CHAPTER 4
CHAPTER 4
HARDWARE FEATURES

4.1 Introduction

The present work is implemented using the embedded ARM processor. The block diagram and the circuit diagrams are shown in Figures 4.1 and 4.2 respectively. And also the Photographs of a complete experimental setup and the circuit along with ARM7TDMI Evaluation Board are shown in Figures 4.3 and 4.4. Here the LPC2378 is the 32 bit embedded processor (made by Philips). The temperature is sensed by the sensor LM35. This analog data is converted to digital data by using the 10-bit on-chip ADC. A brushless DC motor is used for the fan to cool the temperature of the VLSI chip. The pulse width modulated signal generated by the processor is fed to the H-bridge in turn it runs the Fan motor. Depending on the temperature sensed by the sensor, the speed of the fan is either increased or decreased. Finally the output is displayed on 128x64 Pixels Graphics LCD, which is interfaced to the LPC2378 processor [37]. The same result is also observed on the Hyperterminal of the computer using the UART. A facility is also provided to start or stop the fan rotation using the keyboard of the computer.

Fig 4.1: Block Diagram
Fig 4.2: Circuit Diagram
Fig 4.3: Photograph of Complete Experimental Setup

Fig 4.4: Photograph of the Circuit and ARM7TDMI Evaluation Board
4.2 LPC 2378 ARM Processor

4.2.1 General Description

The LPC2387 microcontroller is based on a 16-bit/32-bit ARM7TDMI-S CPU with real-time emulation that combines the microcontroller with 512 kB of embedded high-speed flash memory. A 128-bit wide memory interface and a unique accelerator architecture enable 32-bit code execution at the maximum clock rate. For critical performance in interrupt service routines and DSP algorithms, this increases performance up to 30 % over Thumb mode. For critical code size applications, the alternative 16-bit Thumb mode reduces code by more than 30 % with minimal performance penalty. The LPC2387 is ideal for multi-purpose serial communication applications. It incorporates a 10/100 Ethernet Media Access Controller (MAC), USB full speed device with 4 kB of endpoint RAM, four UARTs, two CAN channels, an SPI interface, two Synchronous Serial Ports (SSP), three I2C interfaces, and an I2S interface. This blend of serial communications interfaces combined with an on-chip 4 MHz internal oscillator, 64 kB SRAM, 16 kB SRAM for Ethernet, 16 kB SRAM for USB and general purpose use, together with 2 kB battery powered SRAM makes this device very well suited for communication gateways and protocol converters. Various 32-bit timers, an improved 10-bit ADC, 10-bit DAC, one PWM unit, a CAN control unit, and up to 70 fast GPIO lines with up to 12 edge or level sensitive external interrupt pins make this microcontroller particularly suitable for industrial control and medical systems [37].

4.2.2 Salient Features

- ARM7TDMI-S processor, running at up to 72 MHz.
- 512 kB on-chip flash program memory with In-System Programming (ISP) and In-Application Programming (IAP) capabilities. Flash program memory is on the ARM local bus for high performance CPU access.
- 64 kB of SRAM on the ARM local bus for high performance CPU access.
- 16 kB SRAM for Ethernet interface. Can also be used as general purpose SRAM.
- 16 kB SRAM for general purpose DMA use also accessible by USB.
- Dual Advanced High-performance Bus (AHB) system that provides for
simultaneous Ethernet DMA, USB DMA, and program execution from on-chip flash with no contention between those functions. A bus bridge allows the Ethernet DMA to access the other AHB subsystem.

- Advanced Vectored Interrupt Controller (VIC), supporting up to 32 vectored interrupts.
- General Purpose AHB DMA controller (GPDMA) that can be used with the SSP serial interfaces, the I2S port, and the Secure Digital/MultiMediaCard (SD/MMC) card port, as well as for memory-to-memory transfers.

**Serial Interfaces**

- Ethernet MAC with associated DMA controller. These functions reside on an independent AHB.
- USB 2.0 full-speed device with on-chip PHY and associated DMA controller.
- Four UARTs with fractional baud rate generation, one with modem control I/O, one with IrDA support, all with FIFO.
- CAN controller with two channels.
- SPI controller.
- Two SSP controllers, with FIFO and multi-protocol capabilities. One is an alternate for the SPI port, sharing its interrupt and pins. These can be used with the GPDMA controller.
- Three I2C-bus interfaces (one with open-drain and two with standard port pins).
- I2S (Inter-IC Sound) interface for digital audio input or output. It can be used with the GPDMA.

**Other Peripherals**

- SD/MMC memory card interface.
- 70 general purpose I/O pins with configurable pull-up/down resistors.
- 10-bit ADC with input multiplexing among 6 pins.
10-bit DAC.

Four general purpose timers/counters with a total of 8 capture inputs and 10 compare outputs. Each timer block has an external count input.

One PWM/timer block with support for three-phase motor control. The PWM has two external count inputs.

Real-Time Clock (RTC) with separate power pin, clock source can be the RTC oscillator or the APB clock.

2 KB SRAM powered from the RTC power pin, allowing data to be stored when the rest of the chip is powered off.

WatchDog Timer (WDT). The WDT can be clocked from the internal RC oscillator, the RTC oscillator, or the APB clock.

Standard ARM test/debug interface for compatibility with existing tools.

Emulation trace module supports real-time trace.

Single 3.3 V power supply (3.0 V to 3.6 V).

Three reduced power modes: idle, sleep, and power-down.

Four external interrupt inputs configurable as edge/level sensitive. All pins on port 0 and port 2 can be used as edge sensitive interrupt sources.

Processor wake-up from Power-down mode via any interrupt able to operate during Power-down mode (includes external interrupts, RTC interrupt, USB activity, Ethernet wake-up interrupt).

Two independent power domains allow fine tuning of power consumption based on needed features.

Each peripheral has its own clock divider for further power saving.

Brownout detect with separate thresholds for interrupt and forced reset.

On-chip power-on reset.

On-chip crystal oscillator with an operating range of 1 MHz to 24 MHz.

4 MHz internal RC oscillator trimmed to 1% accuracy that can optionally be used as the system clock. When used as the CPU clock, does not allow CAN and USB
On-chip PLL allows CPU operation up to the maximum CPU rate without the need for a high frequency crystal. May be run from the main oscillator, the internal RC oscillator, or the RTC oscillator.

Versatile pin function selections allow more possibilities for using on-chip peripheral functions.

4.2.3 Architectural Overview

The block diagram of LPC 2378 is shown in Fig 4.5. The LPC2387 microcontroller consists of an ARM7TDMI-S CPU with emulation support, the ARM7 local bus for closely coupled, high-speed access to the majority of on-chip memory, the AMBA AHB interfacing to high-speed on-chip peripherals, and the AMBA APB for connection to other on-chip peripheral functions. The microcontroller permanently configures the ARM7TDMI-S processor for little-endian byte order. The LPC2387 implements two AHB in order to allow the Ethernet block to operate without interference caused by other system activity. The primary AHB, referred to as AHB1, includes the VIC and GPDMA controller. The second AHB, referred to as AHB2, includes only the Ethernet block and an associated 16 kB SRAM. In addition, a bus bridge is provided that allows the secondary AHB to be a bus master on AHB1, allowing expansion of Ethernet buffer space into off-chip memory or unused space in memory residing on AHB1. In summary, bus masters with access to AHB1 are the ARM7 itself, the GPDMA function, and the Ethernet block (via the bus bridge from AHB2). Bus masters with access to AHB2 are the ARM7 and the Ethernet block. AHB peripherals are allocated a 2 MB range of addresses at the very top of the 4 GB ARM memory space. Each AHB peripheral is allocated a 16 kB address space within the AHB address space. Lower speed peripheral functions are connected to the APB. The AHB to APB bridge interfaces the APB to the AHB. APB peripherals are also allocated a 2 MB range of addresses, beginning at the 3.5 GB address point. Each APB peripheral is allocated a 16 kB address space within the APB address space.
4.2.4 10-bit ADC

The LPC2387 contains one 10-bit successive approximation ADC with six channels.

Features

- 10-bit successive approximation ADC.
- Input multiplexing among 6 pins.
Power-down mode.
Measurement range 0 V to Vi (VREF).
10-bit conversion time $\geq 2.44 \mu s$.
Burst conversion mode for single or multiple inputs.
Optional conversion on transition of input pin or Timer Match signal.
Individual result registers for each ADC channel to reduce interrupt overhead.

4.2.5 UARTs
The LPC2387 contains four UARTs. In addition to standard transmit and receive data lines, UART1 also provides a full modem control handshake interface. The UARTs include a fractional baud rate generator. Standard baud rates such as 115200 can be achieved with any crystal frequency above 2 MHz.

Features
- 16 B Receive and Transmit FIFOs.
- Register locations conform to 16C550 industry standard.
- Receiver FIFO trigger points at 1 B, 4 B, 8 B, and 14 B.
- Built-in fractional baud rate generator covering wide range of baud rates without a need for external crystals of particular values.
- Fractional divider for baud rate control, auto baud capabilities and FIFO control mechanism that enables software flow control implementation.
- UART1 equipped with standard modem interface signals. This module also provides full support for hardware flow control (auto-CTS/RTS).
- UART3 includes an IrDA mode to support infrared communication.

4.2.6 Pulse Width Modulator
The PWM is based on the standard Timer block and inherits all of its features, although only the PWM function is pinned out on the LPC2387. The Timer is designed to count cycles of the system derived clock and optionally switch pins, generate interrupts or perform other actions when specified timer values occur, based on seven match registers. The PWM function is in addition to these features, and is based on match register events. The ability to separately control rising and falling edge locations allows
the PWM to be used for more applications. For instance, multi-phase motor control typically requires three non-overlapping PWM outputs with individual control of all three pulse widths and positions.

Two match registers can be used to provide a single edge controlled PWM output. One match register (PWMMR0) controls the PWM cycle rate, by resetting the count upon match. The other match register controls the PWM edge position. Additional single edge controlled PWM outputs require only one match register each, since the repetition rate is the same for all PWM outputs. Multiple single edge controlled PWM outputs will all have a rising edge at the beginning of each PWM cycle, when an PWMMR0 match occurs.

Three match registers can be used to provide a PWM output with both edges controlled. Again, the PWMMR0 match register controls the PWM cycle rate. The other match registers control the two PWM edge positions. Additional double edge controlled PWM outputs require only two match registers each, since the repetition rate is the same for all PWM outputs.

With double edge controlled PWM outputs, specific match registers control the rising and falling edge of the output. This allows both positive going PWM pulses (when the rising edge occurs prior to the falling edge), and negative going PWM pulses (when the falling edge occurs prior to the rising edge).

Features

- LPC2387 has one PWM block with Counter or Timer operation (may use the peripheral clock or one of the capture inputs as the clock source).
- Seven match registers allow up to 6 single edge controlled or 3 double edge controlled PWM outputs, or a mix of both types. The match registers also allow:
  - Continuous operation with optional interrupt generation on match.
  - Stop timer on match with optional interrupt generation.
  - Reset timer on match with optional interrupt generation.
- Supports single edge controlled and/or double edge controlled PWM outputs. Single edge controlled PWM outputs all go high at the beginning of each cycle unless the output is a constant low. Double edge controlled PWM outputs can
have either edge occur at any position within a cycle. This allows for both positive going and negative going pulses.

- Pulse period and width can be any number of timer counts. This allows complete flexibility in the trade-off between resolution and repetition rate. All PWM outputs will occur at the same repetition rate.
- Double edge controlled PWM outputs can be programmed to be either positive going or negative going pulses.
- Match register updates are synchronized with pulse outputs to prevent generation of erroneous pulses. Software must ‘release’ new match values before they can become effective.
- May be used as a standard timer if the PWM mode is not enabled.
- A 32-bit Timer/Counter with a programmable 32-bit Prescaler.

4.3 LM35 Temperature Sensor

The LM35 series are precision integrated-circuit temperature sensors, whose output voltage is linearly proportional to the Celsius (Centigrade) temperature. The LM35 thus has an advantage over linear temperature sensors calibrated in ° Kelvin, as the user is not required to subtract a large constant voltage from its output to obtain convenient Centigrade scaling. The LM35 does not require any external calibration or trimming to provide typical accuracies of \( \pm 1/4 ^\circ \text{C} \) at room temperature and \( \pm 3/4 ^\circ \text{C} \) over a full \(-55\) to \(+150\)°C temperature range. Low cost is assured by trimming and calibration at the wafer level. The LM35’s low output impedance, linear output, and precise inherent calibration make interfacing to readout or control circuitry especially easy. It can be used with single power supplies, or with plus and minus supplies. As it draws only 60 µA from its supply, it has very low self-heating, less than 0.1°C in still air. The LM35 is rated to operate over a \(-55\)° to \(+150\)°C temperature range, while the LM35C is rated for a \(-40\)° to \(+110\)°C range (\(-10\)° with improved accuracy). The LM35 series is available packaged in hermetic TO-46 transistor packages, while the LM35C, LM35CA, and LM35D are also available in the plastic TO-92 transistor package. The LM35D is also available in an 8-lead surface mount small outline package and a plastic TO-220 package [38].
Features:

- Calibrated directly in ° Celsius (Centigrade)
- Linear + 10.0 mV/°C scale factor
- 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
- Nonlinearity only ±1/4°C typical
- Low impedance output, 0.1 Ω for 1 mA load

Applications

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. This presumes that the ambient air temperature is almost the same as the surface temperature; if the air temperature were much higher or lower than the surface temperature, the actual temperature of the LM35 die would be at an intermediate temperature between the surface temperature and the air temperature. This is especially true for the TO-92 plastic package, where the copper leads are the principal thermal path to carry heat into the device, so its temperature might be closer to the air temperature than to the surface temperature. To minimize this problem, be sure that the wiring to the LM35, as it leaves the device, is held at the same temperature as the surface of interest. The easiest way to do this is to cover up these wires with a bead of epoxy which will insure that the leads and wires are all at the same temperature as the surface, and that the LM35 die’s temperature will not be affected by the air temperature. The TO-46 metal package can also be soldered to a metal surface or pipe without damage. Of course, in that case the V− terminal of the circuit will be grounded to that metal.
Alternatively, the LM35 can be mounted inside a sealed-end metal tube, and can then be dipped into a bath or screwed into a threaded hole in a tank. As with any IC, the LM35 and accompanying wiring and circuits must be kept insulated and dry, to avoid leakage and corrosion. This is especially true if the circuit may operate at cold temperatures where condensation can occur. Printed-circuit coatings and varnishes such as Humiseal and epoxy paints or dips are often used to insure that moisture cannot corrode the LM35 or its connections.

These devices are sometimes soldered to a small light-weight heat fin, to decrease the thermal time constant and speed up the response in slowly-moving air. On the other hand, a small thermal mass may be added to the sensor, to give the steadiest reading despite small deviations in the air temperature [39,40].

4.4 Hantronics HDM64GS12 LCD Graphic Display (128 X 64 Graphic Display)

Due to its thin profile, light weight, low power consumption and easy handling, liquid crystal graphic display modules are used in a wide variety of applications. The HDM64GS12 has a built-in Hitachi HD61202, or Samsung KS107, controller which performs all of the refreshing and data storage tasks of the LCD display. The driving micro-controller is the popular 87C751 [41].

The display is split logically in half. It contains two controllers with controller #1 (Chip select 1) controlling the left half of the display and controller #2 (Chip select 2) controlling the right half. Each controller must be addressed independently. The page addresses, 0-7, specify one of the 8 horizontal pages which are 8 bits (1 byte) high.

4.5 H-bridge Driver

Usually H-bridge is preferred way of interfacing a DC motor. These days many IC manufacturers have H-bridge motor drivers available in the market like L293D is most used H-Bridge driver IC. H-bridge can also be made with the help of transistors and MOSFETs etc. rather of being cheap, they only increase the size of the design board, which is sometimes not required so using a small 16 pin IC is preferred for this purpose [42].
Working Theory of H-Bridge

The name "H-Bridge" is derived from the actual shape of the switching circuit which control the motion of the motor. It is also known as "Full Bridge". Basically there are four switching elements in the H-Bridge as shown in the Fig 4.6.

As you can see in the Fig 4.6 there are four switching elements named as "High side left", "High side right", "Low side right", "Low side left". When these switches are turned on in pairs motor changes its direction accordingly. Like, if we switch on High side left and Low side right then motor rotate in forward direction, as current flows from Power supply through the motor coil goes to ground via switch low side right.

![Fig 4.6: H-Bridge](image)

Similarly, when you switch on low side left and high side right, the current flows in opposite direction and motor rotates in backward direction. This is the basic working of H-Bridge. We can also make a small truth table according to the switching of H-Bridge explained above.
As already said, H-bridge can be made with the help of transistors as well as MOSFETs, the only thing is the power handling capacity of the circuit. If motors are needed to run with high current then lot of dissipation is there. So heat sinks are needed to cool the circuit.

**Features of L293D (Quadruple Half-H Drivers)**

- Featuring Unitrode L293 and L293D Products Now From Texas Instruments
- Wide Supply Voltage Range: 4.5 V to 36 V
- Separate Input-Logic Supply
- Internal ESD Protection
- Thermal Shutdown
- High-Noise-Immunity Inputs
- Functional Replacements for SGS L293 and SGS L293D
- Output Current 1 A Per Channel (600 mA for L293D)
- Peak Output Current 2 A Per Channel (1.2 A for L293D)
- Output Clamp Diodes for Inductive Transient Suppression (L293D)

**Description:**

The L293 and L293D are quadruple high-current half-H drivers. The L293 is designed to provide bidirectional drive currents of up to 1 A at voltages from 4.5 V to 36

<table>
<thead>
<tr>
<th>High Left</th>
<th>High Right</th>
<th>Low Left</th>
<th>Low Right</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>On</td>
<td>Off</td>
<td>Off</td>
<td>On</td>
<td>Motor runs clockwise</td>
</tr>
<tr>
<td>Off</td>
<td>On</td>
<td>On</td>
<td>Off</td>
<td>Motor runs anti-clockwise</td>
</tr>
<tr>
<td>On</td>
<td>On</td>
<td>Off</td>
<td>Off</td>
<td>Motor stops or decelerates</td>
</tr>
<tr>
<td>Off</td>
<td>Off</td>
<td>On</td>
<td>On</td>
<td>Motor stops or decelerates</td>
</tr>
</tbody>
</table>
V. The L293D is designed to provide bidirectional drive currents of up to 600-mA at voltages from 4.5 V to 36 V. Both devices are designed to drive inductive loads such as relays, solenoids, dc and bipolar stepping motors, as well as other high-current/high-voltage loads in positive-supply applications.

All inputs are TTL compatible. Each output is a complete totem-pole drive circuit, with a Darlington transistor sink and a pseudo-Darlington source. Drivers are enabled in pairs, with drivers 1 and 2 enabled by 1,2EN and drivers 3 and 4 enabled by 3,4EN. When an enable input is high, the associated drivers are enabled and their outputs are active and in phase with their inputs. When the enable input is low, those drivers are disabled and their outputs are off and in the high-impedance state. With the proper data inputs, each pair of drivers forms a full-H (or bridge) reversible drive suitable for solenoid or motor applications [42].

On the L293, external high-speed output clamp diodes should be used for inductive transient suppression. A VCC1 terminal, separate from VCC2, is provided for the logic inputs to minimize device power dissipation. The L293 and L293D are characterized for operation from 0°C to 70°C. The pin diagram of L293 D is shown in Fig 4.7.

![Pin diagram of L293D DC Motor Driver](image)

**Fig 4.7: Pin diagram of L293D DC Motor Driver**

4.6. DC Motor

4.6.1 Principle of Motor

All motors require two magnetic fields, one produced by the stationary part of the motor (the *stator, or field*), and one by the rotating part (the *rotor, or armature*). These
are produced either by a winding of coils carrying a current, or by permanent magnets. If
the field is a coil of wire, this may be connected in a variety of ways, which produces
different motor characteristics.

The basic law of a motor, the reason why they rotate, is governed by Fleming’s
left hand rule, as shown in Fig 4.8. This tells you the direction of the force on a wire that
is carrying current when it is in a magnetic field.

![Fleming’s Left hand rule](image)

**Fig 4.8: Fleming’s Left hand rule**

The next Fig 4.9 shows the force acting on a wire carrying current, obeying the
left hand rule:

![Force acting on a wire carrying current](image)

**Fig 4.9: Force acting on a wire carrying current**

If we now bend the wire round in a loop, and place it in a magnetic field caused
by two permanent magnets, we have the situation shown in the diagram below. Here,
both sides of the wire loop will have a force on them, trying to make the wire loop rotate.
The current is applied to the loop through the commutator, which is shown as two pieces
of metal formed into a ring in Fig 4.10. Current is applied to the commutator by stationary graphite blocks, called *brushes*, which rub against the commutator ring.

![Commutator](image)

**Fig 4.10: Commutator**

The loop will continue to rotate anticlockwise (as we see it in the figure) until it is vertical. At this point, the stationary brushes won't be applying current around the loop any more because they will be contacting the gap between the commutator segments, but the inertia of the loop keeps it going a little more, until the DC supply reconnects to the commutator segments, and the current then goes around the loop in the opposite direction. The force though is still in the same direction, and the loop continues to rotate.

This is how DC motors work. In a real motor, there are many wire loops (windings) all at varying angles around a solid iron core. Each loop has its own pair of commutator segments. This block of core and wire loops is called the *rotor* because it rotates, or the *armature*.

### 4.6.2 Brushless DC Motor

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 realised. These motors are now known as brushless dc motors [43].
4.6.3 Theory of DC Motor Speed Control

Now a days DC motors plays a vital role in most of the industrial areas, it can be seen in most of the electronic devices. They are mainly used for the mechanical movements of physical applications such as rolling the bundle of sheets or CD drives, lifts etc.

Many methods evolved to control the revolution of a motor. DC motors can be controlled either by software or directly by hardware. The speed of a DC motor is directly proportional to the supply voltage, so if we reduce the supply voltage from 12 Volts to 6 Volts, the motor will run at half the speed.

The speed controller works by varying the average voltage sent to the motor. It could do this by simply adjusting the voltage sent to the motor, but this is quite inefficient to do. A better way is to switch the motor's supply on and off very quickly. If the switching is fast enough, the motor doesn't notice it, it only notices the average effect.

When you watch a film in the cinema, or the television, what you are actually seeing is a series of fixed pictures, which change rapidly enough that your eyes just see the average effect - movement. Your brain fills in the gaps to give an average effect.

Now imagine a light bulb with a switch. When you close the switch, the bulb goes on and is at full brightness, say 100 Watts. When you open the switch it goes off (0 Watts). Now if you close the switch for a fraction of a second, then open it for the same amount of time, the filament won't have time to cool down and heat up, and you will just get an average glow of 50 Watts. This is how lamp dimmers work, and the same principle is used by speed controllers to drive a motor. When the switch is closed, the motor sees 12 Volts, and when it is open it sees 0 Volts. If the switch is open for the same amount of time as it is closed, the motor will see an average of 6 Volts, and will run more slowly accordingly.

As the amount of time that the voltage is on increases compared with the amount of time that it is off, the average speed of the motor increases.

This on-off switching is performed by power MOSFETs. A MOSFET (Metal-Oxide-Semiconductor Field Effect Transistor) is a device that can turn very large currents on and off under the control of a low signal level voltage.
The time that it takes a motor to speed up and slow down under switching conditions is dependant on the inertia of the rotor (basically how heavy it is), and how much friction and load torque there is. The graph (Fig 4.11) below shows the speed of a motor that is being turned on and off fairly slowly:

![Graph showing speed of a motor based on supply voltage.](image-url)

**Fig 4.11: Speed of a Motor based on Supply Voltage**

You can see that the average speed is around 150, although it varies quite a bit. If the supply voltage is switched fast enough, it won’t have time to change speed much, and the speed will be quite steady. This is the principle of switch mode speed control. Thus the speed is set by PWM – Pulse Width Modulation.

### 4.6.4 Pulse Width Modulation

Pulse width modulation is a technique for reducing the amount of power delivered to a DC motor. Instead of reducing the voltage operating the motor (which would reduce its power), the motor’s power supply is rapidly switched on and off. The percentage of time that the power is on determines the percentage of full operating power that is accomplished. This type of motor speed control is easier to implement with digital circuitry. It is typically used in mechanical systems that will not need to be operated at full power all of the time. For an ELEC 201 robot, this would often be a system other than the main drivetrain or when the main drivetrain is steered.
Fig 4.12: Example of Several Pulse Width Modulation Waveforms

Fig 4.12 illustrates this concept, showing pulse width modulation signals to operate a motor at 75%, 50%, and 25% of the full power potential.

4.6.5 Applications of DC Motor

Brushless dc motors are widely used in various applications. Two examples of them are illustrated in the following.

Laser Printer

In a laser printer, a polygon mirror is coupled directly to the motor shaft and its speed is controlled very accurately in the range from 5000 to 40,000 rpm. When an intensity modulated laser beam strikes the revolving polygon mirror, the reflected beam travels in different direction according to the position of the rotor at that moment. Therefore, this reflected beam can be used for scanning.

Hard Disk Drive

As the main secondary memory device of the computer, hard disks provide a far greater information storage capacity and shorter access time than either a magnetic tape or floppy disk. 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. 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 [44].