Chapter 1

Introduction

1.1 Introduction

Design and implementation of a motor speed controller is a necessary device in our daily life. From the very beginning and till now a lot of methods for motor speed control have been introduced. That is a basic fact that in today’s world costs of all forms of energy are increasing. Therefore in our project and thesis, we have tried to construct a system design to run a motor with economically, efficiently and also power saving. The device presented here makes the motor to control its speed smoothly. Moreover it will allow the motor to run in accordance to the necessary speed. That is let in the summer the temperature is high, then the motor will run with high speed and that will fall with falling in the temperature. Additionally we can also switch the motor ON and OFF from whatever the distance is.

1.2 Historical background

The basic principles of electromagnetic induction were discovered in the early 1800's by Oersted, Gauss, and Faraday. In 1819, Hans Christian Oersted and Andie Marie Ampere discovered that an electric current produces a magnetic field. The next 15 years saw a flurry of cross-Atlantic experimentation and innovation. Finally using the principles developed by Michael Faraday and Joseph Henry, he built the first electric motor in 1834. However the first modern DC motor was invented in 1873. Five years later; these motors got microprocessor improvements that were mainly used in car dispatch and motor drive controllers. The induction motor was first realized by Galileo Ferraris in 1885 in Italy. In 1888, Ferraris published his research in a paper to the Royal Academy of Sciences in Turin where he exposed the theoretical foundations for understanding the way the motor operates. The induction motor with a cage was invented by Mikhail Dolivo-Dobrovolsky about a year later. Reliance Electric was founded in 1904 in Cleveland, Ohio, as a partnership between two cousins: inventor John Lincoln and industrialist Peter Hitchcock. Lincoln had been working on a new type of direct current motor. Direct current was the primary means of electrification at the time because alternating current was considered dangerous and unpredictable.

Lincoln invented the first adjustable-speed direct current motor. They shipped their first industrial electric motor in 1905. That year, the company's chief engineer, Alex McCutcheon, designed a new DC motor that soon became Reliance's primary product. It was used in many of Cleveland's booming steel mills and was a mainstay of the DC product line until the early 1950s. First electric motor with reverse switch was invented in 1965. DC servo motors are suitable for complex motion tasks because
the speed and torque in DC motors are easy to control by varying the voltage and current. Yet, due to the feedback characteristic, motion systems using this kind of motor are expensive and highly complex. When the functions of commutator and brushes were implemented by solid-state switches, maintenance-free motors were realized. In brushless DC motor the maintenance requirements are minimal and the relatively high torque produced by these motors makes the system stable.

The theory of motor speed control has devolved since the late 18th century. Simply, speed control is defined as accurately controlling the change of a parameter based on speed that is voltage and current. Since human society entered the industrial age in the 18th century, motor control, especially precision motor speed control, has steadily gathered attention in terms of research. After many years' innovations in the attempt to provide higher resolution and lower cost, the step motor has become a popular solution for achieving controllable speed due to its unique feature of the output shaft rotating in a discrete number of steps.

However in 1880 first electrical motor controlling was done by Sprague. Ward Leonard Control, also known as the Ward Leonard Drive System, was a widely used DC motor speed control system introduced by Harry Ward Leonard in 1891. In early 1900s, the control system of Ward Leonard was adopted by the U.S. Navy and also used in passenger lift of large mines. It also provided a solution to a moving sidewalk at the Paris Exposition of 1900, where many others had failed to operate properly. An outstanding contribution to the war effort was with the use of Ward-Leonard Control systems in antiaircraft radars.

Reliance made its first inroads into the AC business in 1927 with a modification of the General Electric enclosed fan-cooled motor. The company grew quickly on the basis of these new technologies, and in 1929, The introduction of the first electrical variable-speed drive package during the 1930s established Reliance's enduring leadership in that facet of the business.

With the advent of solid state electronic in the 1950's and 1960's and this technology becoming very affordable in the 1970’s & 80’s the use of pulse width modulation (PWM) became much more practical. The subharmonic control method presented by A. Schonung and H. Stemmler of BBC in 1964 was the simple modulation, where the switching instants are determined as the intersections between the reference signal and triangular carrier signals having the constant frequency. This subharmonic PWM has been a standard technique thereafter. The basic concept is to keep the voltage at the full value and simply vary the amount of time the voltage is applied to the motor windings. Most PWM circuits use large transistors to simply allow power On & Off, like a very fast switch. This sends a steady frequency of pulses into the motor windings. When full power is needed one pulse ends just as the next pulse begins, 100% modulation. At lower power settings the pulses are of shorter duration. When the pulse is on as long as it is off, the motor is operating at 50% modulation. Pulse Width Modulation (PWM) technology enabled elimination of harmonics from the inverter output voltage, allowing quasi-sinusoidal machine waveforms and
eliminating torque pulsations. The output voltage waveform of the PWM inverter contains miscellaneous harmonics and its precious analysis was reported by K. Takahashi and S. Miyairi in 1975. As the PWM inverters using turn-off elements have the simple circuit configuration it can improve their operating efficiencies as a great deal.

Since around 1975, more turn-off power semiconductor elements such as bipolar transistors and GTOs were developed and implemented during the next 20 years. In the 1980, the Ward Leonard control system started to be replaced by other systems, primarily thyristor controllers, it was widely used for elevators because it offered smooth speed control and consistent torque. Many Ward Leonard control systems and variations on them remain in use.

In 1983, the space vector modulation was introduced by Y. Murai and Y. Tsunehiro and has been applied to the analysis of the magnetic flux and to actual implementations as well. In the same year, the inverter drive systems were applied for high-speed elevators and in the next year were extended to low-speed elevators as well. First compact bow-mount, built-in electronic speed control with first automatic electronic battery gauge was introduced in 1987. Then gradually thyristor inverters were replaced with forced commutating circuits. In 1991 first computer-controlled as well as first self-steering unit motor was developed.

1.3 Objectives of this work

The main purpose of our project is to construct a system design that will allow as to run a motor efficiently and economically with protection, power saving and smoothly. Here using PWM controller the motor speed can be controlled easily. In the modified design using LM35 and LM324 the motor speed will be controlled automatically. Here the motor speed is linearly proportional to the temperature. Additionally by using SRD-24VDC and GSM network it has been an interesting features that to control the motor power from a long distance.

1.4 Introduction to this thesis

In chapter 2, descriptions on brushless DC motor are given. Here Basic Structures, equivalent circuit, general equations and its applications are described. Also through comparison of conventional motor and brushless DC Motors with some advantages it is discussed that why the brushless DC Motors have been chosen for the project.

Chapter 3 contains the basic operation, internal construction and application information of the PWM controller. The necessary equipments, their purpose and also their operational procedure are discussed in the chapter.
In chapter 4 and chapter 5 two additional features of motor speed control are discussed. Here in chapter 4 motor switching technique with mobile GSM network and its operating mechanism are described. And chapter 5 describes the basic operation, equivalent circuit and general equation of motor speed control using thermal detector.

Chapter 2

Brushless DC Motors

2.1 Introduction

Conventional dc motors are highly efficient and their characteristics make them suitable for use as servomotors. However, their only drawback is that they need a commutator and
brushes which are subject to wear and require maintenance. When the functions of
commutator and brushes were implemented by solid-state switches, maintenance-free
motors were realized. These motors are now known as brushless dc motors Brushless
Direct Current (BLDC) motors are one of the motor types rapidly gaining popularity. As
the name implies, BLDC motors do not use brushes for commutation; instead, they are
electronically commutated. In addition, the ratio of torque delivered to the size of the motor
is higher, making it useful in applications where space and weight are critical factors. There
is an increasing demand for battery–operated motor applications in the market today.
Traditionally, the high efficiency, high power densities and reliability make brushless DC
motor an ideal choice for battery-operated motor applications

2.2 Basic Construction and Operating Principle

In any electric motor, operation is based on simple electromagnetism. A current carrying
conductor generates a magnetic field which when placed in an external magnetic field; it
will experience a force proportional to the current in the conductor and to the strength of
the external magnetic field. The internal configuration of a DC motor is designed to
harness the magnetic interaction between a current-carrying conductor and an external
magnetic field to generate rotational motion.

The construction of modern brushless motors is very similar to the ac motor, known as the
permanent magnet synchronous motor. Fig.2.1 illustrates the structure of a typical three-
phase brushless DC motor. The stator windings are similar to those in a polyphase ac
motor, and the rotor is composed of one or more permanent magnets.
BLDC motors are a type of synchronous motor. This means the magnetic field generated by the stator and the magnetic field generated by the rotor rotates at the same frequency. BLDC motors do not experience the “slip” that is normally seen in induction motors. BLDC motors come in single-phase, 2-phase and 3-phase configurations. Corresponding to its type, the stator has the same number of windings. Out of these, 3-phase motors are the most popular and widely used. This application note focuses on 3-phase motors.

**Stator**

The stator of a BLDC motor consists of stacked steel laminations with windings placed in the slots that are axially cut along the inner periphery (as shown in Figure 2.2). Traditionally, the stator resembles that of an induction motor; however, the windings are distributed in a different manner. Most BLDC motors have three stator windings connected in star fashion. Each of these windings is constructed with numerous coils interconnected to form a winding. One or more coils are placed in the slots and they are interconnected to make a winding. Each of these windings is distributed over the stator periphery to form an even number of poles. There are two types of stator windings variants: trapezoidal and sinusoidal motors. This differentiation is made on the basis of the interconnection of coils in the stator windings to give the different types of back Electromotive Force (EMF).
Back EMF

When a BLDC motor rotates, each winding generates a voltage known as back Electromotive Force or back EMF, which opposes the main voltage supplied to the windings according to Lenz’s Law. The polarity of this back EMF is in opposite direction of the energized voltage. Back EMF depends mainly on three factors:

- Angular velocity of the rotor
- Magnetic field generated by rotor magnets
- The number of turns in the stator windings

Once the motor is designed, the rotor magnetic field and the number of turns in the stator windings remain constant. The only factor that governs back EMF is the angular velocity or speed of the rotor and as the speed increases, back EMF also increases. The motor technical specification gives a parameter called, back EMF constant that can be used to estimate back EMF for a given speed. The potential difference across a winding can be calculated by subtracting the back EMF value from the supply voltage. The motors are designed with a back EMF constant in such a way that when the motor is running at the rated speed, the potential difference between the back EMF and the supply voltage will be sufficient for the motor to draw the rated current and deliver the rated torque. If the motor is driven beyond the rated speed, back EMF may increase substantially, thus decreasing the potential difference across the winding results in a reducing to the current.

![Figure 2.2: Stator of a brushless DC motor](image)

Rotor

The rotor is made of permanent magnet and can vary from two to eight pole pairs with alternate North (N) and South (S) poles. Based on the required magnetic field density in the rotor, the proper magnetic material is chosen to make the rotor. Ferrite magnets are traditionally used to make permanent magnets. As the technology advances, rare earth alloy
magnets are gaining popularity. The ferrite magnets are less expensive but they have the disadvantage of low flux density for a given volume. In contrast, the alloy material has high magnetic density per volume and enables the rotor to compress further for the same torque. Also, these alloy magnets improve the size-to-weight ratio and give higher torque for the same size motor using ferrite magnets. Neodymium (Nd), Samarium Cobalt (SmCo) and the alloy of Neodymium, Ferrite and Boron (NdFeB) are some examples of rare earth alloy magnets. Continuous research is going on to improve the flux density to compress the rotor further. Figure 2.3 shows cross sections of different arrangements of magnets in a rotor.

![Cross sections of different arrangements of magnets in a rotor](image)

**Figure 2.3: Rotor magnet cross sections**

**Hall Sensors**

Unlike a brushed DC motor, the commutation of a BLDC motor is controlled electronically. To rotate the BLDC motor, the stator windings should be energized in a sequence. It is important to know the rotor position in order to understand which winding will be energized following the energizing sequence. Rotor position is sensed using Hall Effect sensors embedded into the stator. Hall Effect Theory: If an electric current carrying conductor is kept in a magnetic field, the magnetic field exerts a transverse force on the moving charge carriers which tends to push them to one side of the conductor. This is most evident in a thin flat conductor. A buildup of charge at the sides of the conductors will balance this magnetic influence, producing a measurable voltage between the two sides of the conductor. The presence of this measurable transverse voltage is called the Hall Effect. Most BLDC motors have three Hall sensors embedded into the stator on the non-driving end of the motor. Whenever the rotor magnetic poles pass near the Hall sensors, they give a high or low signal, indicating the N or S pole is passing near the sensors. Based on the combination of these three Hall sensor signals, the exact sequence of commutation can be determined. The Hall sensors require a power supply. The voltage may range from 4 volts to 24 volts. Required current can range from 5 to 15 mAmps. The Hall sensor output is normally an open-collector type. A pull-up resistor may be required on the controller side.
Brushless DC motors are different from ac synchronous motors in that the former incorporates some means to detect the rotor position (or magnetic poles) to produce signals to control the electronic switches as shown in Fig.2.4.

![Figure 2.4: Brushless DC motor = Permanent magnet ac motor + Electronic commutator](image)

Figure 2.4: Brushless DC motor = Permanent magnet ac motor + Electronic commutator

Although the most conventional and efficient motors are three-phase, two-phase brushless DC motors are also very commonly used for the simple construction and drive circuits. A sketch of a small simple brushless DC motor and its associated control unit is shown in figure 2.5. The input to the control unit consists of a dc power source and a signal proportional to the current rotor position. The rotor is similar to that of a permanent magnet stepper motor, except that it is nonsalient. The stator can have three of more phases. The figure shows four phases motor. A brushless DC motor functions by energizing one stator coil at a time with a constant dc voltage. When a coil is turned on, it produces a stator magnetic field $B_s$ and a torque is produced on the rotor which tends to align the rotor with the stator magnetic field.
From the above figure at the time when the stator magnetic field points to the left while the permanent magnet rotor magnetic field points up, producing a counterclockwise torque on the rotor. As a result, the rotor will turn to the left. If coil a remains energizing all the time, the rotor would turn until the two magnetic fields are aligned, and then it would stop, just like a stepper motor. The key to the operation of a brushless DC motor is that it includes a position sensor, so that the control circuit will know when the rotor is almost aligned with the stator magnetic field. At that time, coil a will be turned off and coil b will be turned on, causing the rotor to again experience a counterclockwise torque, and to continue rotating. This process continues indefinitely with the coils turned on in the order, b, c, d, a, -b, -c, -d, and so on, so that the motor turns continuously. The electronic of the control circuit can be used to control both the speed and direction to the motor. The net effect of this design is a motor that runs from a dc power source, with full control over both the speed and the direction of rotation.

Each commutation sequence has one of the windings energized to positive power (current enters into the winding), the second winding is negative (current exits the winding) and the third is in a non-energized condition. Torque is produced because of the interaction between the magnetic field generated by the stator coils and the permanent magnets. Ideally, the peak torque occurs when these two fields are at 90° to each other and falls off as the fields move together. In order to keep the motor running, the magnetic field produced by the windings should shift position, as the rotor moves to catch up with the stator field. What is known as “Six-Step Commutation” defines the sequence of energizing the windings.

Figure 2.6 shows an example of Hall sensor signals with respect to back EMF and the phase current. Every 60 electrical degrees of rotation, one of the Hall sensors changes the state. Given this, it takes six steps to complete an electrical cycle. In synchronous, with every 60 electrical degrees, the phase current switching should be updated. However, one
electrical cycle may not correspond to a complete mechanical revolution of the rotor. The number of electrical cycles to be repeated to complete a mechanical rotation is determined by the rotor pole pairs. For each rotor pole pairs, one electrical cycle is completed. So, the number of electrical cycles/rotations equals the rotor pole pairs. However the Hall sensors may be at 60° or 120° phase shift to each other. When deriving a controller for a particular motor, the sequence defined by the motor manufacturer should be followed.

Figure 2.6: Hall sensor signal, back emf, output torque and phase current
2.3 Comparison of Conventional and Brushless DC Motors

Although it is said that brushless dc motors and conventional dc motors are similar in their static characteristics, they actually have remarkable differences in some aspects. Table 2.1 and table 2.1 compare the advantages and disadvantages of these two types of motors. When we discuss the functions of electrical motors, we should not forget the significance of windings and commutation. Commutation refers to the process which converts the input direct current to alternating current and properly distributes it to each winding in the armature. In a conventional dc motor, commutation is undertaken by brushes and commutator; in contrast, in a brushless dc motor it is done by using semiconductor devices such as transistors.

Table 2.1 Comparing a BLDC motor to a brushed DC motor

<table>
<thead>
<tr>
<th>Feature</th>
<th>BLDC Motor</th>
<th>Brushed DC Motor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commutation</td>
<td>Electronic commutation based on Hall position sensors</td>
<td>Brushed commutation.</td>
</tr>
<tr>
<td>Maintenance</td>
<td>Less required due to absence of brushes</td>
<td>Periodic maintenance is required</td>
</tr>
<tr>
<td>Life</td>
<td>Longer</td>
<td>Shorter</td>
</tr>
<tr>
<td>Speed/Torque Characteristics</td>
<td>Flat – Enables operation at all speeds with rated load</td>
<td>Moderately flat – At higher speeds, brush friction increases, thus reducing useful torque.</td>
</tr>
<tr>
<td>Efficiency</td>
<td>High – No voltage drop across brushes</td>
<td>Moderate.</td>
</tr>
<tr>
<td>Output Power/Frame Size</td>
<td>High – Reduced size due to superior thermal characteristics. Because BLDC has the windings on the stator, which is connected to the case, the heat dissipation is better.</td>
<td>Moderate/Low – The heat produced by the armature is dissipated in the air gap, thus increasing the temperature in the air gap and limiting specs on the output power/frame size.</td>
</tr>
<tr>
<td>Rotor Inertia</td>
<td>Low, because it has permanent magnets on the rotor. This improves the dynamic response</td>
<td>Higher rotor inertia which limits the dynamic characteristics.</td>
</tr>
<tr>
<td>Speed Range</td>
<td>Higher – No mechanical limitation imposed by brushes/commutator</td>
<td>Lower – Mechanical limitations by the brushes.</td>
</tr>
<tr>
<td>Electric Noise Generation</td>
<td>Low</td>
<td>Arcs in the brushes will generate noise causing EMI</td>
</tr>
</tbody>
</table>
Cost of Building | Higher – Since it has permanent magnets, building costs are higher | Low.
--- | --- | ---
Control | Complex and expensive | Simple and inexpensive
Control Requirements | A controller is always required to keep the motor running. The same controller can be used for variable speed control | No controller is required for fixed speed; a controller is required only if variable speed is desired.

### Table 2.2 Comparing a BLDC motor to an induction motor

<table>
<thead>
<tr>
<th>Feature</th>
<th>BLDC Motor</th>
<th>AC Induction Motor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed/Torque Characteristics</td>
<td>Flat – Enables operation at all speeds with rated load.</td>
<td>Nonlinear – Lower torque at lower speeds.</td>
</tr>
<tr>
<td>Output Power/Frame Size</td>
<td>High – Since it has permanent magnets on the rotor, smaller size can be achieved for a given output power.</td>
<td>Moderate – Since both stator and rotor have windings, the output power to size is lower than BLDC.</td>
</tr>
<tr>
<td>Rotor Inertia</td>
<td>Low – Better dynamic characteristics</td>
<td>High – Poor dynamic characteristics.</td>
</tr>
<tr>
<td>Starting Current</td>
<td>Rated – No special starter circuit required</td>
<td>Approximately up to seven times of rated – Starter circuit rating should be carefully selected. Normally uses a Star-Delta starter.</td>
</tr>
<tr>
<td>Control Requirements</td>
<td>A controller is always required to keep the motor running. The same controller can be used for variable speed control</td>
<td>No controller is required for fixed speed; a controller is required only if variable speed is desired.</td>
</tr>
<tr>
<td>Slip</td>
<td>No slip is experienced between stator and rotor frequencies</td>
<td>The rotor runs at a lower frequency than stator by slip frequency and slip increases with load on the motor</td>
</tr>
</tbody>
</table>
2.4 Equivalent Circuit and General Equations

The per phase equivalent circuit is shown in Fig.2.4 as following, where $\lambda_m$ is the flux linkage of stator winding per phase due to the permanent magnet. For steady state conditions, assuming $v$ and $e$ are sinusoidal at frequency $\omega$, the equivalent circuit becomes the one shown in Fig.2.5, where $X=\omega L$, and $V$, $I$, $E$, and $\lambda_m$ are phasors with rms amplitudes. The steady state circuit equation can be written as

$$V = E + (R + j\omega L)I \quad (2.1)$$

**Figure 2.7: Dynamic per phase equivalent circuit of brushless dc motors**

**Figure 2.8: Steady state per phase equivalent circuit of brushless dc motors**

For a maximum mechanical power at a given speed, $I$ and $E$ are in phase. This also gives maximum torque/ampere (minimum current/Nm). A brushless dc motor has position feedback from the rotor via Hall devices, optical devices, and encoder etc. to keep a particular angle between $V$ and $E$, since $E$ is in phase with rotor position, and $V$ is determined by the inverter supply to the motor. Assuming that $\dot{\phi}<<R$, when $I$ is in phase with $E$, $V$ will also be in phase with $E$. Thus the circuit can be analyzed using magnitudes of $E$, $V$, and $I$ as if it were a dc circuit. But first note that when $E$ and $I$ are in phase, the motor mechanical power output (before friction, windage, and iron losses) i.e. the electromagnetic output power is
\[ P_{em} = m \ |E| \ |I| = m\omega |\lambda_m| |I| \]  \hspace{1cm} (2.2)

where \( m \) is the number of phases, \( |E|, |I|, \) and \( |\lambda_m| \) are the amplitudes of phasor \( E, I, \) and \( \lambda_m, \) and the electromagnetic torque is

\[ T_{em} = \frac{P_{em}}{\omega_r} = \frac{m\omega |\lambda_m||I|}{\omega_r} \]  \hspace{1cm} (2.3)

where \( \omega = 2\phi \) is the rotor speed in Rad/s, and \( p \) the number of poles.

\[ \therefore T_{em} = \frac{mp}{2} |\lambda_m| |I| \]  \hspace{1cm} (2.4)

The actual shaft output torque is

\[ T_{load} = T_{em} - T_{losses} \]  \hspace{1cm} (2.5)

where \( T_{losses} \) is the total torque due to friction, windage, and iron losses. Dropping the amplitude (modulus) signs, we have

\[ T_{em} = \frac{mp}{2} \lambda_m I \]  \hspace{1cm} (2.6)

and in terms of rotor speed

\[ E = \frac{p}{2} \omega_r \lambda_m \]  \hspace{1cm} (2.7)

\[ 2.5 \text{ Performance of Brushless DC Motors} \]

**Speed-Torque (T-\( \omega \)) curve**

Still assuming \( \phi << R \) and position feedback keeps \( V \) and \( E \) (and hence \( I \)) in phase, the voltage equation can be simplified in algebraic form as
\[ V = E + RI \quad (2.8) \]

Substituting relations of \( E \sim \omega \) and \( T \sim I \), we obtain

\[ V = \frac{p}{2} \omega_T \lambda_m + \frac{2R}{mp \lambda_m} T_{em} \quad (2.9) \]

and

\[ \therefore \omega_T = \frac{V}{p\lambda_m/2} - \frac{R}{m(p\lambda_m/2)^2} T_{em} \quad (2.10) \]

**Figure 2.9: Torque-Speed curve of a brushless DC motor**

Figure 2.6 shows an example of torque/speed characteristics. There are two torque parameters used to define a BLDC motor, peak torque (TP) and rated torque (TR). During continuous operations, the motor can be loaded up to the rated torque. As in a BLDC motor, the torque remains constant for a speed range up to the rated speed the motor can be run up to the maximum speed, which can be up to 150\% of the rated speed, but the torque starts dropping.

**Efficiency**

Efficiency is defined as the ratio of output power and input power, i.e.
\[ \eta = \frac{P_{\text{out}}}{P_{\text{in}}} \]  

(2.11)

Where \( P_{\text{in}} = mVI \), and \( P_{\text{out}} = T_{\text{load}} \omega \) In term of the power flow,

\[ P_{\text{in}} = P_{\text{cu}} + P_{\text{Fe}} + P_{\text{mec}} + P_{\text{out}} \]  

(2.12)

Where \( P_{\text{cu}} = mRI^2 \) is the copper loss due to winding resistance, \( P_{\text{Fe}} \) the iron loss due to hysteresis and eddy currents, and \( P_{\text{mec}} \) the mechanical loss due to windage and friction.

**Speed Range**

The motor speed required to drive the application is determined by the type of application. For example, an application like a blower where the speed variation is not very frequent and the maximum speed of the blower can be the average motor speed required. Whereas in the case of a point-to-point positioning system, like in a high-precision conveyer belt movement or robotic arm movements, this would require a motor with a rated operating speed higher than the average movement speed. It is always suggested to allow a safety margin of 10%, as a rule of thumb, to account for miscellaneous factors which are beyond our calculations.

**2.6 Advantages of Brushless DC Motor**

Conventional DC motors have traditionally been used in applications where dc power sources are available. But if the conventional DC motor work in a low-pressure environment then brush wear can be so bad that the brushes require replacement after less than an hour of operation. Moreover excessive sparking and brush wear leads to its major disadvantages. From these concerns the brushless DC motor includes many significant advantages. A few of these are:

- Relatively high efficiency.
- Long life and reliability
- Little or no maintenance
- Very little RF noise compared to a DC motor with brushes
- Very high speeds are possible (greater than 50,000 rpm)
- Higher speed ranges
- Better speed versus torque characteristics
- High dynamic response
- Higher speed ranges
· BLDC motors produce more output power per frame size than brushed DC motors and induction motors.
· Since the rotor is made of permanent magnets, the rotor inertia is less, compared with other types of motors.
· Low-voltage models are ideal for battery operation, portable equipment or medical applications.
· Improved acceleration and deceleration characteristics.

2.7 Applications

Brushless DC motors are widely used in various applications. Particularly where regular maintenance requirement may be unacceptable such as laser printer, floppy, hard disk drives, some more sectors are Appliances, Automotive, Aerospace, Consumer, Medical, Industrial Automation. Formerly, ac synchronous motors were used as the spindle motor in floppy or hard disk drives. However, brushless dc motors which are smaller and more efficient have been developed for this application and have contributed to miniaturization and increase in memory capacity in computer systems. However the applications of the brushless DC motor can be classified to the following categories:

Applications with Constant Loads

These are the types of applications where a variable speed is more important than keeping the accuracy of the speed at a set speed. In addition, the acceleration and deceleration rates are not dynamically changing. In these types of applications, the load is directly coupled to the motor shaft. For example, fans, pumps and blowers come under these types of applications.

Applications with Varying Loads

These are the types of applications where the load on the motor varies over a speed range. These applications may demand high-speed control accuracy and good dynamic responses. In home appliances, washers, dryers and compressors are good examples. In automotive, fuel pump control, electronic steering control, engine control and electric vehicle control are good examples of these. In aerospace, there are a number of applications, like centrifuges, pumps, robotic arm controls, gyroscope controls and so on.

Positioning Applications

Most of the industrial and automation types of application come under this category. The applications in this category have some kind of power transmission, which could be mechanical gears or timer belts, or a simple belt driven system. In these applications, the dynamic response of speed and torque are important. In some cases, the same sensors are
used to get relative position information. Otherwise, separate position sensors may be used to get absolute positions.

2.8 Summary:

In this chapter, the basic structures, drive circuits, fundamental principles, steady state characteristics, and applications of brushless DC motors have been discussed. Although the brushless dc motor is a little complicated structurally because of the Hall elements or ICs mounted on the stator, and its circuit costs, the merits of the brushless dc motor far outweigh the drawbacks. The high efficiency, high power densities and reliability make brushless DC motor an ideal choice for battery-operated motor applications because the combination of power electronic and innovative control techniques provide a high performance, efficient, compact and low cost solution.
Chapter 3

Motor Speed Control using PWM Controller

3.1 Introduction

The speed control of the motor is achieved by reducing the voltage applied across the motor. Typical methods are rheostat control or linear electronic control. Although they are simple solutions, both methods causes suffering like low efficiency at low speed, low charge cycle time for battery, switch must be enough to dissipate generated heat, high cost and so on. Pulse-width modulation (PWM) or duty-cycle variation methods improve speed control and reduce power losses in the system that increase the mean time between charge cycle of the battery with greater efficiency as well as better protection schemes for the motor and control circuits.

3.2 Basic Feature of PWM Controller

Pulse-width modulation (PWM) or duty-cycle variation methods are commonly used in speed control of DC motors. The duty cycle is defined as the percentage of digital ‘high’ to digital ‘low’ plus digital ‘high’ pulse-width during a PWM period. Fig. 1 shows the 5V pulses with 0% through 50% duty cycle. The average DC voltage value for 0% duty cycle is zero; with 25% duty cycle the average value is 1.25V (25% of 5V). With 50% duty cycle the average value is 2.5V, and if the duty cycle is 75%, the average voltage is 3.75V and so on.

![Figure 3.1: 5V pulses with 0% through 50% duty cycle](image)

The maximum duty cycle can be 100%, which is equivalent to a DC waveform. Thus by varying the pulse-width, we can vary the average voltage across a DC motor and hence its speed. The PWM switching circuits and synchronous rectification improve the efficiency and increases the speed of the battery-operated motor drive system. Then can apply to DC Motor at use 20 Amp get comfortably and still have Shot Circuit Protection as well.
In the PWM controller circuit a voltage regulator has been used connected with the voltage supply. The output of the voltage regulator provides necessary input voltage for the modulator chip. Two power MOSFETs get the sufficient voltage from the chip to run the motor. The losses in switching control circuits depend on the switch parameters. MOSFETs with low RDSON and switching losses dissipate less power; therefore using MOSFETs with the appropriate characteristics reduces the overall system losses, size and cost.

3.3 SG3526-PWM Controller

The SG1526B is a high-performance pulse width modulator for switching power supplies which offers improved functional and electrical characteristics over the industry-standard SG1526. A direct pin-for-pin replacement for the earlier device with all its features, it incorporates the following enhancements: a band gap reference circuit for improved regulation and drift characteristics, improved under voltage lockout, lower temperature coefficients on oscillator frequency and current-sense threshold, tighter tolerance on soft start time, much faster SHUTDOWN response, improved double-pulse suppression logic for higher speed operation, and an improved output driver design with low shoot-through current, and faster rise and fall times. This versatile device can be used to implement single-ended or push-pull switching regulators of either polarity, both transformer-less and transformer-coupled. The SG1526B is specified for operation over the temperature range of -55°C to 150°C. The SG2526B is characterized for the industrial range of -25°C to 150°C, and the SG3526B is designed for the commercial range of 0°C to 125°C.

Feature:
· 8 to 35 volt operation
· 1Hz to 500 KHz oscillator range
· Digital current limiting
· Double pulse control
· Programmable dead time
· Improved under voltage lockout
· Single pulse metering
· Programmable soft-start
· Wide current limit common mode range
· TTL/CMOS compatible logic ports
· Symmetry correction capability
· Improved shutdown delay
· Improved rise and fall time
3.4 Internal Construction and Application Information

Figure 3.2: Pin configuration of SG3526 PWM controller

Figure 3.3: Block diagram of SG3526 PWM controller
Voltage Reference

The reference regulator of the SG1526B is a “band-gap” type; that is, the precision +5V output is derived from the very predictable base-emitter voltage of an NPN transistor. Since this is a sub-surface phenomenon, the resulting output exhibits excellent stability compared to earlier surface-breakdown zener designs. The reference output is stabilized at input voltages as low as +8 volts, and can provide up to 20mA of load current to external circuitry. An external PNP transistor can be used to boost the available current to many hundreds of mA. A rugged low-frequency audio type transistor should be used, and lead lengths between the PWM and transistor should be as short as possible to minimize the risk of oscillation.

![Figure 3.4: extending reference output current](image)

Under voltage Lockout

The under voltage lockout circuit protects the SG1526B and the power devices it controls from inadequate supply voltage. If +VIN is too low, the circuit disables the output drivers and holds the RESET pin LOW. This prevents spurious output pulses while the control circuitry is stabilizing, and holds the soft-start timing capacitor in a discharged state. The circuit consists of a merged band gap reference and comparator circuit which is active when the reference voltage has risen to 2VBE or 1.2 volts at 25°C. When the reference voltage rises to approximately +4.4 volts, the circuit enables the output drivers and releases the RESET pin, allowing a normal soft start. The comparator has 200mV of hysteresis to minimize oscillation at the trip point. When +VIN to the PWM is removed and the reference drops to +4.2 volts, the under voltage circuit pulls RESET LOW again. The soft-start capacitor is immediately discharged, and the PWM is ready for another soft-start cycle. The SG1526B can operate from a +5 volt supply regulated to within ±4% by connecting the VREF pin to the +VIN pin.
The Soft-Start Circuit

The soft-start circuit protects the power transistors and rectifier diodes from high current surges during power supply turn-on. When supply voltage is first applied to the SG1526B, the undervoltage lockout circuit holds RESET LOW with Q3. Q1 is turned on, which holds the soft-start capacitor voltage at zero. The second collector of Q1 clamps the output of the error amplifier to ground, guaranteeing zero duty cycle at the driver outputs. When the supply voltage reaches normal operating range, RESET will go HIGH. Q1 turns off, allowing the internal 100mA current source to charge CS. Q2 clamps the error amplifier output to 1.0 VBE above the voltage on CS. As the soft-start voltage ramps upto +5 volts, the duty cycle of the PWM linearly increases to whatever value the voltage regulation loop requires for an error null. Figure 7 gives the timing relationship between CS ramp time to 100% duty cycle.
Digital Control Ports

The three digital control ports of the SG1526B are bidirectional. Each pin can drive TTL and 5 volt CMOS logic directly, up to a fan-out of 10 low-power Schottky gates. Each pin can also be directly driven by open-collector TTL; open-drain CMOS, and open-collector voltage comparators, fan-in is equivalent to 1 low-power Schottky gate. Each port is normally HIGH; the pin is pulled LOW to activate the particular function. Driving SYNC LOW initiates a discharge cycle in the oscillator. Pulling SHUTDOWN LOW immediately inhibits all PWM output pulses. Holding RESET LOW discharges the soft-start capacitor. The logic threshold is +1.1 volts at +25°C. Noise immunity can be gained at the expense of fan-out with an external 2K pull-up resistor to +5 volts.

![Figure 3.7: digital control port schematic](image)

Oscillator

The oscillator is programmed for frequency and dead time with three components: $R_T$, $C_T$, and $R_D$. Two waveforms are generated: a sawtooth waveform at pin 10 for pulse width modulation, and a logic clock at pin 12. The following procedure is recommended for choosing timing values:

1. With $R_D = 0\Omega$ (pin 11 shorted to ground) select values for $R_T$ and $C_T$ to give the desired oscillator period. Here the frequency at each driver output is half the oscillator frequency, and the frequency at the $+V_C$ terminal is the same as the oscillator frequency.

2. If more dead time is required, then have to select a larger value of $R_D$.

3. Increasing the dead time will cause the oscillator frequency to decrease slightly. To bring the frequency back to the nominal design value has to decrease the value of $R_T$ slightly. The SG1526B can be synchronized to an external logic clock by programming the oscillator to free-run at a frequency 10% slower than the sync frequency. A periodic LOW logic pulse approximately 0.5 mSec wide at the SYNC pin will then lock the oscillator to the external frequency. Multiple devices can be synchronized together by programming one
master unit for the desired frequency, and then sharing its sawtooth and clock waveforms with the slave units.

![Oscillator Connection and Waveforms](image)

**Figure: 3.8: oscillator connection and waveforms**

**Error Amplifier**

The error amplifier is a transconductance design, with an output impedance of 2 MΩ. Since all voltage gain takes place at the output pin, the open-loop gain/frequency characteristics can be controlled with shunt reactance to ground. When compensated for unity-gain stability with 100 pF, the amplifier has an open-loop pole at 400 Hz. The input connections to the error amplifier and determined by the polarity of the switching supply output voltage. For positive supplies, the common-mode voltage is +5.0 volts and the feedback connections in Figure 25A are used. With negative supplies, the common-mode voltage is ground and the feedback divider is connected between the negative output and the +5.0 volt reference voltage, as shown in Figure 25B.

![Error Amplifier Connections](image)

**Figure 3.9: error amplifier connections**
Output Drivers

The totem-pole output drivers of the SG1526B are designed to source and sink 100mA continuously and 200mA peak. Loads can be driven either from the output pins 13 and 16, or from the +V_C pin, as required. The totem-pole outputs cannot be connected together because such a connection might produce excessive current and result in damage to the devices.

![Diagram](image)

Figure 3.10: driving N channel power MOSFET

3.5 Operating Principle

The PWM controller that has been used in the project is designed to operate at 24V dc input voltage. A voltage regulator LM7812C is directly connected to the positive terminal of the input voltage. The voltage regulator gives an output voltage that is necessarily input voltage of the PWM controller chip. Two power MOSFETs, IRFP3710 have been used to run the motor.
From the fig. 4.10 the voltage regulator is directly connected to the positive voltage terminal. When the voltage source is available the regulator gives an output voltage to a reduced value. The diode D4 (D 1N4002) makes the input voltage as forward bias voltage and resists the backward direction current flow. The capacitors C8 and C4 are used for filtering the voltage as well as to support the IC to operate appropriately. When the PWM controller chip gets the input voltage from the voltage regulator then it gives power (output voltage) to the power MOSFETs. Pin no. 1 and 2 of the chip compare the error. If it is more than the limited value then the shut pin (pin no. 3) shuts down and reset the IC as well through reset pin (pin no. 4). The resistance R11 senses the current across the motor through current sense pin (pin no. 6 and 7). If the current is excessively high for the motor that is more than 20A then the current sense pins give a signal to the error pin (pin no 1 and 2) that lead to shuts down the IC and reset as well.

The LED that is connected with the motor in series indicates whether the motor has got the power or not. If the motor gets power the led turn on and increasing the current across the motor, the led glows more brightly. The resistances R12, R13 and capacitors C1, C5 are used to balance the total circuitry operation. Now changing the variable resistance R3 the motor speed can be controlled easily. When the value of R3 is set maximum, the voltage drop across R3 is maximum and the voltage across the motor is minimum as well. It is also for the vice versa. The filter capacitor C7 has been connected across the motor to run out the motor rated velocity.
3.6 Advantages of PWM Controller

- PWM is economical, space saving, and noise immune.
- Improved under voltage lockout
- Single pulse metering one of the advantages of PWM is that the signal remains digital all the way from the processor to the controlled system; no digital-to-analog conversion is necessary. By keeping the signal digital, noise effects are minimized.
- Improve speed control and reduce power losses in the system that increases the mean time between charge cycles of the battery.
- Increased noise immunity is yet another benefit of choosing PWM over analog control, and is the principal reason PWM is sometimes used for communication.
- The PWM switching circuits and synchronous rectification improve the efficiency and increases the speed of the battery-operated motor drive system.
- Protect against reverse polarity and eliminate any voltage spikes.
- Using digital control lines will reduce the susceptibility of the circuit to interference.
- A PWM current can create short pulses of magnetic flux at full strength, which can turn the rotor at extremely slow speeds.

3.7 Summary

The popularity of PWM will continue to grow as the functionality becomes more popular in microcontrollers and development tools make it easier to use. Having a good understanding of PWM will make it easier to incorporate in your designs. And, when you are working on a PWM design, a function generator can be a great tool for creating waveforms. Based on your needs for creating static or dynamic PWM signals, you can select a function generator that has the functionality you need. Static or dc equivalent PWM waveforms can be generated from the front panel of most function generators by varying the duty cycle or using burst mode. For dynamic PWM, you need an arbitrary waveform generator or a function generator with built-in PWM.
Chapter 4

Mobile Signaling for Motor ON and OFF

4.1 Introduction:

Motor switching ON and OFF through Mobile signaling is an interesting feature. In this technique the mobile signaling has been used. The output signal from a successful mobile call with GSM network has been directly connected to the motor in parallel through a relay. This phenomenon provides us to control the motor switching from whatever the distance is.

4.2 Circuit Diagram:

![Circuit Diagram](image)

Figure 4.1: Motor speed control with mobile signaling.

4.3 Operational Mechanism:

From the figure 4.1 the output signal of the power MOSFETs is controlled by mobile signaling through out a relay SRD-12VDC-SL-C. The description of the relay is coming later. Here a GSM network based mobile phone has been used as the source of the controlling signal. The internal terminals are drawn out from the mobile at where a voltage signal is introduced at each receive of successful call. The negative voltage terminal is directly grounded and the positive terminal is connected to the gate terminal of a MOSFET ISD 540. The source of the MOSFET is directly grounded and the drain terminal is
connected to the pin 1 of the relay. The relay consists of five terminals. Pin 3 is connected to the Vcc that ranges to 6-12 volts. And pin 5 is connected to the motor. Pin 2 and 4 act as a switching devices. Pin 2 of the relay is normally connected to the pin 4. When the MOSFET gets enough voltage supply from the positive terminal of the mobile then the MOSFET is turned ON. Then current from the drain flows to the relay that leads a change of connection of the relay pin 2 from pin 4 to pin 5. Now the circuit has a close path, current flows and motor starts to run. Similarly when the MOSFET gets another pulse from the mobile, the relay contact is open and the motor is turned OFF. Thus the motor may switched ON and OFF through the mobile switching.

4.4 Relay SRD-12VDC-SL-C:

A relay SRD-12VDC-SL-C is an electrical switch that opens and closes under the control of another electrical circuit. In the original form the switch is operated by an electromagnet to open and close one or many sets of contacts. When a current flows through the coil, the resulting magnetic field attracts an armature that is mechanically linked to a moving contact. The movement either makes or breaks with a connection with a fixed contact. When the current to the coil is switched off the armature is returned to the force approximately half as strong as the magnetic force to its relaxed position.

Figure 4.2: Disassembled view and internal circuit of Relay SRD-12VDC-SL-C:

Usually this is a spring, but gravity is also commonly used in industrial motor starters. Most relays are manufactured to operate quickly. In low voltage applications, this is used to reduce noise. In a high voltage or high current applications, this is used to reduce arcing. If the coil is energized with DC a diode is frequently installed across the coil to dissipate the energy from the collapsing magnetic field at deactivation, which would otherwise generate a spike of voltage and might cause damage to circuit components. If the coil is designed to be energized with AC, a small copper ring can be crimped to the end of the solenoid. This “shading ring” creates a small out of phase current, which increases minimum pull on the armature during the AC cycle. However these relays are largely used in Domestic
appliance, office machine, audio, equipment, automobile, etc. Some applications are Remote control TV receiver, monitor display, audio equipment with high rushing current

**Feature:**
- Switching capacity available by 10A in spite of small size design for high density P.C. board mounting technique
- Selection of plastic material for high temperature and better chemical solution performance
- Simple relay magnetic circuit to meet low cost of mass production
- UL, CUL, TUV recognized.
- Sealed types available

**4.5 Summary**

In this chapter the operational mechanism and scheme of Mobile Signaling for Motor Switching Control with its main circuit construction has been introduced. The output signal from a successful mobile call has been used to the control the motor switching through a relay. Although the motor controlling through this way is an interesting feature but the problem is that whenever any sms is received, the motor switching action will operate which is totally unexpected. This problem may be solved by adding a microcontroller based circuitry that will lead to sense the acceptable actual signals only for the best operation. However this method provides us to control the motor switching from any distance.
Chapter 5

Speed Control with Thermal Detector

5.1 Introduction

Design and implementation of an automatic motor controller is necessary device in our daily life. Nowadays we want to use our devices works automatically. During summer, the temperature is initially quite high. As time passes, it starts falling and at night it is quite low. In our project, we have design such a circuit that will sense the temperature and the motor speed will be controlled in proportional to the temperature.

Deciding on what temperature sensor to use can be a confusing matter, so this application note will go over some common temperature sensors and show sample circuits of how to integrate each one into a standard Galil analog input. The main four types of temperature sensors are:
- LM35
- RTDs
- Thermistors
- Thermocouple

Temperature can be sensed by all of the above devices. It is important to decide what will ensure a better performance. Now let see their characteristics and recitation to chose the best one.

5.2 Basic Operation

Thermistors

A thermistor is a type of resistor whose resistance varies with temperature. The word is a portmanteau of thermal and resistor. Thermistor are widely used as inrush current limiters, temperature sensors, self-resetting overcurrent protectors, and self-regulating heating elements.

A Thermistor is an inexpensive and readily available temperature sensor that is most commonly used for simple temperature measurements less than 200°C. Like an RTD, a thermistor can be thought of as a resistor that is extra sensitive to changes in temperature. The semiconductor material that a thermistor is made from takes advantage of this property to produce a temperature measurement. However, since the change in resistance is not linear with respect to temperature - an equation must be used to extract the temperature based on the resistance. This is known as the Steinhardt-Hart equation. To get a temperature value from resistance, you can use the following formula:

\[ T = \frac{1}{A + B \ln(R) + C(\ln(R))^3} \]  

(5.1)
where R is in Watts and T in °K.

Because the resistance characteristic drops down with increasing temperature they are called negative temperature coefficient (NTC) sensors

Thermistors differ from resistance temperature detectors (RTD) in that the material used in a thermistor is generally a ceramic or polymer, while RTDs use pure metals. The temperature response is also different; RTDs are useful over larger temperature ranges, while thermistors typically achieve a higher precision within a limited temperature range [usually -90°C to 130°C].

Thermocouples

A thermocouple is based on the “thermoelectric effect” which occurs when two different metals are connected together a voltage is produced that is dependant on the type of metals used and the temperature. In order for the thermal voltage to produce a current, the metals must be connected together at both ends so that a closed circuit is formed. If the temperature is the same at both ends, there is no flow of current. Thus, a thermocouple can only measure temperature differences. For this reason, the reference junction temperature must be known for an accurate measurement to occur. Since the reference temperature point is generally lower than the measured temperature – it is generally called the cold junction. At the “cold junction” or reference junction, an RTD or similar temperature sensor is used to have an accurate reference temperature. The voltage produced by a thermocouple is very small and amounts to only a few microvolts per degree Celsius. Thermocouples are generally not used in applications in the range of -30 to 50°C because the difference between the reference temperature and the measurement temperature is too small to get accurate noise-free signals. However, compared with other sensors – thermocouples offer the clear advantage of a higher upper temperature limit (up to several thousand degrees Celsius) and are therefore frequently used to measure temperatures in ovens, furnaces, etc.

RTDs

An RTD is a Resistive Temperature Device that takes advantage of the fact that a material’s resistance changes as a function of temperature. Most RTD elements consist of a fine coiled wire wrapped around a ceramic or glass core. The RTD element is made from a pure material whose resistance at different temperatures is known. Since the material used has a predictable change in resistance based on temperature – this is used to accurately measure temperature. Typical materials used for RTD’s include: Platinum (most common), Nickel, Copper, Balco, or Tungsten.

Some benefits of RTDs are:

• Wide temperature range (-200 to 850°C)
• Good Accuracy (better than Thermocouples)
• Repeatability and resistance to electrical noise
• Long-Term stability (ie: aging)
RTDs are positive temperature coefficient (PTC) sensors which mean their resistance increases with temperature.

**LM35 Temperature Sensor**

The LM35 temperature sensor is the easiest of all the temperature sensors to use because it is an integrated circuit that outputs a voltage proportional to the temperature in degrees Celsius. The sensor itself takes care of the non-linear effects that occur with some other sensors so the sensor input circuitry is simplified. Another benefit is that the output voltage is higher than other sensors (such as thermocouples) and therefore an amplifier circuit is not necessary. The scale factor for a typical LM35 is 0.01V/°C. It has a typical accuracy of ±1/4°C at room temperature and ±3/4°C over a full −55 to +150°C temperature range. The conversion factor is 100°C/V so a voltage reading of 0.234V is 23.4°C.

The LM35 can be applied easily in the same way as other integrated-circuit temperature sensors. It can be glued or cemented to a surface and its temperature will be within about 0.01°C of the surface temperature.

**Typical Circuit**

![Fig 5.1: circuit construction of LM35 temperature sensor](image)

**Features**

- Calibrated directly in ° Celsius (Centigrade)
- 0.5°C accuracy guaranteeable (at +25°C)
- Rated for full −55° to +150°C range
- Suitable for remote applications
- Low cost due to wafer-level trimming
- Operates from 4 to 30 volts
- Less than 60 μA current drain
- Low self-heating, 0.08°C in still air
Low impedance output, 0.1 W for 1 mA load

Fig 5.2: Disassembled LM35 temperature sensor

**LM324 Low Power Quad Operational Amplifiers**

The LM324 consists of four independent, high gains; internally frequency compensated operational amplifiers which were designed specifically to operate from a single power supply over a wide range of voltages. Operation from split power supplies is also possible and the low power supply current drain is independent of the magnitude of the power supply voltage.

**Features**

- Internally frequency compensated for unity gain.
- Very low supply current drain (700 mA).
- Essentially independent of supply voltage.
- Low input biasing current 45 nA (temperature compensated).
- Low input offset voltage 2 mV and offset current 5 nA.
- Input common-mode voltage range includes ground.

- Differential input voltage range equal to the power supply voltage.
- Large DC voltage gain 100 dB Wide bandwidth (unity gain) 1 MHz (temperature compensated).
- Large output voltage swing 0V to Vab 1.5V.

Application areas include transducer amplifiers, DC gain blocks and all the conventional op amp circuits which now can be more easily implemented in single power supply systems. For example, the LM324 series can be directly operated off of the standard 5V power supply voltage which is used in digital systems and will easily provide the required
interface electronic without requiring the additional 15V power supplies. In the linear mode the input common-mode voltage range includes ground and the output voltage can also swing to ground, even though operated from only a single power supply voltage.

Fig 5.3: Disassembled views of LM324 low power operational amplifier

Internal Block Diagram

Fig 5.4: Internal block diagram of LM324 low power operational amplifier
5.3 Electrical Output Characteristics

Table 5.1 Electrical Output Characteristics of LM 324 for (VCC=5.0V, VEE=GND, TA=25 °C, unless otherwise specified)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Conditions</th>
<th>Min</th>
<th>Type.</th>
<th>Max.</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input offset voltage</td>
<td>( V_{\text{io}} )</td>
<td>VCM=0V to VCC -1.5V, ( V_{\text{O}}(\text{P}) = 1.4V, RS=0\Omega )</td>
<td></td>
<td>1.5</td>
<td>7.0</td>
<td>mV</td>
</tr>
<tr>
<td>Input offset current</td>
<td>( I_{\text{io}} )</td>
<td>VCM=OV</td>
<td></td>
<td>3.0</td>
<td>50</td>
<td>nA</td>
</tr>
<tr>
<td>Input bias current</td>
<td>( I_{\text{bias}} )</td>
<td>VCM=OV</td>
<td></td>
<td>40</td>
<td>250</td>
<td>nA</td>
</tr>
<tr>
<td>Input common mode voltage range</td>
<td>( V_{\text{iR}} )</td>
<td>Note 1</td>
<td>0</td>
<td>VCC</td>
<td>0</td>
<td>V</td>
</tr>
<tr>
<td>Supply current</td>
<td>( I_{\text{cc}} )</td>
<td>( RL = \infty, VCC = 30V ) (all Amps)</td>
<td></td>
<td>1.0</td>
<td>3.0</td>
<td>mA</td>
</tr>
<tr>
<td>Large signal voltage gain</td>
<td>( G_{V} )</td>
<td>( VCC = 15V, RL \geq 2K\Omega ), ( V_{\text{O}}(\text{P}) = 1V \text{ to } 11V )</td>
<td>25</td>
<td>100</td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td>Output voltage swing</td>
<td>CMRR</td>
<td></td>
<td></td>
<td>65</td>
<td>100</td>
<td>V</td>
</tr>
<tr>
<td>Common mode rejection ratio</td>
<td>PSRR</td>
<td></td>
<td></td>
<td>120</td>
<td></td>
<td>dB</td>
</tr>
</tbody>
</table>

Figure 5.5: Output voltage vs. temperature
Table 5.2 Electrical Output Characteristics of LM 324 for (VCC=5.0V, VEE=GND, unless otherwise specified) and over the range of -25 °C ≤ TA ≤ + 85 °C

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Conditions</th>
<th>Min</th>
<th>Type.</th>
<th>Max.</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Offset Voltage</td>
<td>VIO</td>
<td>VICM = 0V to VCC -1.5V and VO(P) = 1.4V, RS = 0 Ω</td>
<td>—</td>
<td>—</td>
<td>9.0</td>
<td>mV</td>
</tr>
<tr>
<td>Input Offset Voltage Drift</td>
<td>ΔVIO/ΔT</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>7.0</td>
<td>μV</td>
</tr>
<tr>
<td>Input Offset Current</td>
<td>ΔIIO</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>150</td>
<td>nA</td>
</tr>
<tr>
<td>Input Offset Current Drift</td>
<td>ΔIIO/ΔT</td>
<td>—</td>
<td>8.0</td>
<td>—</td>
<td>—</td>
<td>pA</td>
</tr>
<tr>
<td>Input Bias Current</td>
<td>IBIAS</td>
<td>—</td>
<td>500</td>
<td>—</td>
<td>—</td>
<td>nA</td>
</tr>
<tr>
<td>Common-Mode Input Voltage</td>
<td>VI(R)</td>
<td>Note1</td>
<td>0</td>
<td>—</td>
<td>—</td>
<td>V</td>
</tr>
<tr>
<td>Large Signal Voltage Gain</td>
<td>GV</td>
<td>VCC = 15V ≥ RL Ω 2.0K Ω to 11V VO(P) = 1V</td>
<td>15</td>
<td>—</td>
<td>—</td>
<td>mV</td>
</tr>
<tr>
<td>Output Voltage Swing</td>
<td>VO(H)</td>
<td>RL = 2K Ω</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>mV</td>
</tr>
</tbody>
</table>

**Why LM324 is preferred over IC741 or other sensor**

1. If we use IC741 as comparator with Vcc=5V and -Vee=0 then for HIGH=4.5V and LOW=1.52, so in both condition transistor will be saturated, so in order to use IC741 as a comparator better apply -15,+15.

2. When LM324 is used with Vcc=5V then HIGH=3.6V (but this is the logic high for digital circuit) and LOW=0. So this will be better, will not be able to get HIGH=5V.

3. In 741 when Vcc=5V,Vee=1.33V then experimentally HIGH=4.0 and LOW=0V.
4. The best way of checking IC741 and IC324 is by using comparator configuration. But in checking case the input voltage to the comparator should be less than the supply voltages used. The output voltage will be some Vcc-2V and -Vee+2V at max.

**5.4 Relation between Temperature and Resistance**

\[ \Delta R = k \Delta T \quad (5.2) \]

Where

\[ \Delta R = \text{change in resistance} \]
\[ \Delta T = \text{change in temperature} \]
\[ k = \text{first-order temperature coefficient of resistance} \]

Thermistor can be classified into two types, depending on the sign of \( k \). If \( k \) is positive, the resistance increases with increasing temperature, and the device is called a positive temperature coefficient (PTC) thermistor, or posistor. If \( k \) is negative, the resistance decreases with increasing temperature, and the device is called a negative temperature coefficient (NTC) thermistor. Resistors that are not thermistor are designed to have a \( k \) as close to zero as possible, so that their resistance remains nearly constant over a wide temperature range.

Instead of the temperature coefficient \( k \), sometimes the temperature coefficient of resistance \( \alpha \) (alpha) or \( \alpha_T \) is used. It is defined as

\[ \alpha_T = \frac{1}{R(T)} \frac{dR}{dT} \quad (5.3) \]

For example, for the common PT100 sensor, \( \alpha = 0.00385 \) or 0.385 \%/°C. This \( \alpha_T \) coefficient should not be confused with the \( \alpha \) parameter below.
<table>
<thead>
<tr>
<th>Resistance (kΩ)</th>
<th>Temperature (degreeF)</th>
<th>Temperature (degree C)</th>
<th>Resistance (kΩ)</th>
<th>Temperature (degreeF)</th>
<th>Temperature (degree C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.05</td>
<td>215</td>
<td>100</td>
<td>2.62</td>
<td>148</td>
<td>64.44</td>
</tr>
<tr>
<td>1.07</td>
<td>208</td>
<td>98.65</td>
<td>2.72</td>
<td>146</td>
<td>63.33</td>
</tr>
<tr>
<td>1.10</td>
<td>207</td>
<td>97.5</td>
<td>2.82</td>
<td>144</td>
<td>62.22</td>
</tr>
<tr>
<td>1.15</td>
<td>204</td>
<td>95.6</td>
<td>2.97</td>
<td>141</td>
<td>60.56</td>
</tr>
<tr>
<td>1.18</td>
<td>202</td>
<td>94.2</td>
<td>3.03</td>
<td>140</td>
<td>60.66</td>
</tr>
<tr>
<td>1.20</td>
<td>200</td>
<td>93.24</td>
<td>3.13</td>
<td>138</td>
<td>58.89</td>
</tr>
<tr>
<td>1.22</td>
<td>199</td>
<td>92.8</td>
<td>3.25</td>
<td>136</td>
<td>57.78</td>
</tr>
<tr>
<td>1.24</td>
<td>198</td>
<td>92.22</td>
<td>3.31</td>
<td>135</td>
<td>57.22</td>
</tr>
<tr>
<td>1.25</td>
<td>197</td>
<td>91.67</td>
<td>4.51</td>
<td>118</td>
<td>47.78</td>
</tr>
<tr>
<td>1.28</td>
<td>195</td>
<td>90.56</td>
<td>5.02</td>
<td>112</td>
<td>44.44</td>
</tr>
<tr>
<td>1.30</td>
<td>194</td>
<td>90.00</td>
<td>5.87</td>
<td>104</td>
<td>40.05</td>
</tr>
<tr>
<td>1.40</td>
<td>188</td>
<td>86.67</td>
<td>6.17</td>
<td>101</td>
<td>38.38</td>
</tr>
<tr>
<td>1.42</td>
<td>187</td>
<td>86.12</td>
<td>7.07</td>
<td>94</td>
<td>34.44</td>
</tr>
<tr>
<td>1.44</td>
<td>186</td>
<td>85.55</td>
<td>8.12</td>
<td>87</td>
<td>30.56</td>
</tr>
<tr>
<td>1.5</td>
<td>193</td>
<td>83.88</td>
<td>9.17</td>
<td>81</td>
<td>27.22</td>
</tr>
<tr>
<td>1.55</td>
<td>181</td>
<td>82.78</td>
<td>10.17</td>
<td>76</td>
<td>24.44</td>
</tr>
<tr>
<td>1.58</td>
<td>179</td>
<td>81.66</td>
<td>11.07</td>
<td>72</td>
<td>22.22</td>
</tr>
<tr>
<td>1.65</td>
<td>176</td>
<td>79.45</td>
<td>11.55</td>
<td>70</td>
<td>21.47</td>
</tr>
<tr>
<td>1.70</td>
<td>174</td>
<td>78.89</td>
<td>12.06</td>
<td>68</td>
<td>20.39</td>
</tr>
<tr>
<td>1.74</td>
<td>173</td>
<td>78.33</td>
<td>12.87</td>
<td>65</td>
<td>18.34</td>
</tr>
<tr>
<td>1.78</td>
<td>171</td>
<td>77.20</td>
<td>13.15</td>
<td>64</td>
<td>17.78</td>
</tr>
<tr>
<td>1.81</td>
<td>170</td>
<td>76.65</td>
<td>14.05</td>
<td>61</td>
<td>16.11</td>
</tr>
<tr>
<td>1.84</td>
<td>169</td>
<td>76.11</td>
<td>14.36</td>
<td>60</td>
<td>15.56</td>
</tr>
<tr>
<td>1.87</td>
<td>168</td>
<td>75.56</td>
<td>14.69</td>
<td>59</td>
<td>14.44</td>
</tr>
<tr>
<td>1.90</td>
<td>167</td>
<td>75.00</td>
<td>15.70</td>
<td>56</td>
<td>13.35</td>
</tr>
<tr>
<td>1.93</td>
<td>166</td>
<td>74.44</td>
<td>16.42</td>
<td>54</td>
<td>11.76</td>
</tr>
<tr>
<td>1.96</td>
<td>165</td>
<td>73.90</td>
<td>17.58</td>
<td>51</td>
<td>10.56</td>
</tr>
<tr>
<td>2.00</td>
<td>164</td>
<td>73.33</td>
<td>18.39</td>
<td>49</td>
<td>9.44</td>
</tr>
<tr>
<td>2.10</td>
<td>161</td>
<td>71.67</td>
<td>19.25</td>
<td>47</td>
<td>8.33</td>
</tr>
<tr>
<td>2.138</td>
<td>160</td>
<td>71.11</td>
<td>20.63</td>
<td>44</td>
<td>6.67</td>
</tr>
<tr>
<td>2.21</td>
<td>158</td>
<td>70.00</td>
<td>21.60</td>
<td>42</td>
<td>5.56</td>
</tr>
<tr>
<td>2.32</td>
<td>155</td>
<td>68.33</td>
<td>22.62</td>
<td>40</td>
<td>4.44</td>
</tr>
<tr>
<td>2.41</td>
<td>153</td>
<td>67.22</td>
<td>23.69</td>
<td>38</td>
<td>3.33</td>
</tr>
<tr>
<td>2.51</td>
<td>151</td>
<td>66.11</td>
<td>25.99</td>
<td>34</td>
<td>1.11</td>
</tr>
<tr>
<td>2.58</td>
<td>150</td>
<td>65.56</td>
<td>26.61</td>
<td>33</td>
<td>0.56</td>
</tr>
</tbody>
</table>
Graph of R-T Values

Figure 5.6: Resistance vs. temperature
5.5 Typical Circuit and Operating Principle:

![Figure 5.7: Typical Circuit of motor Speed Control with Thermal Detector](image)

**Operating Principle**

Here LM 35 has been used as temperature sensor and LM324 as Low Power Operational Amplifiers. The LM 35 has three terminals. From the above figure pin No1 is connected to the Vcc = 5V DC. And pin no2 is directly grounded. When the sensor gets the input voltage then it gives the output to the LM324 Low Power Operational Amplifier. The output of the thermal sensor is directly proportional to the present temperature. When temperature increases the output voltage also increase and the vice versa. When the LM324 Amplifiers input terminal that is pin no. 3 get the input from the thermal sensor then the voltage is amplified to a necessary value in order to run the motor. Here the pin no. 12 and 13, pin no8 and 9 are shorted to let the amplifier chip properly. A resistance is connected parally with pin no 1 and 2 in order protect the output voltage from over flow. Now easily the motor or fan may run with a speed linearly proportional to the temperature.
5.6 Summary

In this chapter the operation principle and method of motor Speed Control with thermal detector with its main circuit construction has been introduced. Also electrical output characteristics of the thermal elements of the main circuit are discussed. From the output characteristics we may get an idea that for which temperature and resistance what will be the output voltage of the amplifier circuit.
6.1 Introduction

PWM controller and thermal detector, both are important techniques of controlling the motor speed. It may more efficient and useful when these two mechanisms are added together in a single circuit design and operates simultaneously. Moreover with the introduction of mobile switching for motor ON – OFF, it makes the project interesting. Therefore, the motor speed may be controlled then both manually and automatically and also at the same time the motor power switch from a large distance.

6.2 Circuit Design of an Implemented Circuit

![Implemented circuit design of Motor Speed Control with thermal detection and mobile signaling.](image-url)
6.3 Operating Mechanism

From the modified circuit the motor speed may control by PWM controller and the thermal detector at the same time. Here the PWM controller acts as manual speed control technique and the thermal detector as automatic control. The PWM controller that has been used in the project is designed to operate at 24V dc input voltage. A voltage regulator LM7812C is directly connected to the positive terminal of the input voltage. The voltage regulator gives an output voltage that is necessarily input voltage of the PWM controller chip. To get the clear concept it is necessary to know the voltage regulator that is described later.

The diode D4 (D 1N4002) resists the backward direction current flow. The capacitors C8 and C4 are used for filtering the voltage. When the PWM controller chip gets the input voltage from the voltage regulator then it gives power (output voltage) to the power MOSFETs IRF 3710 that consists advanced processing techniques to achieve extremely low on-resistance combined with the fast switching speed and ruggedized device. The description of the power MOSFETs IRF 3710 is coming later with detail. Pin no. 1 and 2 of the chip compare the error. If it is more than the limited value then the shut pin (pin no. 3) shuts down and reset the IC. The resistance R11 senses the current across the motor. The current sense pins give a signal to the error pin (pin no 1 and 2).that lead to shut down the IC and reset if the current is excessively high for the motor that is more than 20A.

The LED that is connected with the motor in series indicates whether the motor has got the power or not. The resistances R12, R13 and capacitors C1, C5 are used to balance the total circuitry operation. Now changing the variable resistance R3 the motor speed can be controlled easily. When the value of R3 is set maximum, the voltage drop across R3 is maximum and the voltage across the motor is minimum as well.

For motor speed control with thermal detection, here LM 35 has been used as temperature sensor and LM324 as Low Power Operational Amplifiers. When the sensor gets the input voltage then it gives the output to the LM324 Low Power Operational Amplifier. The output of the thermal sensor is directly proportional to the present temperature. When temperature increases the output voltage also increases. When the LM324 Amplifiers input terminal that is pin no. 3 get the input from the thermal sensor then the voltage is amplified to a necessary value in order to run the motor. A resistance is connected prarally with pin no 1 and 2 in order protect the output voltage from over flow.

For motor switching control by mobile signaling, the output signal of the power MOSFETs has been directed through out a relay SRD-12VDC-SL-C. Here a GSM network based mobile phone has been used as the source of the controlling signal. The internal voltage terminals are drawn out from the mobile. The negative voltage terminal is directly grounded and the positive terminal is connected to the gate terminal of a MOSFET ISD 540. The source of the MOSFET is directly shorted and the drain terminal is connected to the pin 1 of the relay. Pin 3 is connected to the Vcc that ranges to 6-12 volts. And pin 5 is connected to the motor. Pin 2 and 4 act as a switching devices. Pin 2 of the relay is normally connected to the pin 4. When the MOSFET gets enough voltage supply from the positive terminal of the mobile then the MOSFET is turned ON. Then current from the
drain flows to the relay that leads a change of connection of the relay pin 2 from pin 4 to pin 5. Now the circuit has a close path, current flows and motor starts to run. Similarly when the MOSFET gets another pulse from the mobile, the relay contact is open and the motor is turned OFF. Through out this method the mobile signaling the motor switching is controlled.

### 6.4 LM 7812-C voltage regulator

The LM7812-C is three terminal regulators that provide a fixed output voltage making them useful in a wide range of applications. One of these is local on card regulation, eliminating the distribution problems associated with single point regulation. The voltages available allow these regulators to be used in logic systems, instrumentation, and other solid state electronic equipment. Although designed primarily as fixed voltage regulators these devices can be used with external components to obtain adjustable voltages and currents. Current limiting is included to limit the peak output current to a safe value. Safe area protection for the output transistor is provided to limit internal power dissipation. If internal power dissipation becomes too high for the heat sinking provided, the thermal shutdown circuit takes over preventing the IC from overheating. It is not necessary to bypass the output, although this does improve transient response. Input bypassing is needed only if the regulator is located far from the filter capacitor of the power supply. For output voltage other than 5V, 12V and 15V the LM117 series provides an output voltage range from 1.2V to 57V.

The LM7812-C allows over 1.0A load current if adequate heat sinking is provided. Current limiting is included to limit the peak output current to a safe value. Safe area protection for
the output transistor is provided to limit internal power dissipation. If internal power dissipation becomes too high for the heat sinking provided, the thermal shutdown circuit takes over preventing the IC from overheating. Considerable effort was expanded to make the LM7812-C regulators easy to use and minimize the number of external components. It is not necessary to bypass the output, although this does improve transient response. Input bypassing is needed only if the regulator is located far from the filter capacitor of the power supply.

![Circuit block diagram of LM 7812-C voltage regulator](image)

**Figure 6.3: Circuit block diagram of LM 7812-C voltage regulator**

**Basic features:**

- Output current in excess of 1A
- Internal thermal overload protection
- No external components required
- Output transistor safe area protection
- Internal short circuit current limit
- Available in the aluminum TO-3 package
- Output voltage ranges from 1.2V to 57V.

**Table 6.1 Electrical Output Characteristics of L7812 (refer to the test circuits, \( T_J = -55 \) to 150°C, \( V_I = 19V \), \( I_o = 500mA \), \( C_I = 0.33 \mu F \), \( C_o = 0.1 \mu F \) unless otherwise specified).**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>parameter</th>
<th>Min</th>
<th>Type</th>
<th>Max</th>
<th>Unit</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>( V_o )</td>
<td>Output Voltage</td>
<td>11.5</td>
<td>12.0</td>
<td>12.5</td>
<td>V</td>
<td>( T_J = 25°C )</td>
</tr>
<tr>
<td>( V_o )</td>
<td>Output Voltage</td>
<td>11.4</td>
<td>12.0</td>
<td>12.6</td>
<td>V</td>
<td>( I_o = 5 ) mA - 1 A ( V_I = 15.5 ) to</td>
</tr>
</tbody>
</table>
### Table: MOSFET Characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value 1</th>
<th>Value 2</th>
<th>Value 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta V_o$</td>
<td>Line Regulation</td>
<td></td>
<td></td>
<td>120 mV</td>
</tr>
<tr>
<td>$\Delta V_o$</td>
<td>Load Regulation</td>
<td></td>
<td></td>
<td>100 mV</td>
</tr>
<tr>
<td>$I_D$</td>
<td>Quiescent Current</td>
<td></td>
<td></td>
<td>6.0 mA</td>
</tr>
<tr>
<td>$\Delta I_D$</td>
<td>Quiescent Current Change</td>
<td></td>
<td></td>
<td>0.5 mA</td>
</tr>
<tr>
<td>$\Delta V_D/\Delta T$</td>
<td>Output Voltage Drift</td>
<td></td>
<td>1.5</td>
<td>1.5 mV/°C</td>
</tr>
</tbody>
</table>

### 6.5 IRF 3710 Power MOSFET:

We all know how to use a diode to implement a switch. But we can only switch with it, not gradually control the signal flow. Furthermore, a diode acts as a switch depending on the direction of signal flow; we can’t program it to pass or block a signal. For such applications involving either “flow control” or programmable on/off switching we need a 3-terminal device, which is the bipolar transistor. When the bipolar transistor scaled-up for power applications starts showing some annoying limitations. Transistors are still used in some UPSs, motor controls or welding robots but their usage is practically limited to less than 10 kHz. In this circumstance the Power MOSFET provides great performance that leads to its vast area of application.

Discrete power MOSFETs employ semiconductor processing techniques that are similar to those of today's VLSI circuits, although the device geometry, voltage and current levels are significantly different from the design used in VLSI devices. The metal oxide semiconductor field effect transistor (MOSFET) is based on the original field-effect transistor introduced in the 70s. The invention of the power MOSFET was partly driven by the limitations of bipolar power junction transistors (BJTs) which, until recently, were the device of choice in power electronic applications. The bipolar power transistor is a current controlled device. A large base drive current as high as one-fifth of the collector current is required to keep the device in the ON state. Also, higher reverse base drive currents are required to obtain fast turn-off. Despite the very advanced state of manufacturability and lower costs of BJTs, these limitations have made the base drive circuit design more complicated and hence more expensive than the power MOSFET.

Another BJT limitation is that both electrons and holes contribute to conduction. Presence of holes with their higher carrier lifetime causes the switching speed to be several orders of magnitude slower than for a power MOSFET of similar size and voltage rating. Also, BJTs suffer from thermal runaway. Their forward voltage drop decreases with increasing temperature causing diversion of current to a single device when several devices are
paralleled. Power MOSFETs, on the other hand, are majority carrier devices with no minority carrier injection. They are superior to the BJTs in high frequency applications where switching power losses are important. Plus, they can withstand simultaneous application of high current and voltage without undergoing destructive failure due to second breakdown. Power MOSFETs can also be paralleled easily because the forward voltage drop increases with increasing temperature, ensuring an even distribution of current among all components.

**Figure 6.4: IRF 3710 Power MOSFET**

Advanced HEXFET® Power MOSFETs from International Rectifier utilize advanced processing techniques to achieve extremely low on-resistance per silicon area. This benefit combined with the fast switching speed and ruggedized device design that HEXFET power MOSFETs are well known for, provides the designer with an extremely efficient and reliable device for use in a wide variety of applications. This is universally preferred for all commercial-industrial applications at power dissipation levels to approximately 50 watts. The low thermal resistance and low package cost contribute to its wide acceptance throughout the industry.

The high voltage power MOSFETs that are available today are N-channel, enhancement-mode, double diffused, Metal-Oxide-Silicon, Field Effect Transistors. They perform the same function as NPN, bipolar junction transistors except the former are voltage controlled in contrast to the current controlled bi-polar devices. Today MOSFETs owe their ever-increasing popularity to their high input impedance and to the fact that being a majority carrier device; they do not suffer from minority carrier storage time effects or second breakdown. An understanding of the operation of MOSFETs can best be gleaned by first considering the later MOSFET shown in Figure 6.5 With no electrical bias applied to the gate G, no current can flow in either direction underneath the gate because there will always be a blocking PN junction. When the gate is forward biased with respect to the source S, the free hole carriers in the p-epitaxial layer are repelled away from the gate area creating a channel, which allows electrons to flow from the source to the drain.
Threshold voltage

Threshold voltage, $V_{th}$, is defined as the minimum gate electrode bias required strongly inverting the surface under the poly and forming a conducting channel between the source and the drain regions. $V_{th}$ is usually measured at a drain-source current of 250mA. Common values are 2-4V for high voltage devices with thicker gate oxides, and 1-2V for lower voltage, logic-compatible devices with thinner gate oxides. With power MOSFETs finding increasing use in portable electronic and wireless communications where battery power is at a premium, the trend is toward lower values of $R_{DS(on)}$ and $V_{th}$.

Breakdown voltage

Breakdown voltage, $BVDSS$, is the voltage at which the reverse-biased body-drift diode break down and significant current starts to flow between the source and drain by the avalanche multiplication process, while the gate and source are shorted together. $BVDSS$ is normally measured at 250mA drain current. For drain voltages below $BVDSS$ and with no bias on the gate, no channel is formed under the gate at the surface and then drain voltage is entirely supported by the reverse-biased body-drift p-n junction. Two related phenomena can occur in poorly designed and processed devices punch-through and reach-through. Punchthrough is observed when the depletion region on the source side of the body-drift p-n junction reaches the source region at drain voltages below the rated avalanche voltage of...
the device. This provides a current path between source and drain and causes a soft breakdown that is shown in figure 6.6.

![Power MOSFET Breakdown characteristics](image)

**Figure 6.6: Power MOSFET Breakdown characteristics**

**Safe area of operation**

The power MOSFET is not subject to forward or reverse bias second breakdown, which can easily occur in bipolar junction transistors. Second breakdown is a potentially catastrophic condition in bi-polar transistors caused by thermal hot spots in the silicon as the transistor turns on or off. However in the MOSFET, the carriers travel through the device much as if it were a bulk semiconductor, which exhibits a positive temperature coefficient. If current attempts to self-constrict to a localized area, the increasing temperature of the spot will raise the spot resistance due to the positive temperature coefficient of the bulk silicon. The ensuing higher voltage drop will tend to redistribute the current away from the hot spot. It is important to note that the safe area boundaries are only thermally limited and exhibit no derating for second breakdown. This shows that while the MOSFET transistor is very rugged, it may still be destroyed thermally by forcing it to dissipate too much power.
Table 6.2 Electrical Output Characteristics of IRF3710 for T=25 °C (unless otherwise specified)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>parameter</th>
<th>Min</th>
<th>Type</th>
<th>Max</th>
<th>Unit</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{DSS}$</td>
<td>Drain-to-Source Breakdown Voltage</td>
<td>100</td>
<td>—</td>
<td>—</td>
<td>V</td>
<td>$V_{GS} = 0V, I_D = 250\mu A$</td>
</tr>
<tr>
<td>$\Delta V_{DSS}$</td>
<td>$V_{GS} = 0V, I_D = 250\mu A$</td>
<td>—</td>
<td>0.13</td>
<td>—</td>
<td>V/°C</td>
<td>Reference to 25°C, $I_D = 1mA$</td>
</tr>
<tr>
<td>$V_{GS}$</td>
<td>Gate Threshold Voltage</td>
<td>2.0</td>
<td>—</td>
<td>4.0</td>
<td>V</td>
<td>$V_{DS} = V_{GS}, I_D = 250\mu A$</td>
</tr>
<tr>
<td>$R_{DS(ON)}$</td>
<td>Static Drain-to-Source On-Resistance</td>
<td>—</td>
<td>—</td>
<td>23</td>
<td>mΩ</td>
<td>$V_{GS} = 10V, I_D = 28A$</td>
</tr>
<tr>
<td>$G_f$</td>
<td>Forward Transconductance</td>
<td>32</td>
<td>—</td>
<td>—</td>
<td>S</td>
<td>$V_{DS} = 25V, I_D = 28A$</td>
</tr>
<tr>
<td>$I_{DSS}$</td>
<td>Drain-to-Source Leakage Current</td>
<td>—</td>
<td>—</td>
<td>25</td>
<td>μA</td>
<td>$V_{DS} = V_{GS}, V_{GS} = 0V$</td>
</tr>
<tr>
<td>$I_{GSS}$</td>
<td>Gate-to-Source Forward Leakage</td>
<td>—</td>
<td>—</td>
<td>100</td>
<td>nA</td>
<td>$V_{GS} = 20V$</td>
</tr>
</tbody>
</table>

**Power dissipation:**

The maximum allowable power dissipation that will raise the die temperature to the maximum allowable when the case temperature is held at 250°C is important. It is given by $P_d$ where:

$$P_d = \frac{T_{j, \text{max}} - 25}{R_{\text{thJC}}}$$  \hspace{1cm} (6.1)

$T_{j, \text{max}} = $ Maximum allowable temperature of the p-n junction in the device (normally 1500°C or 1750°C) $R_{\text{thJC}} = $ Junction-to-case thermal impedance of the device.
6.6 Summary

In this chapter the overall circuit construction and its operation have been described. The significance of this project is how to control a device in various ways with additional, interesting, efficient features and also saving power simultaneously. Here the basic feature, internal circuit and electrical characteristics of LM 7812-C voltage regulator are discussed. The required power to run the motor is drawn by two Power MOSFETs. The advantages of the power MOSFET over bipolar transistor and its operational and electrical characteristics with necessary diagram also have been described in detail.
Chapter 7

Discussions and Conclusions

7.1 Discussions

The problems that occurred during the implementations of the circuit of Motor Speed Controlling Circuit with Thermal Detection and Mobile Signaling have been depicted in this chapter. And also the limitations of our project and some suggestion on the modification of the circuit design have been illustrated in this chapter so that it may be more efficient and applicable for some other sectors.

7.2 Limitations of the Work

We have got the idea of our project through internet and some of our friends. Whenever we went for implementing the circuit design we faced some problems of which some have been solved and others have been done by means of alternate ways. These may be considered the limitations of our project. These are listed briefly below;

· The first thing that has no way to neglect is that we got the main circuit from internet. So the series no of the chips and of some devices were different in our local market and some were totally unavailable.

· Since we used some chips and devices that are quite similar to the actual devices but were not exactly same. Particularly their current ratings were little bit different. So for that the circuit has been limited for the various operations.

· Due to not being available for some devices, if somehow any of them is burned then it is quite difficult to replace it instantly.

· The circuit design is limited for large application area. Here the PWM chip we have used is to operate at maximum 35 vol.

· The circuit is designed for brushless DC motor which is available in small size ie.20 watt and down.

· Though the motor controlling through mobile switching is an interesting feature but the problem is that whenever any sms is received, the motor ON-OFF actions will operate. This action may continue without a control since in GSM mobile network sms will be received automatically by the company which is totally unexpected.
Voltage required for the thermal sensor is different to the voltage supplied to the motor. Therefore it is necessary to connect another dc voltage supply or to reduce the voltage to a value required for the LM35 temperature sensor.

7.3 Suggestions for Future Work

In the central processing unit of a computer we see a fan (motor) running all the time to protect the devices from over heated. But when the pc is just turn on or in stand by mode, the fan runs unnecessarily which is wastage of power. There are so many sectors in our daily life that we are wasting power. By modifying and simulating, the thermal sensor circuit to a more simplifier form, we can easily make it suitable for use in our daily life with both economically and efficiently.

Then the PWM circuit may be modified by a different chip to make the design enable for operating any kind of motor in both AC and DC power supply. Moreover by adding a microcontroller based circuitry in between the PWM circuit and mobile switching it may sense actual signal and sms signal for our accurate operation.

Another possible thing may be is to connect the PWM circuit with the thermal detection circuit in order to operate the parallely. That will lead the motor to control its speed both manually and automatically.

7.4 Conclusions

That is a basic fact that in today’s world costs of all forms of energy are increasing. But every year a vast amount of electric power is wasted. This is a really a big deal particularly for the developing countries as the supply of electricity generation has remained almost static and at the same time demand for power is increasing continuously. Therefore in our project and thesis, we have tried to construct a system design to run a motor with economically, efficiently and also power saving. The device presented here makes the motor to control its speed smoothly. Moreover it will allow the motor to run in accordance to the necessary speed. Additionally we can also switch the motor ON and OFF from any distance.
References


