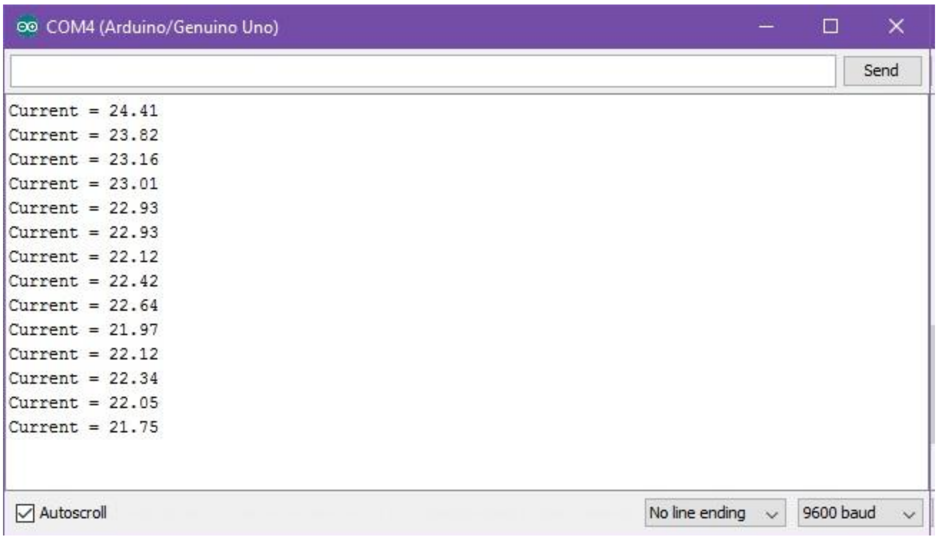

Figure 4.9: Arduino calculated stall current

4.2.3 Hall Effect Tachometer

The implementation of the Hall Effect tachometer is simple. The Hall Effect sensor IC is mounted on the motor and two magnets is mounted on the fan blade which consists of a north pole and a south pole. The implementation of the Hall Effect Tachometer is shown in Figure 4.10.

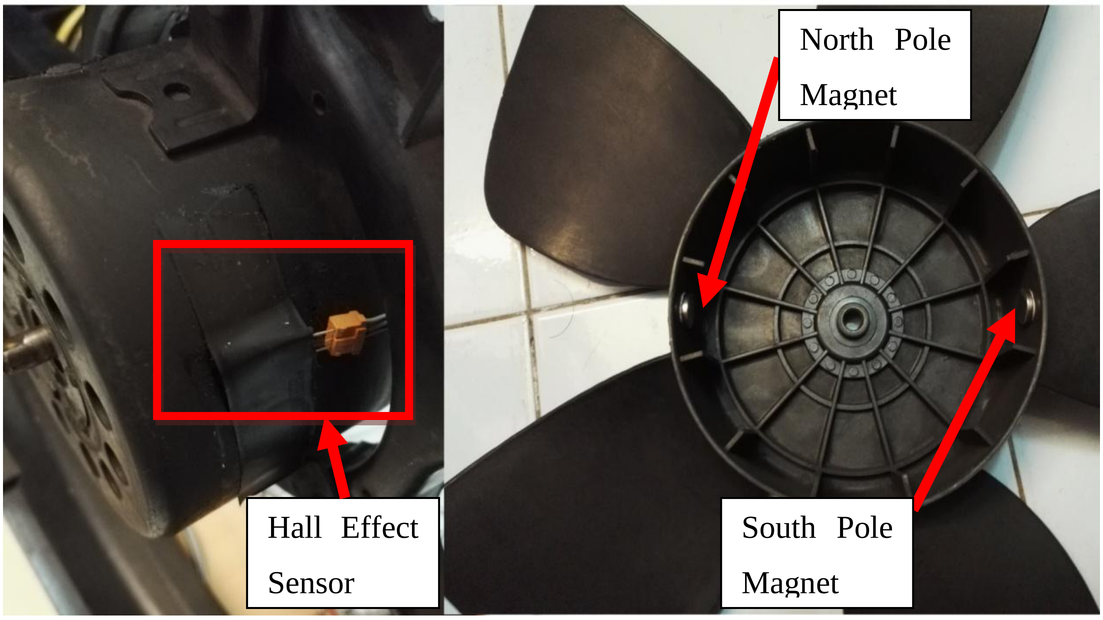

Figure 4.10: Implementation of Hall Effect sensor

Referring to Figure 3.8, Hall Effect tachometer sensor circuit, the signals generated by this sensor serve as PWM signal to the Arduino and calculated as RPM. The input signal is in high and low. Thus, how many high signals in a second determine the Hertz which then will be multiple by 60 to obtain RPM. The reading of RPM from a tachometer meter will be more accurate compared to Hall Effect tachometer which has only one resolution per rotation. Therefore, the displayed RPM will be a multiplier of 60. However, this is good enough as a high accuracy of RPM is not needed in this system. However, the RPM reading of tachometer and Arduino will have ±10 % different in between which is acceptable as stated earlier, accuracy is not importance in this RPM reading. Table 4.3 shows the result obtains from tachometer and Hall Effect sensor. Figure 4.11 shows measurement of tachometer and Hall Effect sensor.

Table 4.3: RPM reading comparison result

	Speed (RPM)	
Reading Attempt	**Tachometer**	**Hall Effect Sensor (Arduino)**
1	1710	1740
2	1703	1800
3	1707	1740
4	1712	1680
5	1712	1740
6	1712	1680
7	1717	1740
8	1720	1740
Average	**1711.63**	**1732.50**

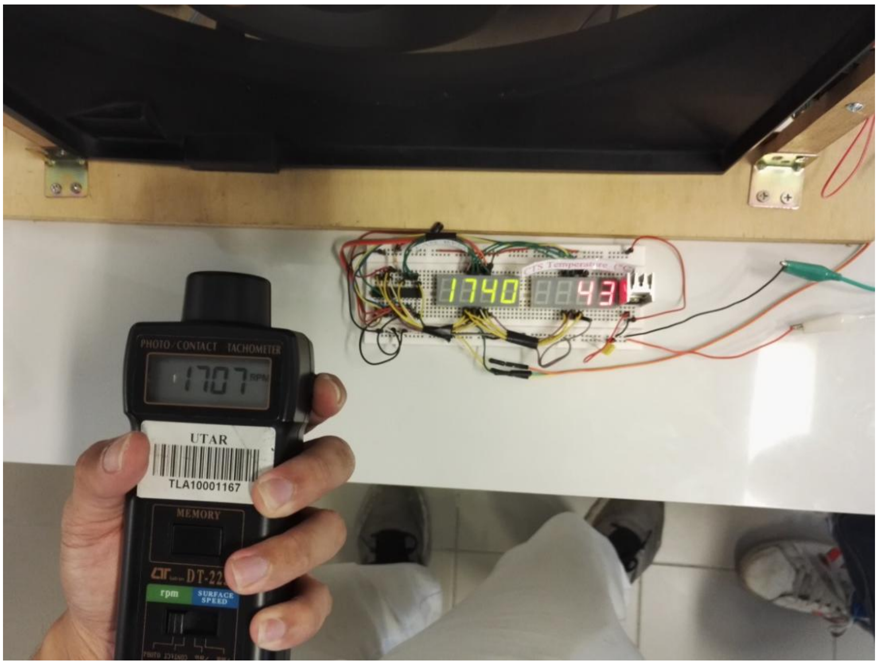

Figure 4.11: Measurement of Tachometer and Hall Effect sensor (Green LED)

4.2.4 Coolant Temperature Sensor

Referring to Figure 3.9, CTS circuit, the voltage reading of the CTS will be feed into Arduino and processed to obtain the temperature. The CTS is a negative temperature coefficient sensor and increasing in temperature will decrease the resistance. The voltage reading obtained is based on the voltage divider rules of the circuit and will be feed into Arduino ADC and converted into resistance using formula. Every 10 °C of temperature step will have different characteristics equation. Thus to obtain accuracy of CTS, every 10 °C step will have a different formula for obtaining the temperature. The resistance obtained earlier will be compared in a range of resistance in each 10 °C. The temperature will only be calculated when it hit the right range of resistance. The temperature reading of both thermometer and CTS are almost the same which the CTS will have higher accuracy than the thermometer. However, the resistance of the CTS will have an accuracy of ±5 % depends on temperature. Table 4.4 shows the results obtain from the thermometer and CTS. Figure 4.12 shows measurement method of CTS.

Table 4.4: Temperature reading comparison result

	Temperature (°C)	
Reading Attempt	**Thermometer**	**CTS (Arduino)**
1	0	0
2	15	15
3	25	25
4	30	30
5	45	47
6	58	60
7	77	80
8	97	100

Figure 4.12: Measurement method of CTS

4.3 Output

4.3.1 Cooling Fan Relay Trigger Circuit

Referring to Figure 3.11, cooling fan relay trigger circuit, the relay turns on when the high signal is given to it and turn off when a low signal is given to it. This circuit works fine. The relay attached is shown in Figure 4.13.

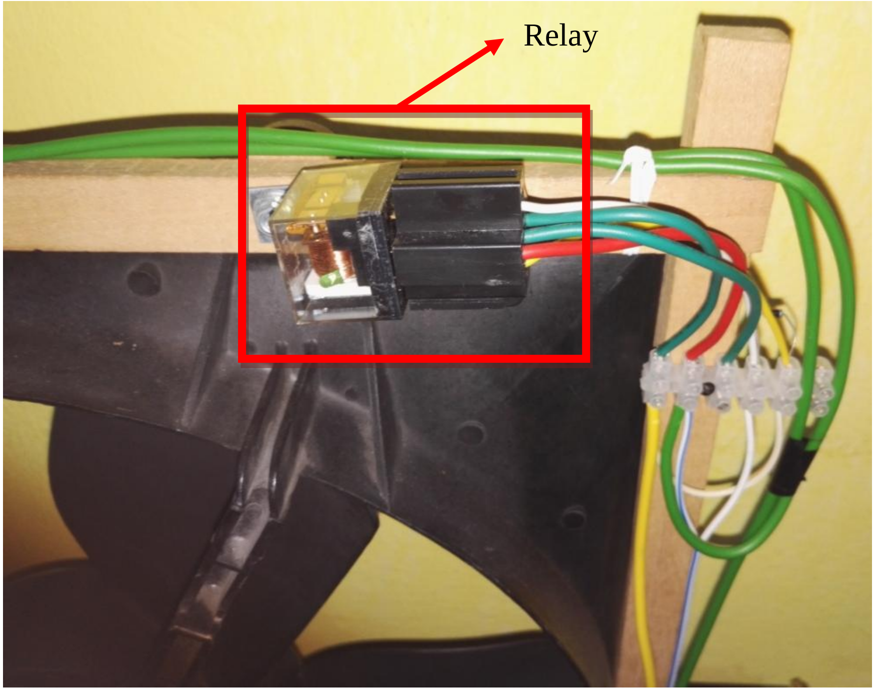

Figure 4.13: Cooling fan relay

4.3.2 Display

Figure 4.14: Cooling fan failure alert system display

Figure 4.14 shows the Cooling Fan Failure Alert System Display. The display will display the temperature of the CTS with a coolant temperature logo in yellow colour indicate normal operating temperature. RPM of the cooling fan will be displayed with a blue fan logo once the cooling fan is turned on. The fan logo will be off once the cooling fan is turned off and a dash will be displayed. Figure 4.15 shows the normal display of the system with the fan on and off.

Figure 4.15: Cooling fan ON (Left) and OFF (Right)

The coolant temperature logo will have 3 different colours which are blue indicate cool, yellow indicate warm and red indicate hot. The coolant temperature logo colour is shown in Figure 4.16.

Figure 4.16: Coolant temperature logo colour (From top to bottom – Hot, Warm, Cold)

There is 3 different components failure logo, which is relay, CTS, and fan. The failed component logo and "FAIL" word will be illuminated with blinking once a component is detected malfunction. Figure 4.17 shows the 3 different component failure logo illuminate.

Figure 4.17: Failure indication (From left to right – Relay Fail, CTS Fail, Fan Fail)

During the implementation of the display circuit, there is interference from the electric cooling fan motor which will cause the MAX7221 IC to be malfunction due to the circuit is placed too near to the motor itself. Due to this interference, the 7-Segment LED display will display weird value or the whole display illuminate or shut down. This circuit is tested at breadboard and this interference happen once the cooling fan is turn on. The display circuit is then transferred into PCB and place into a Perspex housing. The display is now able to display normally even is placed near to the motor. The display circuit mounted on a Perspex box is shown in Figure 4.18.

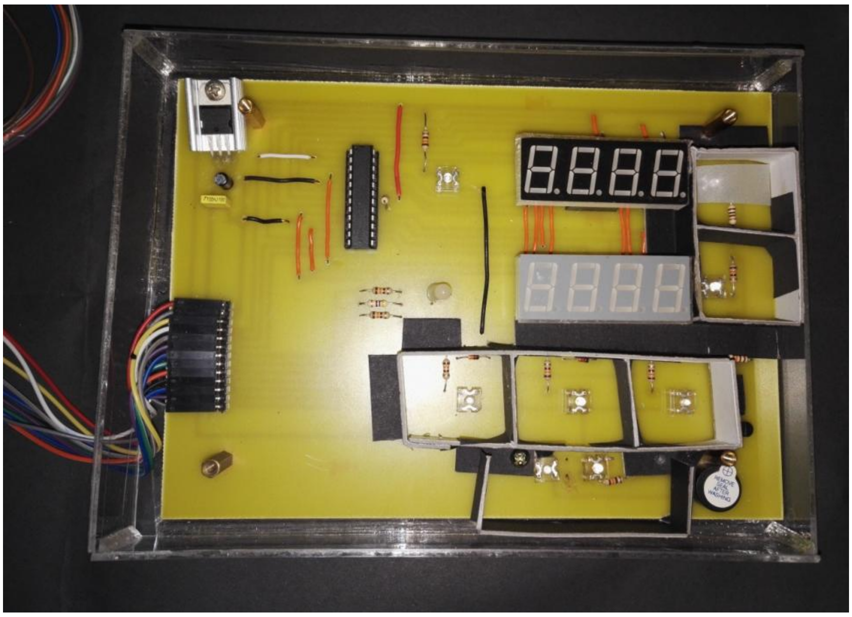

Figure 4.18: Display circuit mounted on Perspex

4.4 Controller

4.4.1 Arduino

Arduino Uno is used as the main controller in this system as it is easy to be re-program to cater other types of electric fans and CTS. The output and input used in this Arduino shown in Table 4.5 below.

Table 4.5: Arduino input and output pins

I/O	Port	Description
Input	A0	Voltage Reading
Input	A1	Current Reading
Input	A2	CTS Reading
Input	2	RPM Reading (Interrupt Pin)
Output	4	Relay trigger circuit
Output	5	Coolant Logo LED – Red
Output	6	Coolant Logo LED – Green
Output	7	Coolant Logo LED – Blue
Output	8	Relay Fail Indicator – Red LED
Output	9	CTS Fail Indicator – Red LED
Output	10	Fan Fail Indicator – Red LED
Output	11	DATA IN-pin for MAX7221
Output	12	CLK-pin for MAX7221
Output	13	LOAD(/CS)-pin for MAX7221

To ensure the 5 V output of Arduino is sufficient and minimal voltage drop, a power supply of 12 V is plug in into the power input jack of Arduino. The 5 V output of the Arduino will be supplying to Hall Effect sensor, CTS voltage divider and ACS712 current sensor. Maintaining voltage of 5 V at Arduino is important because a voltage drop will cause the ADC in the Arduino to not function properly and giving the wrong conversion. Therefore, this inaccurate raw value from ADC will cause the calculated value of voltage, current and temperature to be wrong. Hence, the program will not work properly due to the inaccurate information.

Not only that, ground from the power supply, Arduino and also to all the circuit must be properly connected and linked. A circuit with ground not properly connected will cause misbehave of the circuit. Ground is crucial for voltage divider circuit as these circuit output will be input to the Arduino port which supports a maximum of 5.5 V. Thus, if the ground is not connected in this voltage divider circuit and an input of 12 V is given to the circuit, the voltage drop of 12 V is less and this will burn the Arduino port.

4.4.2 Program Flow Chart

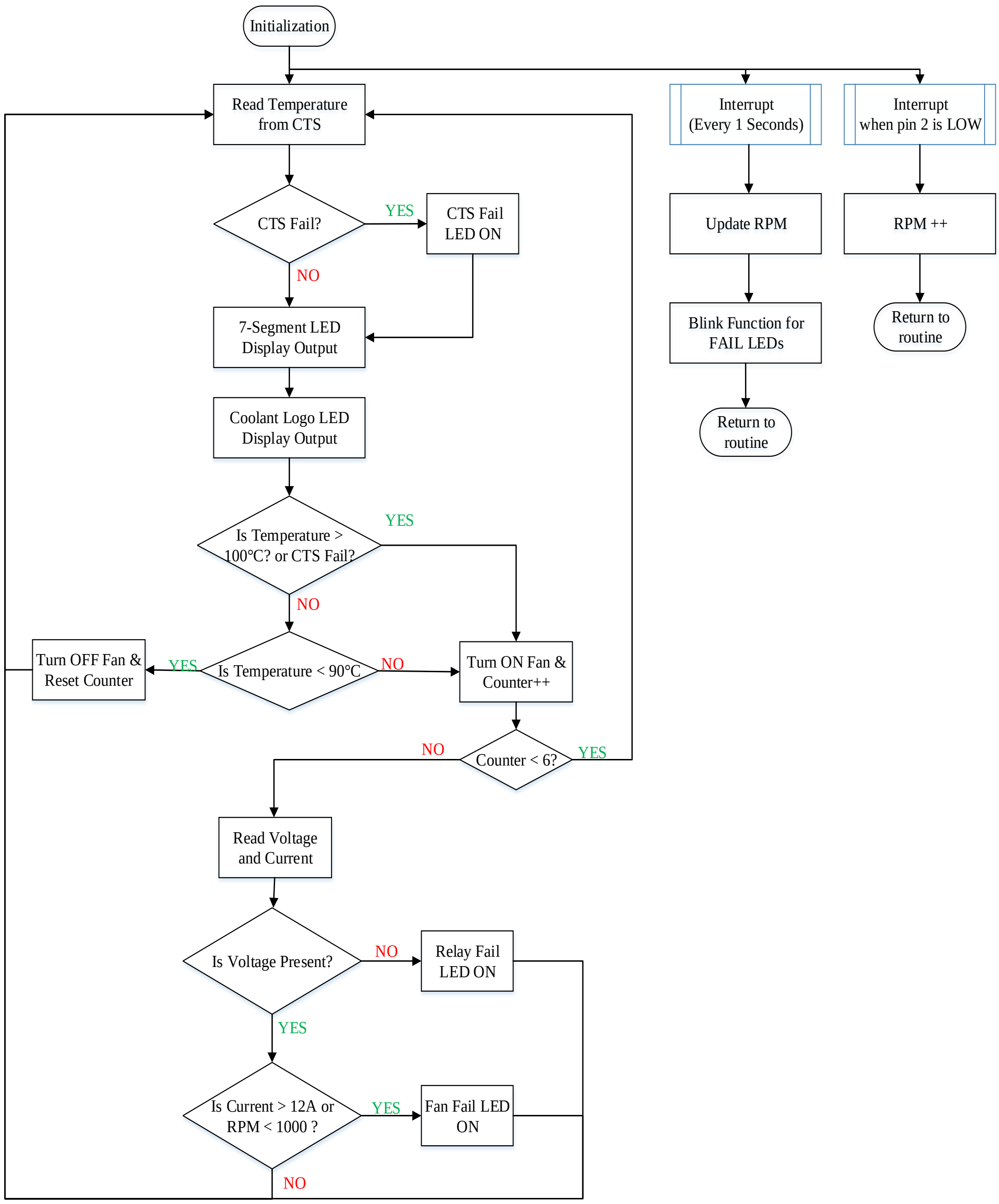

Figure 4.19: Flow chart of cooling fan failure alert system program

Figure 4.19 shows the flow chart of the cooling fan failure alert system program. How the program work is simple. First of all, it will initialize all the parameter which will be used later on such as port input and output, interrupt function and library. After the initialization, the program will run through a loop function with an internal interrupt function which will interrupt every second and external interrupt function which will interrupt every time there is a low signal detected from the digital pin.

When the internal interrupt happens, it will update the RPM and also the blink state of the fail LED whether on or off, if applicable. After all this is done, it will resume to where the program has stopped. In external interrupt, it will increase the RPM temporary data value by one every time this interrupt happen. Same as external interrupt function, it will resume to where the program has stopped.

In the loop function, it starts with reading of CTS voltage and then calculates to convert to temperature. The temperature will be monitor and any abnormal will trigger the fail LED on. After that, it will call the 7-Segement LED display function where here the data of RPM and temperature will be sent to the MAX7221 IC to display these data. Next, the coolant logo LED display output function will be called where here the colour of coolant logo will be updated accordingly.

Then, it will check the temperature if it has reach 100 °C or is CTS failed. If any of it is true, the cooling fan will be turn on. There will be a counter to check it has reached more than 2 seconds. The program will loop back to the beginning if it is less than 2 seconds and proceed to the reading of voltage and current. The voltage and current will be converted to real current and voltage through calculation from raw value. After that, the voltage will be check and if it is less than 10 V, then the relay fail LED will be triggered. The program will loop back to the beginning and will not check current and RPM. However, if the voltage is more than 10 V, it will then check current and RPM. When the current is more than 12 A or RPM is less than 900, then the fan fail LED will be triggered. Same as above the program will loop back to the beginning.

When the temperature has drop below 100 °C, then the next condition will be check which is less than 90 °C. If false, then it will continue to turn on the cooling fan and check voltage and current. If true, the cooling fan will be turn off and loop back to beginning of the program. This is how the whole program works.

4.5 Function Testing

To test the functionality of the system, the CTS is replaced with a variable resistor for testing purposed as the CTS is tested separately and the temperature found to be accurate. The cooling fan turn on temperature is also adjusted to 40 °C and turn off temperature to 35 °C for testing purposes. Other than that, the CTS minimum temperature after 2 minutes is set to less than 30 °C for testing purpose. First of all, the variable is varies until the temperature shows 25 °C. The reset button on the Arduino is pressed to restart the program and the stopwatch started. After 2 minutes the coolant temperature logo is illuminated and blinking indicates the system work. For every new test, the Arduino will be restart and wait for 2 minutes. Next, the variable resistor is detached and the coolant temperature logo is illuminated and blinking.

After that, to test the relay fail, the relay is detached and the temperature is set to 45 °C which the system will trigger the relay. The detached relay is same as a damaged relay which the contactor will not work even after the voltage is applied to the coil. After a while, the relay logo is illuminated and blinking. The relay detached is shown in Figure 4.20.

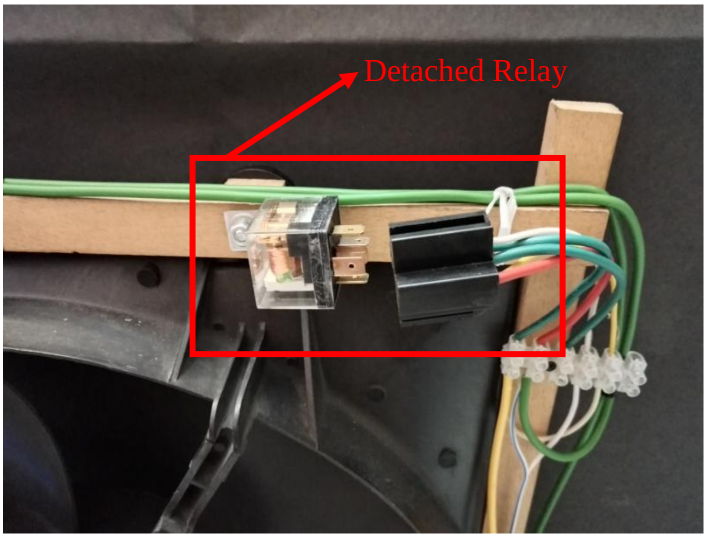

Figure 4.20: Relay detached

Finally, to test the fan fail, there will be two set of testing. First is by locking the cooling fan blade with a wood stick. This will increase the current when it is turned on. The temperature is adjusted to 45 °C and after a while, the fan logo is illuminated and blinking. The locking of the cooling fan blade is shown in Figure 4.21. The second set of test is to limit the current flow through the motor so that the RPM of the fan is low. This can be done by replacing a smaller size cable to the input of the cooling fan motor to limit the current so that the fan will turn slowly. However, this test must be done fast as the cable will be melt or burn due to the stress of high current trying to flow through it. The temperature is adjusted to 45 °C and after a while, the fan logo is illuminated and blinking. The cable replace is shown in Figure 4.22. This two test show the system is working either high current pass through the motor or low RPM on the fan.

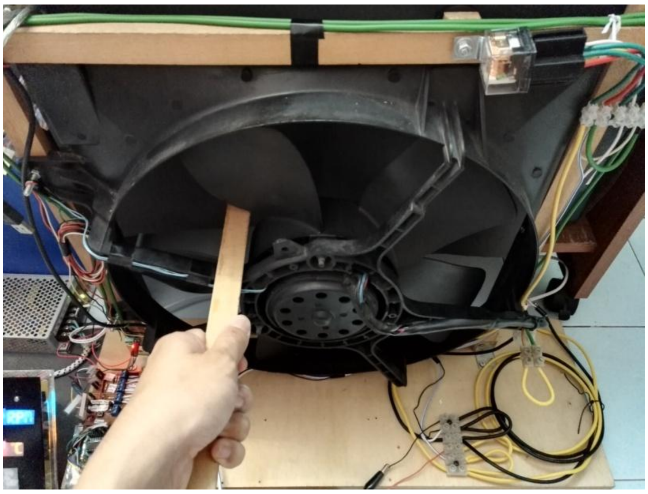

Figure 4.21: Locking of cooling fan motor

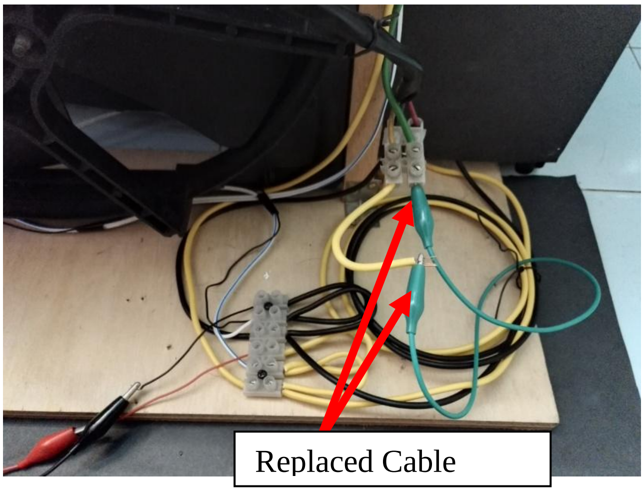

Figure 4.22: Cable replacement

CHAPTER 5

ACHIEVEMENT

5.1 Competition Participation

The author took part in Sustainable and Innovative Green Product Design held at UTAR Multi-Purpose Hall Sg. Long on 23 February 2016. The objective of this competition was to create awareness towards Green Technology among undergraduate student and to stimulate the capabilities of undergraduate students in designing prototypes of engineering related projects. Not only that, it also aim to promote the green innovation and creativity among engineering undergraduate students in Malaysia. The title submitted by the author was Electric Vehicle Cooling Fan Failure Alert System. There were 10 teams competing in this competition and the author has won first prize in the competition. Figure 5.1 shows the author the winning grand prize in the competition.

Figure 5.1: Author champion prize

Besides that, the author also took part FYP poster competition held at UTAR 5th floor KB Block Sg. Long on 13 April 2016. The objective of this competition was to provide an opportunity for FYP II students to demonstrate their independence, originality and ethics. The chosen track for the competition was track 2, applied science. There were 4 different tracks in the competition and track 2 has 17 competitors. Figure 5.2 shows the FYP competition poster. The author has won 1st runner up in the competition. Figure 5.3 shows the author won the 1st runner-up prize.

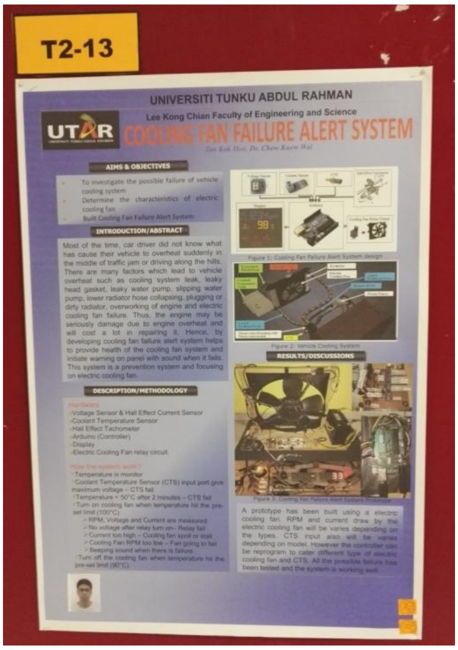

Figure 5.2: FYP competition poster

Figure 5.3: Author first Runner-up prize

CHAPTER 6

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

In conclusion, vehicle overheat prevention system: cooling fan failure alert system is a system which helps serve as a prevention measure to the cooling system before it damages the engine or collapsing the entire cooling system. This system does not cost too expensive to be install. Thus, installing this system serve like buying insurance for the engine and cooling system. From the result and discussion, all the expected systems work and operating well. Besides that, to make sure the system run well, deciding the right component to use in this system is critical as the system will be placed in the harsh and hot environment.

All the objective of this project is achieved and accomplished. The possible failure of the engine cooling system is determined and the characteristic of an electric DC motor is also determined. The prototype of this system is built out and tested working perfectly.

The main problem encounter during the implementation of this project is the accuracy and functionality of the program. By debugging the problem, the accuracy and desired working condition is achieved. Other than that, selecting the right component to use in this project is crucial as it involves high current. Component whenever has lower current rating than the rated current should not be selected in order to avoid the component from burning. Besides that, overloading is also needed to be considered in selecting the component. Hence, some of the component used in this project such as cable, relay and current sensor are high current rated.

Although this project is successfully built and works perfectly, there is still a lot of improvement can be done to it.

6.2 Future Improvements and Recommendations

Several improvements are recommended in this project to further enhance the system failure detection system and also lower cost of implementation.

6.2.1 PIC Microcontroller

Instate of using Arduino as the main controller, PIC Microcontroller is recommended to be implemented into this system. Although the programming of this PIC microcontroller is much harder than the Arduino but the cost of the controller will be cheaper by at least 4 times. The low cost is an added advantage to the PIC microcontroller. However, to do a modification of code to cater different type of electric cooling fan and CTS will be much harder. Modification of code will be done once but the system to be implement into the vehicle is in high volume. Therefore, cheaper systems still the biggest advantage.

6.2.2 Enhancing Detection of Cooling System Failure

To enhance this system to more reliable, instead of focusing only on the electric cooling fan, it should focus on the entire vehicle cooling system. Since, the entire system will consist of more failure part such as water pump, thermostat, and water level of the cooling system. With this system, the vehicle overheat prevention system is complete.

6.2.3 More Precise Tachometer

To enhance the precision of the tachometer, more magnets can be placed on the fan blade. This is to ensure the RPM display is more precise and the value is updated more quickly. Since the RPM display only update once a second, by enhancing the tachometer precision, the RPM display can be updated every quarter of second.

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APPENDICES

APPENDIX A: Full Arduino source codes

```
#include "LedControl.h"
#include "TimerOne.h"

// Pin 11 = DATA IN, Pin 12 = CLK, Pin 13 = LOAD(/CS)
LedControl lc=LedControl(11, 12, 13, 1);

// 7-Segment Display data
byte RPM_One = 0;
byte RPM_Ten = 0;
byte RPM_Hundred = 0;
byte RPM_Thousand = 0;
byte Temp_One = 0;
byte Temp_Ten = 0;
byte Temp_Hundred = 0;
int T1 = 0;
int T2 = 0;

// Voltage Sensor data
int VoltageSensorInput = 0;
float VS_Voltage = 0;

// RPM  data
int rpm = 0;
int Rotation = 0;
unsigned long lastmillis = 0;

// CTS data
int CTS_Input = 0;
float CTS_Voltage = 0;
float CTS_Resistance = 0;
float Temp = 0;

// Current Sensor data
int CurrentSensorInput = 0;
float CS_Current = 0;
int ACSoffset = 2500;
```

```
// Other temporary data
bool Fan = 0;
int Counter = 0;
int Counter1 = 0;
int Counter2 = 0;
bool State1 = 0;
bool F1 = 0;
bool F2 = 0;
bool F3 = 0;

void setup()
{
  Serial.begin(9600);
  pinMode(3, INPUT);
  pinMode(4, OUTPUT);
  pinMode(5, OUTPUT);
  pinMode(6, OUTPUT);
  pinMode(7, OUTPUT);
  pinMode(8, OUTPUT);
  pinMode(9, OUTPUT);
  pinMode(10, OUTPUT);
  Timer1.initialize();
  Timer1.attachInterrupt(RPM);          // enable Internal Interrupt every 1 seconds
  attachInterrupt(0, rpm_fan, FALLING); // enable interrupt
}


void loop()
    {
      // Temperature Reading
      TemperatureReading();

      //CTS Checking
      // To make sure Engine run up to 2 minutes before checking CTS
      if (Counter1 < 60)
      {
        Counter1 ++;
      }

      // CTS Fail if temperature <50 degree for after 2 minutes
      else if (Temp < 50)
      {
        // Turn on CTS fail LED
        F2 = true;
      }

      // CTS giving maximum input voltage(5V) indicate bad CTS
      // CTS given resistance of > 45000 ohm (-40 C) indicate bad CTS
      if (CTS_Input == 1023 || CTS_Resistance > 45000)
      {
        // Turn on CTS fail LED
        F2 = true;
      }

      // Display 7-Segment for RPM and Temperature
      Display_7_Segment ();

      // Coolant Temperature LED Display
      Coolant_LED();

      // Fan Controlling
      // Turn ON when temp reach 100 degree
      // Turn ON when CTS fail
      if (Temp >= 100 || F2 == true)
      {
        digitalWrite(4, HIGH);
        Fan = 1;
      }

      // Turn OFF when temp drop to 90 degree
      else if (Temp <= 90)
      {
        digitalWrite(4, LOW);
```

```
        Counter = 0;
        Fan = 0;
      }

      // Fan Failure Checking System
      // Only check when fan is turn on
      if (Fan == 1)
      {
        Counter ++;
        // Allow fan current and voltage to stabilize before measuring
        if (Counter < 6)
        {
          goto L1;
        }

        // Goto check current and voltage
        RelayFail_FanFail_Check ();
      }

      // Reset Switch
      if ( digitalRead(3) == true)
      {
        digitalWrite(8, LOW);
        digitalWrite(9, LOW);
        digitalWrite(10,LOW);
        F1 = false;
        F2 = false;
        F3 = false;
      }
L1:
      delay(500);
    }

// Increase by 1 when interrupt.
void rpm_fan()
{
  Rotation++;
}


void RPM()
{
  // Convert frequency to RPM
  // Reset the RPM counter
  rpm = Rotation * 60;
  Rotation = 0;

   State1 = !State1;

   //Blinking function for all FAIL LEDs
   // Blink only when Relay Fail is true
   if ( F1 == true)
   {
     digitalWrite(8, State1);
   }

   // Blink only when CTS Fail is true
   if ( F2 == true)
   {
     digitalWrite(9, State1);
   }

   // Blink only when Fan Fail is true
   if ( F3 == true)
   {
     digitalWrite(10, State1);
   }
}
```

```
void Coolant_LED()
{
   // Display temperature logo as blank (CTS Failed)
   if (CTS_Input == 1023 || CTS_Resistance >= 45000)
  {
    digitalWrite(7, LOW);
    digitalWrite(6, LOW);
    digitalWrite(5, LOW);
  }

  // Display temperature logo as Blue (Cold)
  else if (Temp <= 30)
  {
    digitalWrite(7, HIGH);
    digitalWrite(6, LOW);
    digitalWrite(5, LOW);
  }

  // Display temperature logo as Yellow (Normal)
  else if (Temp < 120)
  {
    digitalWrite(7, LOW);
    digitalWrite(6, HIGH);
    digitalWrite(5, HIGH);
  }

  // Display temperature logo as Red (Hot)
  else if (Temp >= 120)
  {
    digitalWrite(7, LOW);
    digitalWrite(6, LOW);
    digitalWrite(5, HIGH);
  }
}

void  RelayFail_FanFail_Check ()
{
  // Voltage Reading
  // Read Sensor Voltage & Convert to Digital
  // Calculating actual voltage (V)
  VoltageSensorInput = analogRead(A0);
  VS_Voltage = VoltageSensorInput * (25.0 / 1023.0);

  // Current Reading
  // Read Sensor Voltage & Convert to Digital
  // Calculating actual current (A)
  CurrentSensorInput = analogRead(A1);
  CS_Current = ((((CurrentSensorInput / 1024.0) * 5000) - ACSoffset) / 66);

  // If no voltage, then relay failed
  if (VS_Voltage <=3 )
  {
    F1 = true;
    return;
  }

  // If current high or fan RPM low, fan failed
  if (CS_Current >= 12 || rpm <= 1000)
  {
    F3 = true;
  }
}

void TemperatureReading ()
{
  // Read CTS Voltage
  // Calculate resistance of CTS
  CTS_Input = analogRead(A2);
  CTS_Voltage = CTS_Input * (5.0 / 1023.0);
  CTS_Resistance = (2000*CTS_Voltage)/(5-CTS_Voltage);
```

```
//Calculate actual temperature in degree Celsius
if (CTS_Resistance >= 26114)                    // Temp is >-30
{
  Temp = ((CTS_Resistance+31483)/-1919);
}
else if (CTS_Resistance >= 15462 )              // Temp is -30 to -20
{
  Temp = ((CTS_Resistance+5842)/-1065);
}
else if (CTS_Resistance >= 9397 )               // Temp is -20 to -10
{
  Temp = ((CTS_Resistance-3332)/-606.5);
}
else if (CTS_Resistance >= 5896 )               // Temp is -10 to 0
{
  Temp = ((CTS_Resistance-5896)/-350.1);
}
else if (CTS_Resistance >= 3792 )               // Temp is 0 to 10
{
  Temp = ((CTS_Resistance-5896)/-210.4);
}
else if (CTS_Resistance >= 2500 )               // Temp is 10 to 20
{
  Temp = ((CTS_Resistance-5084)/-129.2);
}
else if (CTS_Resistance >= 1707 )               // Temp is 20 to 30
{
  Temp = ((CTS_Resistance-4086)/-79.3);
}
else if (CTS_Resistance >= 1175 )               // Temp is 30 to 40
{
  Temp = ((CTS_Resistance-3303)/-53.2);
}
else if (CTS_Resistance >= 834 )                // Temp is 40 to 50
{
  Temp = ((CTS_Resistance-2539)/-34.1);
}
else if (CTS_Resistance >= 596 )                // Temp is 50 to 60
{
  Temp = ((CTS_Resistance-2024)/-23.8);
}
else if (CTS_Resistance >= 436 )                // Temp is 60 to 70
{
  Temp = ((CTS_Resistance-1556)/-16);
}
else if (CTS_Resistance >= 323 )                // Temp is 70 to 80
{
  Temp = ((CTS_Resistance-1227)/-11.3);
}
 else if (CTS_Resistance >= 243 )               // Temp is 80 to 90
{
  Temp = ((CTS_Resistance-963)/-8);
}
else if (CTS_Resistance >= 187 )                // Temp is 90 to 100
{
  Temp = ((CTS_Resistance-747)/-5.6);
}
else if (CTS_Resistance >= 144 )                // Temp is 100 to 110
{
  Temp = ((CTS_Resistance-617)/-4.3);
}
else if (CTS_Resistance >= 113 )                // Temp is 110 to 120
{
  Temp = ((CTS_Resistance-485)/-3.1);
}
else if ( CTS_Resistance < 113)                 // Temp is >120
{
  Temp = ((CTS_Resistance-401)/-2.4);
}
}
```

```
void Display_7_Segment ()
{
    // LedControl lc=LedControl(11, 12, 13, 1);
    // Wake up the MAX72XX from power-saving mode
    lc.setScanLimit(0, 7);
    lc.shutdown(0,false);
    lc.setIntensity(0,10);

    // Print the RPM value
    // When RPM = 0, print "-"
    if (rpm == 0)
    {
      lc.setChar(0,3,'-',false);
      lc.setChar(0,2,' ',false);
      lc.setChar(0,1,' ',false);
      lc.setChar(0,0,' ',false);
    }

    // Print value of RPM
    else
    {
      T1 = rpm;
      RPM_One = T1%10;
      T1 = T1/10;
      RPM_Ten = T1%10;
      T1 = T1/10;
      RPM_Hundred = T1%10;
      T1 = T1/10;
      RPM_Thousand = T1;

        if(RPM_Thousand > 0)
        {
          lc.setDigit(0,0,(byte)RPM_Thousand,false);
          lc.setDigit(0,1,(byte)RPM_Hundred,false);
          lc.setDigit(0,2,(byte)RPM_Ten,false);
          lc.setDigit(0,3,(byte)RPM_One,false);
        }
         else if(RPM_Hundred > 0)
        {
          lc.setChar(0,0,' ',false);
          lc.setDigit(0,1,(byte)RPM_Hundred,false);
          lc.setDigit(0,2,(byte)RPM_Ten,false);
          lc.setDigit(0,3,(byte)RPM_One,false);
        }
        else if(RPM_Ten > 0)
        {
          lc.setChar(0,0,' ',false);
          lc.setChar(0,1,' ',false);
          lc.setDigit(0,2,(byte)RPM_Ten,false);
          lc.setDigit(0,3,(byte)RPM_One,false);
        }
    }


    // Print the CTS Temperature
    // When CTS Fail, print "-"
    if (CTS_Input == 1023 || CTS_Resistance >=45000)
    {
       lc.setChar(0,7,'-',false);
       lc.setChar(0,6,' ',false);
       lc.setChar(0,5,' ',false);
       lc.setChar(0,4,' ',false);
    }

    // Print temperature value
    else
    {
       if ( Temp >= 0)
      {
        lc.setChar(0,4,' ',false);
        T2 = Temp;
      }
      else
```

```
    {
      lc.setChar(0,4,'-',false);
      T2 = (Temp * -1);
    }

    Temp_One = T2%10;
    T2 = T2/10;
    Temp_Ten = T2%10;
    T2 = T2/10;
    Temp_Hundred = T2;

    if ( Temp_Hundred > 0)
    {
      lc.setDigit(0,7,(byte)Temp_One,false);
      lc.setDigit(0,6,(byte)Temp_Ten,false);
      lc.setDigit(0,5,(byte)Temp_Hundred,false);
    }
    else if ( Temp_Ten > 0)
    {
      lc.setDigit(0,7,(byte)Temp_One,false);
      lc.setDigit(0,6,(byte)Temp_Ten,false);
      lc.setChar(0,5,' ',false);
    }
    else
    {
      lc.setDigit(0,7,(byte)Temp_One,false);
      lc.setChar(0,6,' ',false);
      lc.setChar(0,5,' ',false);
    }
  }
}
```

APPENDIX B: MAX7221 IC datasheet

maxim integrated™

MAX7219/MAX7221

Serially Interfaced, 8-Digit LED Display Drivers

General Description

The MAX7219/MAX7221 are compact, serial input/output common-cathode display drivers that interface microprocessors (µPs) to 7-segment numeric LED displays of up to 8 digits, bar-graph displays, or 64 individual LEDs. Included on-chip are a BCD code-B decoder, multiplex scan circuitry, segment and digit drivers, and an 8x8 static RAM that stores each digit. Only one external resistor is required to set the segment current for all LEDs. The MAX7221 is compatible with SPI™, QSPI™, and MICROWIRE™, and has slew-rate-limited segment drivers to reduce EMI.

A convenient 4-wire serial interface connects to all common µPs. Individual digits may be addressed and updated without rewriting the entire display. The MAX7219/MAX7221 also allow the user to select code-B decoding or no-decode for each digit.

The devices include a 150µA low-power shutdown mode, analog and digital brightness control, a scan-limit register that allows the user to display from 1 to 8 digits, and a test mode that forces all LEDs on.

For applications requiring 3V operation or segment blinking, refer to the MAX6951 data sheet.

Applications

Bar-Graph Displays
Panel Meters
Industrial Controllers
LED Matrix Displays

Features

- **10MHz Serial Interface**
- **Individual LED Segment Control**
- **Decode/No-Decode Digit Selection**
- **150µA Low-Power Shutdown (Data Retained)**
- **Digital and Analog Brightness Control**
- **Display Blanked on Power-Up**
- **Drive Common-Cathode LED Display**
- **Slew-Rate Limited Segment Drivers for Lower EMI (MAX7221)**
- **SPI, QSPI, MICROWIRE Serial Interface (MAX7221)**
- **24-Pin DIP and SO Packages**

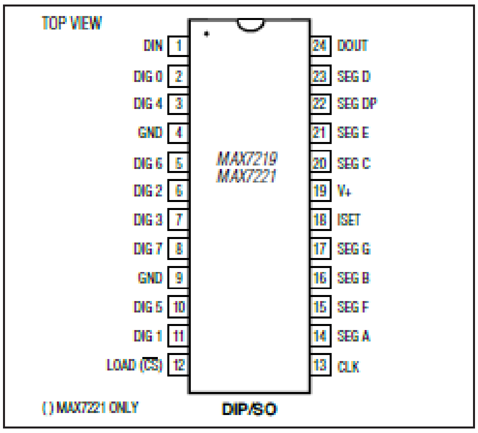
Ordering Information

PART	TEMP RANGE	PIN-PACKAGE
MAX7219CNG	0°C to +70°C	24 Narrow Plastic DIP
MAX7219CWG	0°C to +70°C	24 Wide SO
MAX7219C/D	0°C to +70°C	Dice*
MAX7219ENG	-40°C to +85°C	24 Narrow Plastic DIP
MAX7219EWG	-40°C to +85°C	24 Wide SO
MAX7219ERG	-40°C to +85°C	24 Narrow CERDIP

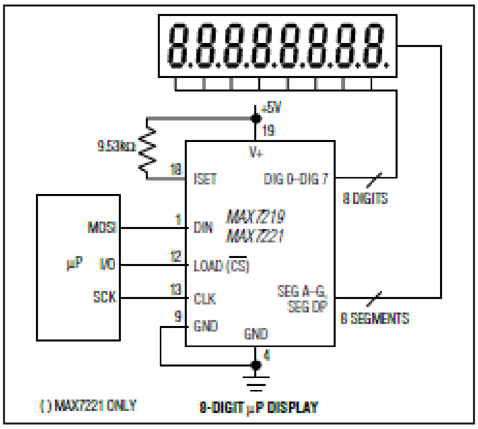
Ordering Information continued at end of data sheet.

*Dice are specified at $T_A = +25°C$.

Pin Configuration



Typical Application Circuit



SPI and QSPI are trademarks of Motorola Inc. MICROWIRE is a trademark of National Semiconductor Corp.

19-4452; Rev 4; 7/03

APPENDIX C: ACS712ELCTR-30A-T datasheet

ACS712

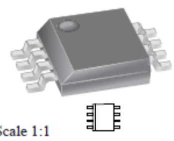
Fully Integrated, Hall Effect-Based Linear Current Sensor IC with 2.1 kVRMS Isolation and a Low-Resistance Current Conductor

Features and Benefits

- Low-noise analog signal path
- Device bandwidth is set via the new FILTER pin
- 5 µs output rise time in response to step input current
- 80 kHz bandwidth
- Total output error 1.5% at T_A = 25°C
- Small footprint, low-profile SOIC8 package
- 1.2 mΩ internal conductor resistance
- 2.1 kVRMS minimum isolation voltage from pins 1-4 to pins 5-8
- 5.0 V, single supply operation
- 66 to 185 mV/A output sensitivity
- Output voltage proportional to AC or DC currents
- Factory-trimmed for accuracy
- Extremely stable output offset voltage
- Nearly zero magnetic hysteresis
- Ratiometric output from supply voltage

TÜV America
Certificate Number:
U8V 06 05 54214 010

Package: 8 Lead SOIC (suffix LC)



Approximate Scale 1:1

Description

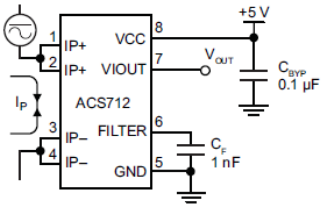
The Allegro™ ACS712 provides economical and precise solutions for AC or DC current sensing in industrial, commercial, and communications systems. The device package allows for easy implementation by the customer. Typical applications include motor control, load detection and management, switch-mode power supplies, and overcurrent fault protection. The device is not intended for automotive applications.

The device consists of a precise, low-offset, linear Hall circuit with a copper conduction path located near the surface of the die. Applied current flowing through this copper conduction path generates a magnetic field which the Hall IC converts into a proportional voltage. Device accuracy is optimized through the close proximity of the magnetic signal to the Hall transducer. A precise, proportional voltage is provided by the low-offset, chopper-stabilized BiCMOS Hall IC, which is programmed for accuracy after packaging.

The output of the device has a positive slope (>$V_{IOUT(Q)}$) when an increasing current flows through the primary copper conduction path (from pins 1 and 2, to pins 3 and 4), which is the path used for current sampling. The internal resistance of this conductive path is 1.2 mΩ typical, providing low power loss. The thickness of the copper conductor allows survival of

Continued on the next page…

Typical Application



Application 1. The ACS712 outputs an analog signal, V_{OUT}, that varies linearly with the uni- or bi-directional AC or DC primary sampled current, I_P, within the range specified. C_F is recommended for noise management, with values that depend on the application.

APPENDIX D: A1220 datasheet

A1220, A1221, A1222, and A1223

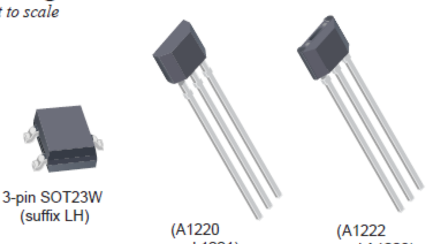
Chopper Stabilized Precision Hall Effect Latches

Features and Benefits

- Symmetrical latch switchpoints
- Resistant to physical stress
- Superior temperature stability
- Output short-circuit protection
- Operation from unregulated supply down to 3 V
- Reverse battery protection
- Solid-state reliability
- Small package sizes

Packages:

Not to scale



3-pin SOT23W (suffix LH)

(A1220 and 1221)

(A1222 and A1223)

3-pin SIP (suffix UA)

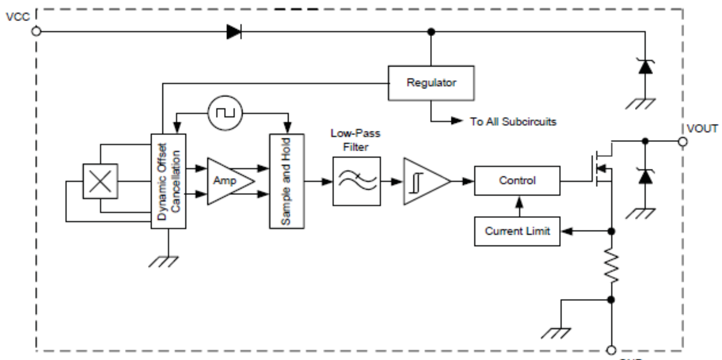
Description

The A1220, A1221, A1222, and A1223 Hall-effect sensor ICs are extremely temperature-stable and stress-resistant devices especially suited for operation over extended temperature ranges to 150°C. Superior high-temperature performance is made possible through dynamic offset cancellation, which reduces the residual offset voltage normally caused by device overmolding, temperature dependencies, and thermal stress. Each device includes on a single silicon chip a voltage regulator, Hall-voltage generator, small-signal amplifier, chopper stabilization, Schmitt trigger, and a short-circuit protected open-drain output to sink up to 25 mA. A south pole of sufficient strength turns the output on. A north pole of sufficient strength is necessary to turn the output off.

An onboard regulator permits operation with supply voltages of 3 to 24 V. The advantage of operating down to 3 V is that the device can be used in 3-V applications or with additional external resistance in series with the supply pin for greater protection against high voltage transient events.

Two package styles provide magnetically optimized packages for most applications. Package type LH is a modified 3-pin SOT23W surface mount package while UA is a three-pin ultra-mini SIP for through hole mounting. Both packages are lead (Pb) free, with 100% matte tin plated leadframes.

Functional Block Diagram



APPENDIX E: Display PCB copper layout