PPU College of Engineering and Technology
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Mechanical Engineering Department

Automotive Engineering

Bachelor Thesis

Graduation Project

Improving Boost Pressure Response Of Turbocharged Diesel Engines

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June, 2012

Abstract

As it is might be aware of, turbochargers display what is known as lag time which is the time needed for the turbine to reach its full throttle from an intermediate rotational speed state. The duration of a turbocharger's lag depends on many factors among which its inertia, airflow efficiency, back pressure, etc.[1]

During lag time the engine is much less responsive and its output well below nominal. To counter the effect of the turbocharger's lag time drivers used to anticipate the engine's reactions by accelerating well before they would have done in a non-turbo car. Others have used a technique known as "left foot braking" where the driver uses his left foot to brake the car while his right foot accelerates to keep the turbocharger in optimal load. Left foot braking is very hard on the brakes which are put into extreme stress but is very efficient in keeping the turbo spinning.

The anti-lag turbocharger system is a technique that allows turbocharged engines to minimize the lag of the turbo in certain situations. As you all probably already know, virtually all turbochargers out there have a "condition" whichdoesn't let them provide their maximum amount of pressure at lower revolution.

So by this system turbo lag will almost completely disappear, since this systemworks with the turbocharger toprovide large amounts of boost pressure and higher volumetric efficiency at acceleration.

كما هو معلوم عن الشواحن الجبرية أنها تظهر ما يعرف بتاخير في عملية بناء ضغط الهواء في مجرى الدخول للمحرك ,حيث ان فراشة التوربينة تحتاج لوقت لبناء عزم القصور الذاتي لبناء هذا الضغط من لحظة الدوس على دواسة الوقود حيث ان عملية التأخير هذه تعتمد على عدد من العوامل وهي عزم القصور الذاتي للفراشة وتدفق الهواء والكفاءة والضغط المعاكس ...الخ .

تؤدي عملية تأخير بناء الضغط هذه الى تاخير استجابة المركبة من حيث الاداء والقدرة على التسارع تحت مختلف الاحمال حيث ان معظم سائقي سيارات السباق التي تعمل بواسطة الشاحن الجبري لضمان استمرار ضغط الهواء , في سيارات السباق ابتكروا تقنية قيادة الرجل اليسرى حيث يتم الدوس على الفرامل بواسطة الرجل اليسرى وابقاء الرجل الاخرى على دواسة الوقود لضمان استمرار ضغط الهواء وبالتالي اداء وسرعه عاليين للمحرك .

نظام تقليل زمن استجابة ضغط الهواء الذي تم تصميمه و بناؤه سوف يقوم بازالة هذه الظاهرة المزعجة , حيث يمكن الشاحن الجبري من ضغط الكمية المناسبة من الهواء تحت أي ظرف أو حمل وبسرعة عالية.

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Chapter

One

Introduction

1.1Overview

In simple terms, a turbocharger consists of a turbine and compressor connected by a common shaft supported on a bearing system.

The turbocharger converts waste energy from exhaust gases into compressed air, an pushes it into the engine. This allows improving efficiency of the combustion process, increasing power of the engine.

So by the system we want to design it, the turbo lag will be significantly reduced, since this system works with the turbocharger provides large amounts of boosts pressure and higher volumetric efficiency at acceleration.

1.2 Backgrounds of the project:

This system consists of mechanical and electrical components like compressors, air tanks, microcontroller …. Etc.

The use of these components is to use them to help the turbocharger to rise to reduce turbo lag.

This operating function depends on the air pressure which can the turbo produce, so, by actuating a compressed air to be produced in the engine manifold anti turbo lag can be produced, which helps the turbo in increasing the inertia of the turbine which means high air pressure can be collected.

1.3 The budget for the project

Table (1.1) Actual budget table for the project

Task	#	COST (NIS)	Total
Turbo diesel vehicle	1	4000	4000
Electronic actuators	3	300	900
Pressure sensors	2	300	600
Pressure tanks	2	100	200
Compressor	1	150	150
Microcontroller (PIC)	1	80	80
		Total	5930 NIS

1.4 The time plan for the project:

The project plan follows the following time schedule which includes the related tasks of study and system analysis. The following time planar for the first semester and second semester.

The time table for the first semester is illustrated in Table 1.1.

Table (1.2): The first semester time plan

Objective	Week #															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Selecting Project title	■	■	■													
Planning and searching for Project data				■	■	■	■									
Completion of calculations								■	■	■	■	■				
Complete content of the project										■	■	■	■			
Collection and order data								■	■	■	■	■	■	■		
Writing project								■	■	■	■	■	■	■	■	
Presentation																■

Table (1.3) the second semester time plan

Task/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
System building	■	■	■	■	■	■	■	■								
Bringing the car		■	■													
Preparing data		■	■						■	■						
Programming the (PIC)											■	■				
Trying to start the system													■			
System test														■		
Recommendations															■	
Conclusions															■	
Project Documentation				■	■	■	■	■	■	■	■	■	■	■	■	■

Chapter

Two

System Components Operating Principles

2.1 Introduction:

Perhaps the best-known engine in the world is the reciprocating internal combustion (IC) engine. Virtually every person who has driven an automobile or pushed a power Lawn mower has used one. By far the most widely used IC engine is the spark-ignition gasoline engine as shown in figure (2-1), which takes us to school and work and on pleasure jaunts. Although others had made significant contributions, Niklaus Otto is generally credited with the invention of the engine and with the statement of its theoretical cycle.

Another important engine is the reciprocating engine that made the name of Rudolf Diesel famous. The Diesel engine, the workhorse of the heavy truck industry, is widely used in industrial power and marine applications. It replaced the reciprocating steam engine in railroad locomotives about fifty years ago and remains dominant in that role today.

The piston, cylinder, crank, and connecting rod provide the geometric basis of the reciprocating engine. While two-stroke-cycle engines are in use and of continuing interest, the discussion here will emphasize the more widely applied four-stroke-cycle engine. In this engine the piston undergoes two mechanical cycles for each thermodynamic cycle.[3]

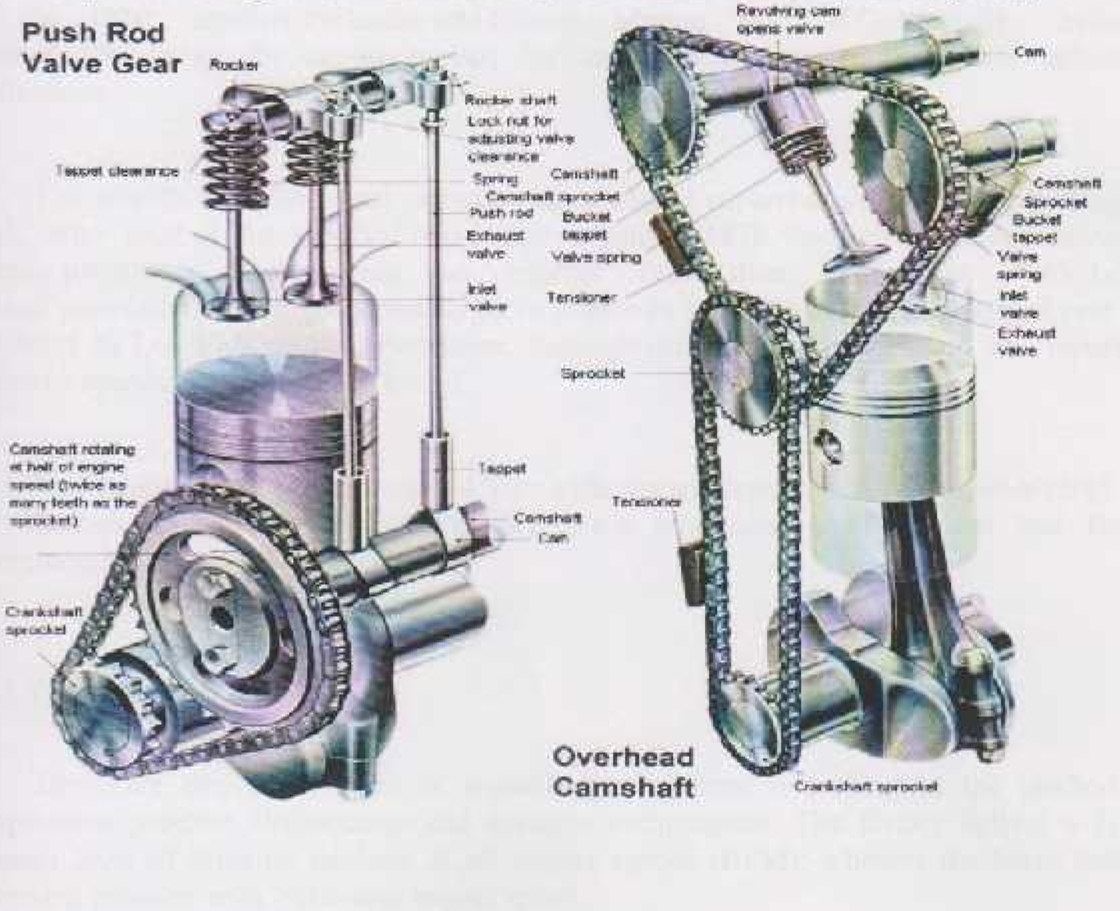


Figure (2-1) Internal Combustion Engines

2.2 Turbo and Super Charging:

2.2.1 Supercharger:

Supercharger is an air compressor used for forced induction of an internal combustion engine. The greater mass flow-rate provides more oxygen to support combustion than would be available in a naturally aspirated engine, which allows more fuel to be burned and more work to be done per cycle, increasing the power output of the engine. Power for the unit can come mechanically by a belt, gear, shaft, or chain connected to the engine's crankshaft.

2.2.2 History:

In 1860, brothers Philander and Francis Marion Roots of Connersville, Indiana, patented the design for an air mover, for use in blast furnaces and other industrial applications.

The world's first functional, actually tested engine supercharger was made by Dugald Clerk, who used it for the first two-stroke engine in 1878. Gottlieb Daimler received a German patent for supercharging an internal combustion engine in 1885. Louis Renault patented a centrifugal supercharger in France in 1902. An early supercharged race car was built by Lee Chadwick of Pottstown, Pennsylvania in 1908, which, it was reported, reached a speed of 100 mph (160 km/h).

The world's first series-produced cars with superchargers were Mercedes 6/25/40 hp and Mercedes 10/40/65 hp. Both models were introduced in 1921 and had Roots superchargers.

2.2.3 Types of supercharger:

There are two main types of superchargers defined according to the method of compression: positive displacement and dynamic compressors. The former deliver a fairly constant level of pressure increase at all engine speeds (RPM), whereas the latter deliver increasing pressure with increasing engine speed.

1) Positive displacement:

Positive-displacement pumps deliver a nearly fixed volume of air per revolution at all speeds (minus leakage, which is almost constant at all speeds for a given pressure, thus its importance decreases at higher speeds). The device divides the air mechanically into parcels for delivery to the engine, mechanically moving the air into the engine bit by bit.

2) Capacity rating:

Positive-displacement superchargers are usually rated by their capacity per revolution. In the case of the Roots blower, the GMC rating pattern is typical. The general motor company [GMC] types are rated according to how many two-stroke cylinders, and the size of those cylinders, it is designed to scavenge.

3) Dynamic:

Dynamic compressors rely on accelerating the air to high speed and then exchanging that velocity for pressure by diffusing or slowing it down.

2.2.4 Supercharger drives types:

Superchargers are further defined according to their method of drive (mechanical-or turbine).

a) Mechanical:

- Belt (V-belt, Synchronous belt, Flat belt).
- Direct drive.
- Gear drive.
- Chain drive.

b) Exhaust gas turbines (Turbocharger discussed later):

- Axial turbine
- Radial turbine [17]

Figure (2-2) shows a screw supercharger and its location on the car engine

2.3 Turbo charger

Turbocharger is a centrifugal compressor powered by a turbine that is driven by an engine's exhaust gases. Its benefit lies with the compressor increasing the mass of air entering the engine (forced induction), thereby resulting in greater performance (for either, or both, power and efficiency). They are popularly used with internal combustion engines (e.g., four-stroke engines like Otto cycles and Diesel cycles). Turbochargers have also been found useful compounding external combustion engines such as automotive fuel cells.

2.3.1 History:

Forced induction dates from the late 19th century, when Gottlieb Daimler patented the technique of using a gear-driven pump to force air into an internal combustion engine in 1885.

The turbocharger was invented by Swiss engineer Alfred Büchi, who received a patent in 1905 for using a compressor driven by exhaust gasses to force air into a piston engine. During the First World War French engineer Auguste Rateau fitted turbochargers to Renault engines powering various French fighters with some success.

In 1918, General Electric engineer Sanford Alexander Moss attached a turbo to a V12 Liberty aircraft engine. The engine was tested at Pikes Peak in Colorado at 14,000 feet (4,300 m) to demonstrate that it could eliminate the power loss usually experienced in internal combustion engines as a result of reduced air pressure and density at high altitude. General Electric called the system turbo supercharging.

Turbochargers were first used in production aircraft engines such as the Napier Lioness in the 1920s, although they were less common than engine-driven centrifugal superchargers. Ships and locomotives equipped with turbocharged Diesel engines began appearing in the 1920s.

In the aviation world, turbochargers were most widely used by the United States, who led the world in the technology due to General Electric's early start. During World War II, notable examples of US aircraft with turbochargers include the B-17 Flying Fortress, B-24 Liberator, P-38 Lightning and P-47 Thunderbolt. The technology was also used in experimental fittings by a number of other manufacturers, notably a variety of Focke-Wulf Fw 190 models, but the need for advanced high-temperature metals in the turbine kept them out of widespread use.

2.3.2 Operating principle:

All naturally aspirated Otto and diesel cycle engines rely on the downward stroke of a piston to create a low-pressure area (less than atmospheric pressure) above the piston in order to draw air through the intake system. With the rare exception of tuned-induction systems, most engines cannot inhale their full displacement of atmospheric-density air. The measure of this loss or inefficiency in four-stroke engines is called volumetric efficiency. If the density of the intake air above the piston is equal to atmospheric, then the engine would have 100% volumetric efficiency. However, most engines fail to achieve this level of performance.

This loss of potential power is often compounded by the loss of density seen with elevated altitudes. Thus, a natural use of the turbocharger is with aircraft engines. As an aircraft climbs to higher altitudes, the pressure of the surrounding air quickly falls off. At 5,486 m (18,000 ft), the air is at half the pressure of sea level, which means that the engine will produce less than half-power at this altitude.

The objective of a turbocharger, just as that of a supercharger, is to improve an engine's volumetric efficiency by increasing the intake density. The compressor draws in ambient air and compresses it before it enters into the intake manifold at increased pressure. This results in a greater mass of air entering the cylinders on each intake stroke. The power needed to spin the centrifugal compressor is derived from the high pressure and temperature of the engine's exhaust gases. The turbine converts the engine exhaust's potential pressure energy and kinetic velocity energy into rotational power, which is in turn used to drive the compressor.

A turbocharger may also be used to increase fuel efficiency without any attempt to increase power. It does this by recovering waste energy in the exhaust and feeding it back into the engine intake. By using this otherwise wasted energy to increase the mass of air, it becomes easier to ensure that all fuel is burned before being vented at the start of the exhaust stage. The increased temperature from the higher pressure gives a higher Carnot efficiency.

The control of turbochargers is very complex and has changed dramatically over the 100-plus years of its use. A great deal of this complexity stems directly from the control and performance requirements of various engines with which it is used. In general, the turbocharger will accelerate in speed when the turbine generates excess power and decelerate when the turbine generates deficient power. Aircraft, industrial diesels, fuel cells, and motor-sports are examples of the wide range of performance requirements. [16]

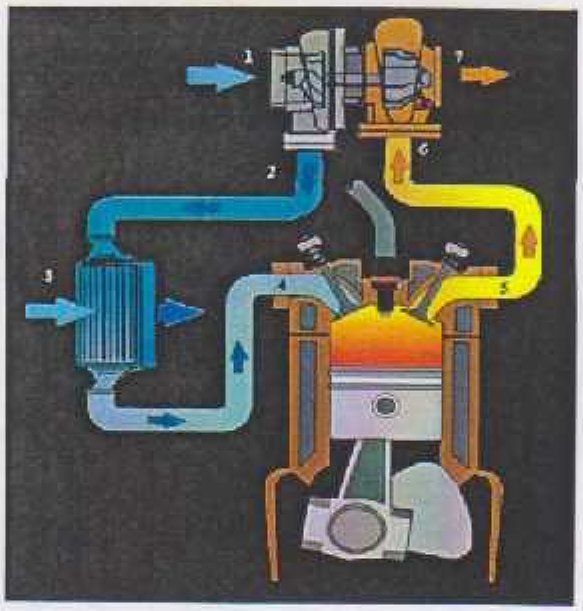


Figure (2-3) shows the main operating components
(1) Compressor inlet (2) compressor outlet (3) air intercooler (4) intake manifold
(5) Exhaust (6) turbine inlet (7) turbine outlet.

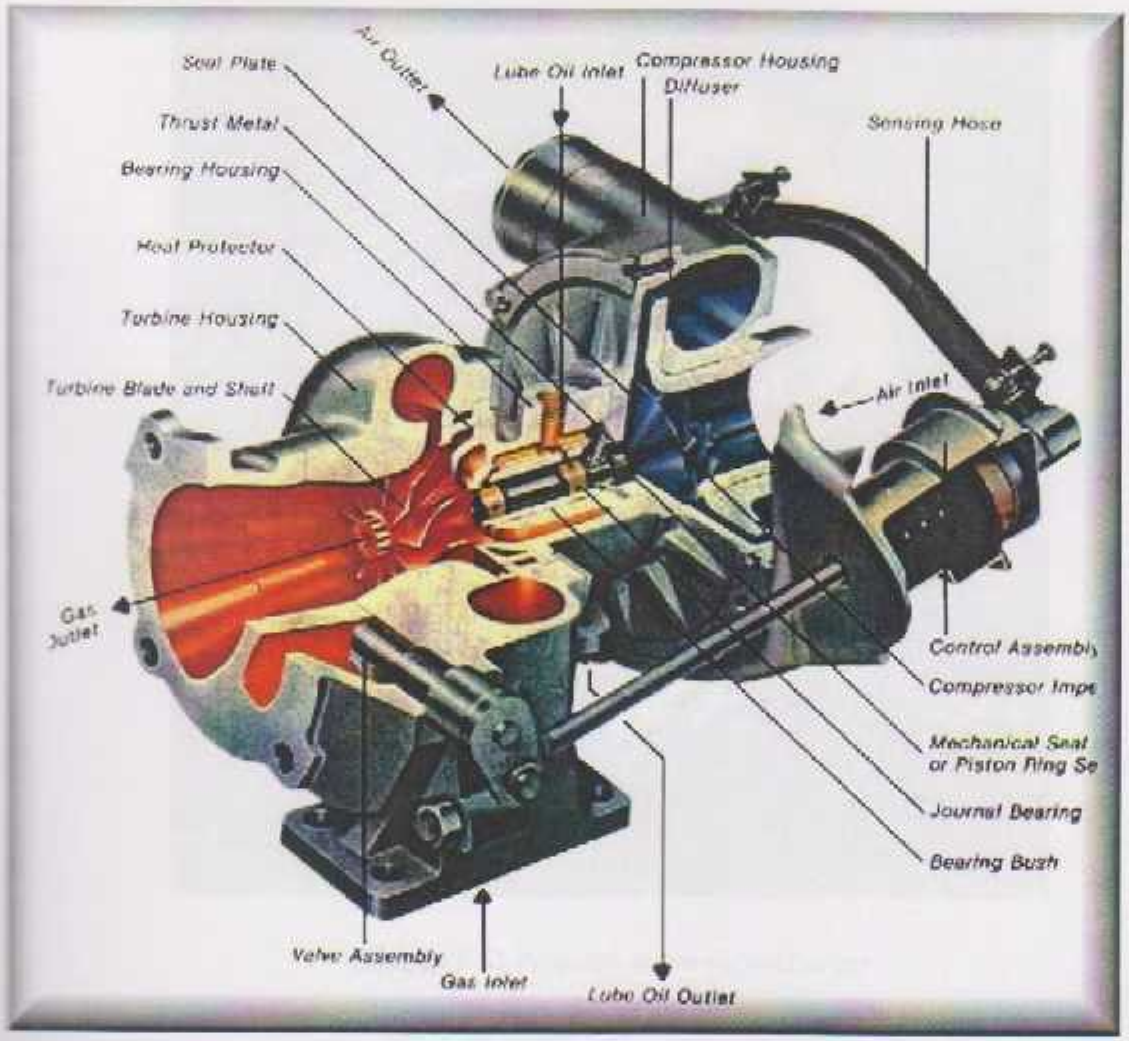


Figure (2-4) shows a cross section of the turbocharger

2.4 Pressure-wave Supercharger

A pressure wave supercharger (also known as a wave rotor) is a type of supercharger technology that harnesses the pressure waves produced by an internal combustion_engine exhaust_gas pulses to compress the intake air. Its automotive use is not widespread; the most widely used example is the Comprex, developed by Brown Boveri Ferrari tested such a device during the development of the126C Formula One car. The system did not lend itself to as tidy an installation as the alternative twin-turbocharger layout, and the car was never raced in this form.

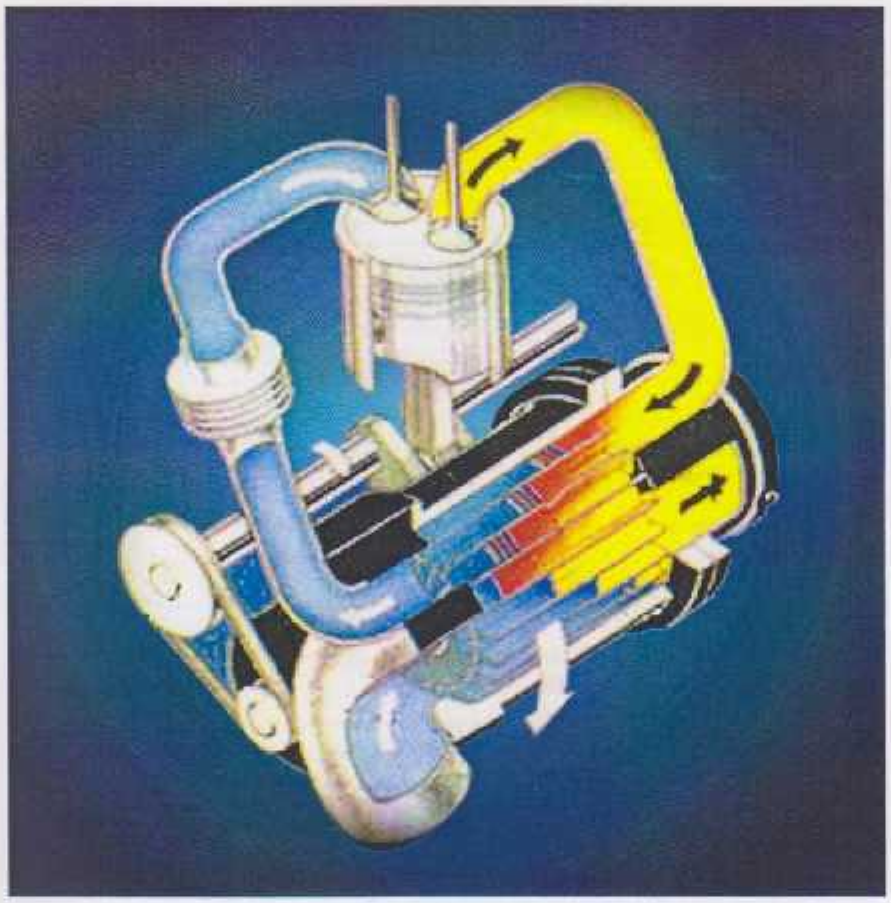


Figure (2-5) Pressure wave supercharger

Many methods have been proposed to control the load without or with reduced throttling. A good way to increase the overall efficiency of an engine-vehicle system is to reduce the engine displacement and to use a supercharger. Today's standard supercharger is the turbocharger, where the enthalpy in the exhaust gas drives a compressor, which in turn raises the pressure in the intake manifold. In a pressure-wave supercharger, one-dimensional unsteady gas dynamical effects are used to transmit the enthalpy in the exhaust gas to the intake air by short-time direct contact of the fluids in narrow flow channels.

Modern pressure-wave supercharging devices offer set the gas pocket valve, the cell-wheel speed, and the offset between air and gas casing as shown in figure (2-6). A multitude of cross-couplings towards the mass flows and, in particular, to the engine torque can be caused thereby

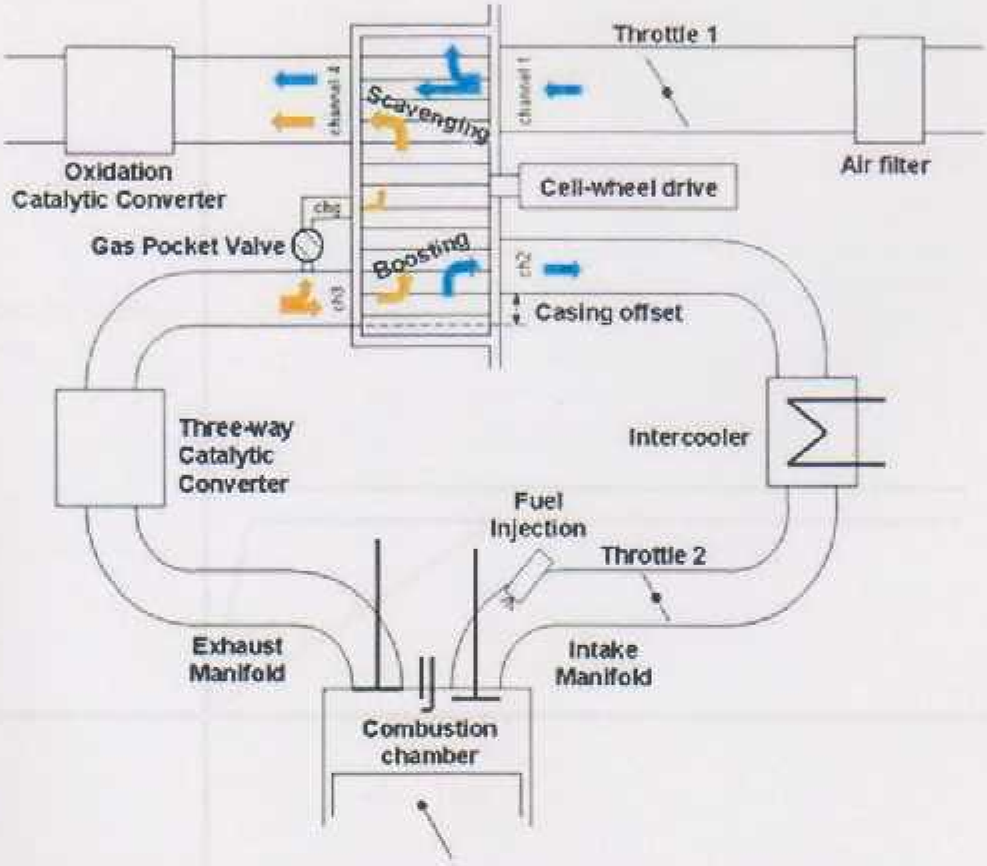


Figure (2-6): Pressure-wave supercharged engine system structure

2.5 Turbocharger time delay (turbo lag):

Turbo lag is the time delay of boost response after pushing on the accelerator pedal when operating above the boost threshold engine speed. Turbo lag is determined by many factors, including turbo size relative to engine size, the state of tuning of the engine, the inertia of the turbo's rotating blades, turbine efficiency, intake plumbing losses, exhaust backpressure, etc.

Boost threshold is the engine speed at which there is sufficient exhaust gas flow to generate positive manifold pressure, or boost.

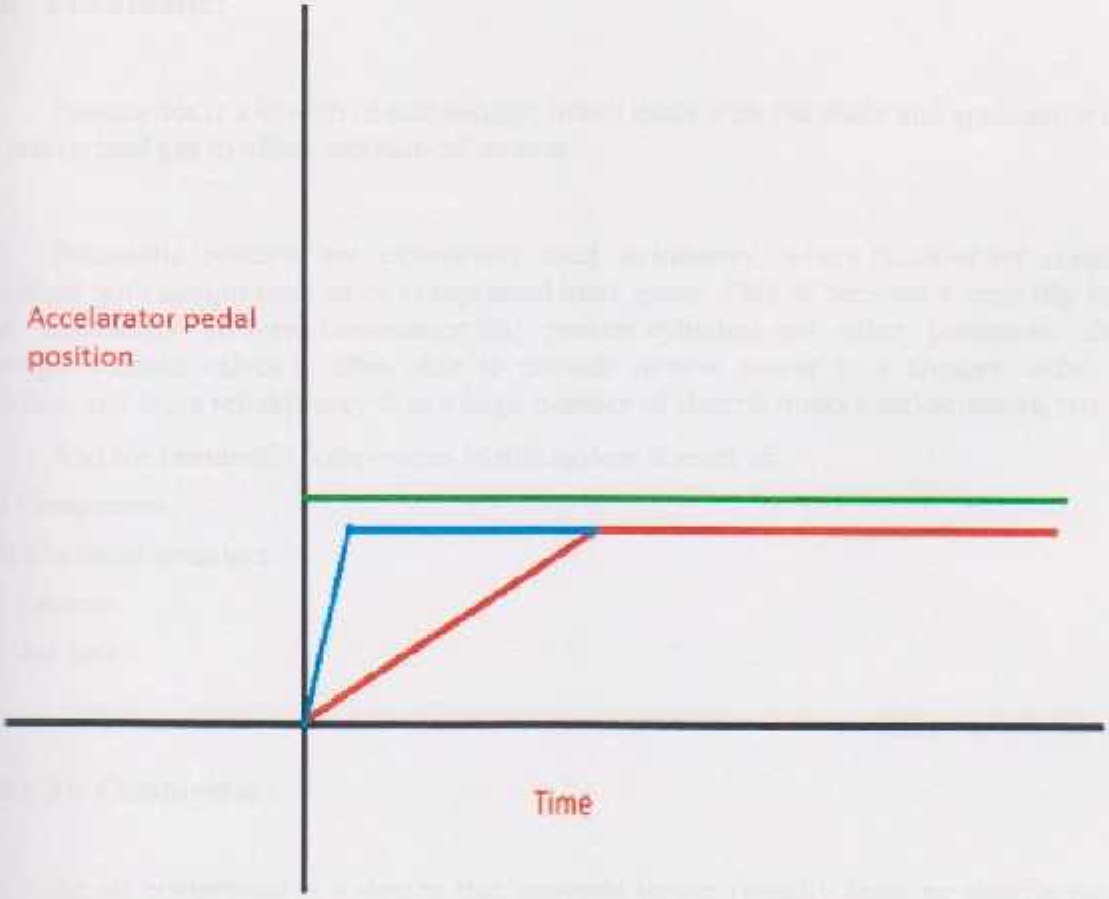


Figure (2-7) shows turbocharger time delay

Red line without applying anti lag system

Blue line with applying anti lag system

The project idea is to inject air previously compressed and stored in an air tank. By opening the flow of this air under a measured pressure under the conditions that make a delay for the turbo charger.

So, sensors and actuators are going to be needed, microcontroller as an Electronic Control Module (ECM), air pressure tanks and there will be an indirect interface between the microcontroller and the cars injection sensors.

The compressor is going to fill the tanks with a compressed air under a constant pressure , there will be a pressure sensor on the air tanks measured the pressure of the air inside the tanks and send it as a signal to the microcontroller , when the pressure rises to the specific pressure the microcontroller stops the work of the compressor and when there is going to be a time delay in the turbo sends an electric signal to a valve actuator which it is occupied on the outlet of the compressor which to fill the pressure of the turbo which has been delayed.

2.6 Pneumatic:

Pneumatics is a branch of technology, which deals with the study and application of use of pressurized gas to effect mechanical motion.

Pneumatic systems are extensively used in industry, where factories are commonly plumbed with compressed air or compressed inert gases. This is because a centrally located and electrically powered compressor that powers cylinders and other pneumatic devices through solenoid valves is often able to provide motive power in a cheaper, safer, more flexible, and more reliable way than a large number of electric motors and actuators. [15]

And the pneumatic components in this system consist of:

(1) Compressor.

(2) Electrical actuators.

(3) Sensors.

(4) Air tanks.

2.6.1 Air Compressor:

An air compressor is a device that converts power (usually from an electric motor, a diesel engine or a gasoline engine) into kinetic energy by compressing and pressurizing air, which, on command, can be released in quick bursts. [14]

Types of compressors:

As shown in Figure 4, there are two basic compressor types: positive-displacement and dynamic. In the positive-displacement type, a given quantity of air or gas is trapped in a compression chamber and the volume it occupies is mechanically reduced, causing a corresponding rise in pressure prior to discharge.

At constant speed, the air flow remains essentially constant with variations in discharge pressure. Dynamic compressors impart velocity energy to continuously flowing air or gas by means of impellers rotating at very high speeds. The velocity energy is changed into pressure energy both by the impellers and the discharge volutes or diffusers.

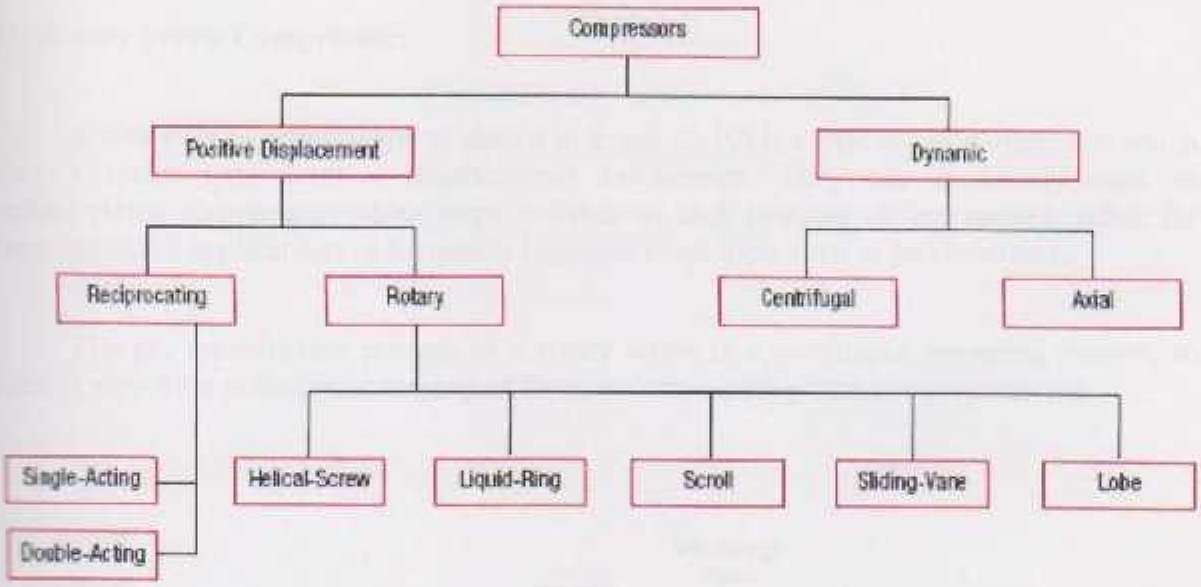


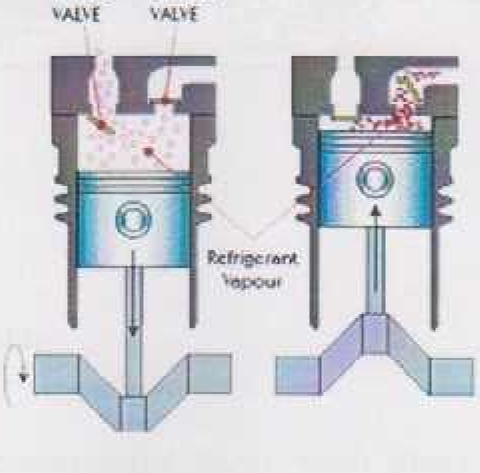
Figure (2-8) Types of Compressors

Type of compressor is going to be used in this system is a Positive Displacement Compressor. These compressors are available in two types: reciprocating and rotary.

1) Reciprocating compressor:

A reciprocating compressor or piston compressor as shown in figure (2-9) is a positive-displacement compressor that uses pistons driven by a crankshaft to deliver gases at high pressure.

The intake gas enters the suction manifold, then flows into the compression cylinder where it gets compressed by a piston driven in a reciprocating motion via a crankshaft, and is then discharged. Applications include Oil refineries, Gas pipelines, chemical plant natural gas processing plants and refrigeration plants. [13]



Figure(2-9)

2) Rotary Screw Compressor:

A rotary screw compressor as shown in figure (2-10) is a type of gas compressor which uses a rotary type positive displacement mechanism. They are commonly used to replace piston compressors where large volumes of high pressure air are needed, either for large industrial applications or to operate high-power air tools such as jackhammers.

The gas compression process of a rotary screw is a continuous sweeping motion, so there is very little pulsation or surging of flow, as occurs with piston compressors. [12]

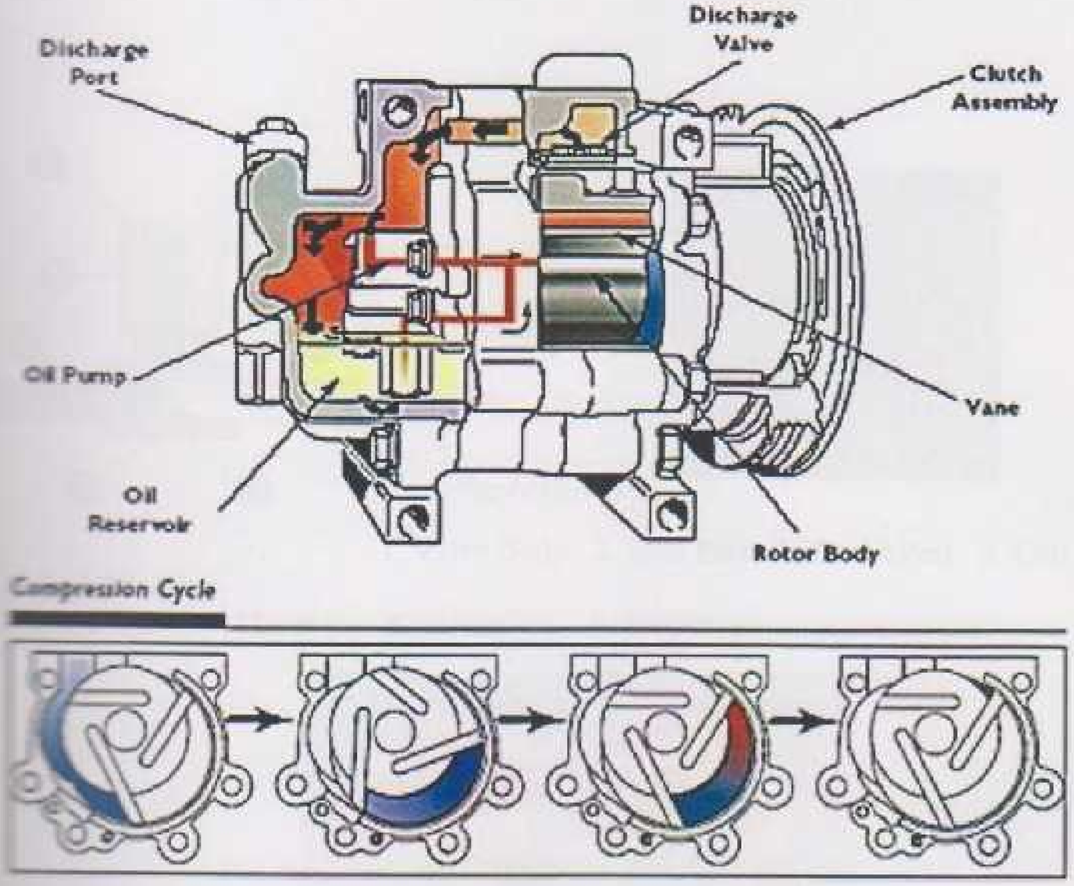


Figure (2-10)

2.6.2 Pressure valve solenoid:

A solenoid is an electromechanical device which allows for an electrical device to control the flow of a gas or liquid. The electrical device causes a current to flow through a coil located on the solenoid valve. This current flow in turn results in a magnetic field which causes the displacement of a metal actuator.

The actuator is mechanically linked to a mechanical valve inside the solenoid valve. The valve then changes state, either opening or closing to allow a liquid or gas to either flow through or be blocked by the solenoid valve. A spring is used to return the actuator and valve back to their resting state when the current flow is removed.

Solenoid valves come in various configurations and sizes. Solenoid valves can be normally open, normally closed. A normally open solenoid valve allows a liquid or gas to flow through unless a current is applied to the solenoid valve. A normally closed valve works in the opposite manner; Figure (2-11) shows the solenoid valve. [11]

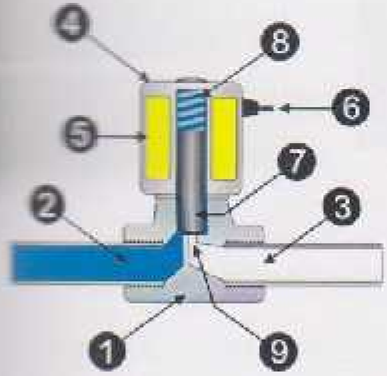


Figure (2-11)

1. Valve Body 2. Inlet Port 3. Outlet Port 4. Coil / Solenoid 5. Coil Windings
6. Lead Wires 7. Plunger 8. Spring 9. Orifice [10]

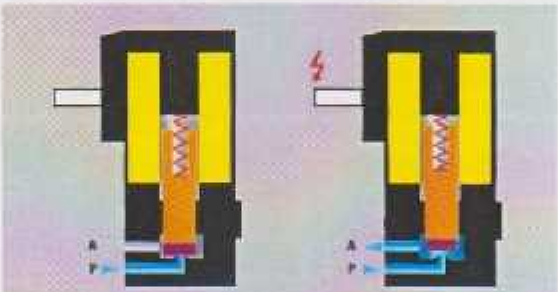
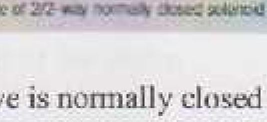


Figure (2-12) A solenoid valve is normally closed (abbreviated - NC) if there is no flow across the valve in its resting position (with no current on the solenoid contacts). And its symbol. [10]



2.6.3 Pressure sensor:

A pressure sensor measures pressure, typically of gases or liquids. Pressure is an expression of the force required to stop a fluid from expanding, and is usually stated in terms of force per unit area. A pressure sensor as show in Figure (2-13) usually acts as a transducer; it generates a signal as a function of the pressure imposed. For the purposes of this article, such a signal is electrical.

Pressure sensors are used for control and monitoring in thousands of everyday Such as fluid/gas flow, speed, water level, and altitude, applications Pressure sensors can also be used to indirectly measure other variables. [9]

Figure (2-13)

2.6.4 Air pressure tanks:

The tanks must be designed to safety standards appropriate for a pressure vessel as shown in the figure (2-14).

The storage tank may be made of:

- Steel,
- Aluminum,
- Carbon fiber,
- Kevlar,
- Other materials or combinations of the above.

The fiber materials are considerably lighter than metals but generally more expensive. Metal tanks can withstand a large number of pressure cycles, but must be checked for corrosion periodically. [7]

HTS-24

Figure (2-14)

2.7 Microcontroller (PIC 18F4550):

The PIC18F4550 family member come in different packages, such as DIP (dual in line package),QFP (quad flat package), and LLC (leadless chip carrier). They all have many pains that are dedicated to various functions such as I/O, ADC, timer, and interrupts. Note that Microchip provides an 18-pin version of the PIC18 family with a reduced number of I/O ports for less demanding applications. Because the vast majority of developers use the 40-pin chip, however, we will concentrate on that. Figure (3-11) shoes the pins for the PIC18F4550.

Figure (2-15)

Examining Figure (2-15), note that of the 40 pins, a total; of 33 are set aside for the five ports A, B, C, D, and E ,with their alternate functions. The rest of the pin is designated as Vdd, GND (Vss), OSCI, OSC2, and MCLR (master clear reset). Next, we describe the function of each pin. Vdd (Vcc).

Tow pins are used to provide supply voltage to the chip. The typical voltage source is +5V. Some PIC18F family members have lower voltage for Vdd pins in order to reduce the noise and power dissipation of the PIC system. We can choose other options for the Vdd voltage level by setting the bits in the configuration register.

Vss(GND) :

Two pins are also used for ground. IN chip with 40 pins and more, it is common to have multiple pins for VCC and GND. This will help reduce the noise (ground bounce) in high-frequency systems.

The PIC18F has many options for the clock source. Most often a quartz crystal oscillator is connected to input pins OSC2. The quartz crystal oscillator connected to the OSC1 and OSC2 pins also needs to capacitors. One side of each capacitor is connected to the ground . Note that PIC18f microcontrollers can have speeds of 0Hz to 40 MHz. We can choose options for the clock frequency by setting bits in the configuration register.

MCLR:

Pin 1 (in PIC18F4550 40-pin DIP) is the MCLR (master clear reset) pin. It is an input and is active-LOW (normally HIGH). When a LOW pulse is applied to this pin, the microcontroller will reset and terminate all activities.

Ports A, B, C, D, and E:

As shown in Figure (3-14), the ports PORTA, PORTB, PORTC, PORTD, and PORTE, use a total of 33 pins. All the ports upon RESET are configured as input, because TRISA – TRISE have the value FFH on them.

PORT A:

Port A occupies a total of 7 pins (RA0_RA6), but for the PIC18F4550, pin A6 is used for the OSC2 pin. A6 is not available if we use a crystal oscillator to provide frequency to the PIC18 chip, To use the pins of port A as both input and output ports, each bit must be connected externally to the pin by enabling the bits of the TRISA register.

PORT B:

Port B occupies a total of 8 pins (RB0_RB7). To use the pins of port B as both input and output ports, each bit must be connected externally to the pin by enabling the bits of the register TRISB.

PORT C:

Port C occupies a total of 8 pins (RC0_RC7). To use the pins of port C as both input and output ports, each bit must be connected externally to the pin by enabling the bits of the register TRISC

PORT D:

Port D occupies a total of 8 pins (RD0_RD7). To use the pins of port D as both input and output ports, each bit must be connected externally to the pin by enabling the bits of the register TRISD.

PORT E:

Port E occupies a total of 3 pins (RE0_RE2) in PIC18F4550. Port E is used for 3 additional analog inputs or simple I/O: AN5, AN^ and AN7. Just like other ports, Port E has alternate functions.

Chapter

Three

Design and Calculations

3.1 V-belts and pulleys:

3.1.1 Introduction:

Accurate alignment, the correct groove profile for the V-belt and an appropriate belt tension are vital for the driving mechanism to function properly. The eccentricity values provided by the V-belt manufacturers are maximum values determined under specific circumstances.

Experience has shown that when fitting compressors to diesel engines, these eccentricity values can be excessive. The v belt can be expanded and be destroyed prematurely. For this reason the eccentricity should be kept as small as possible. Narrow V-belts are preferably used in general engineering and in the motor vehicle industry.

In V-belt drives, the increased friction achieved by the V-shaped groove is utilized. The flanks of the fitted V-belt very effectively transmit the energy through their adherence friction and work practically without slipping. If properly designed, the efficiency of V-belt drives is more than 95 %. It is important that through the use of narrow V-belts, very small eccentricity values can be selected.

The eccentricity A should remain within predefined limits, i.e. it should be larger than 0.7 (Dw + dw) and smaller than 1.5 (Dw + dw).

3.1.2 Fundamentals for the utilization of V-belts:

- Make sure that the driving mechanism receives V-belts of the right number, type and size for the application.

- Before you mount the V-belt pulleys, make sure that the grooves are free of

burrs, rust and dirt.

- Put the V-belt on by hand without using any excessive force and at the smallest possible eccentricity - without the use of any mechanical implements.

A v-belt drive for a-cylinder diesel engine powered a compressor, assume this engine running over 15 hours a day at 3000 rpm, where it develops 90 hp, the driven speed is 2000 rpm, due to space limitations the desired center distance must be around 0.90 meter.

3.2 Air tank design:

The receiver volume may be calculated with the formula

$t = V (p_1 - p_2) / C p_a$ (3.1)

where

V = volume of the receiver tank (cu ft)

t = time for the receiver to go from upper to lower pressure limits (min)

C = free air needed (scfm)

p_a= atmosphere pressure (14.7 psia)

p_1 = maximum tank pressure (psia)

p_2 = minimum tank pressure (psia)

It is also common to size receivers

1) to 1 gallon for each ACFM (Actual Cubic Feet per Minute), or
2) 4 gallons per compressor hp (horse power)

Data:

Engine volume(Veng)= 2000 cm^3=2(litre).

V_t = air tank volume = 10(litre).

P_{min} = minimum pressure = 3 bar = 300(kpa).

P_{max} = maximum pressure = 12 bar = 1200(kpa).

P_{atm} = atmospheric pressure = 1bar = 101(kpa).

The time to supply the engine with air at 3000 rpm, we will first calculate swept volume of the engine:

$V_{sw}=V_{eng}* \eta_v *N/2$ (3.2)

Where
V_{sw}= swept volume.
η_v = volumetric efficincy(20%).

N= engine speed(rpm).

V_{sw}= 2*.20*(3000/60)/2
  = 10 (litre per second).

Now, to find the time:

V_t= P_{atm}*t*V_{sw}/(P_{max}-P_{min}) (3.3)
 = 101*10^3*t*10/(1200-300)*10^3
 = 10
t= 9 (second)
volumetric efficiency calculation:

η_v =2*ma/(ρ *Vd*N) (3.4)

ρ = P_a/RT (3.4)
PV=mRT (3.5)

Where
P_a= atmospheric pressure=101(kpa).
R=gas constant= 0.287 KJ/Kg.K
T_a= temperature of surrounding air = 25 c=298k.
P= turbo pressure=2.3 bar= 230 kpa.
T= 40 c= 313 k.
ma=PV/RT
  = 230*1896/0.287*313
  = 0.4853 g/cycle.
η_v =(2*0.4853*720)/(1.181*1896*3000)
  = 20%

3.3 Turbocharger Mass Moment of Inertia:

Changes in turbocharger rotating inertia GTC have been found to have the strongest influence on the rotational speed response; it is not surprising then that turbocharger manufacturers try to design for the lowest possible inertia.

This can be achieved by adapting lighter materials, e.g., titanium aluminide (TiAl), or ceramic ones such as silicon nitride, in order to decrease the turbine rotor mass, this is the most straightforward technique since it does not influence the turbine nozzle area; hence steady-state operation remains unaltered.

Most of the turbocharger inertia (70% or even more) is typically associated with the turbine wheel owing to the high density material with respect to that of the compressor impeller, and large diameter compared with the shaft. The inertia of the turbocharger disc is proportional to the fourth power of diameter, but since tip width and rotor length tend to increase with diameter, turbine inertia is more closely related to the fifth power of diameter, i.e. 5 GTC ∝d . This suggests that reducing turbine (and compressor) rotor diameter will strongly influence turbocharger and, consequently, engine speed response, albeit at the expense of turbocharger efficiency. Hopefully, as diameter is reduced, the penalty in efficiency changes much more slowly than inertia.

By reducing the turbo-machines diameter, hence turbocharger inertia, faster acceleration of the turbocharger shaft is established; the higher achieved rotationalspeed moves the compressor operating point towards higher boost pressure and airmass flow-rate values. The increased air-supply to the engine cylinders minimizes the fuel limiter's function, thus allowing higher amounts of fuel to be injected Without fear of smoke emissions.

Turbocharger acceleration is significantly influenced by changes in inertia. This affects the subsequent engine response via the fuel controller. Thus at the 1 s point, the lowest inertia turbocharger has developed a pressure ratio of 1.4, allowing the fuel controller to inject more fuel. This enables the engine to continue accelerating rapidly.

Combustion deterioration cannot be totally prevented, but the much smaller duration of the turbocharger lag ensures a smoother response and lowers soot emissions during the early cycles of the transient event. It should be noted, however, that a very low turbocharger inertia may, under some circumstances (*e.g.*, depending on the specific governor characteristics), lead to an oscillatory engine recovery, which is unacceptable both in terms of recovery time and crankshaft stress.

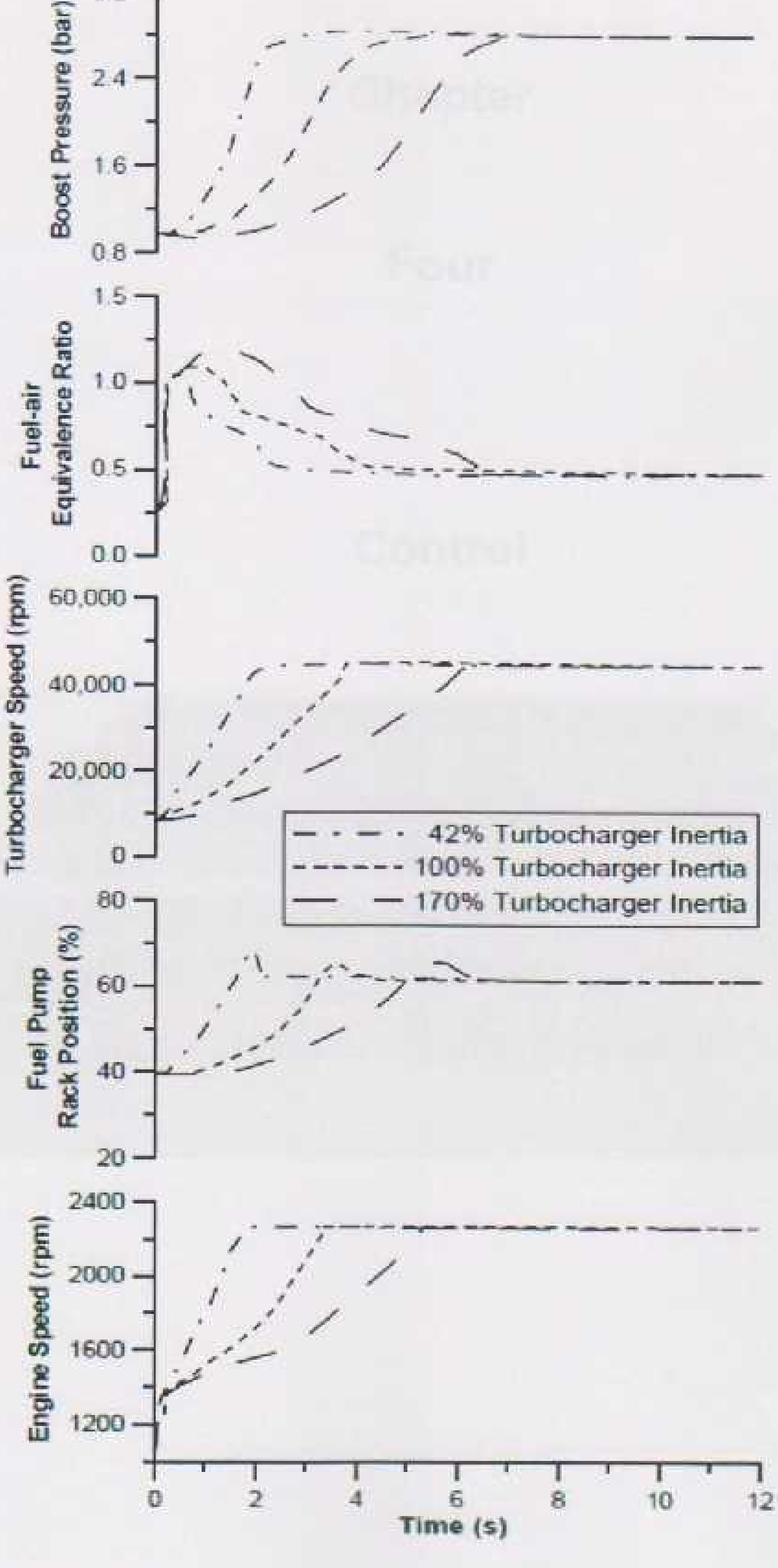
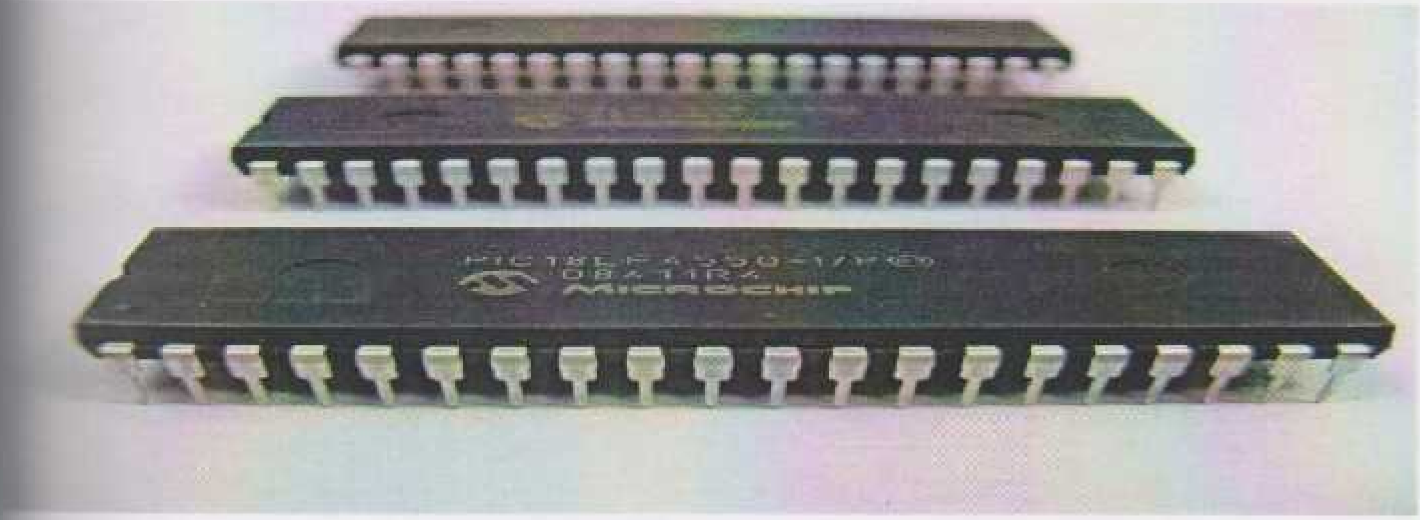


Figure (3.1) Effect of turbocharger moment of inertia (same frame) on propeller law engine acceleration of a highly-rated turbocharged diesel engine. [2]

Chapter Four

Control



4.1 Introduction

Movement of different parts of the device, or even movements of the human body are meaningless and useless without control to serve the purpose and objective of this movement.

This concept is clear from the meaning of control is to reach the intended target of the movement.

And in order for the control system must have important things to explain in the following figure (4-1).

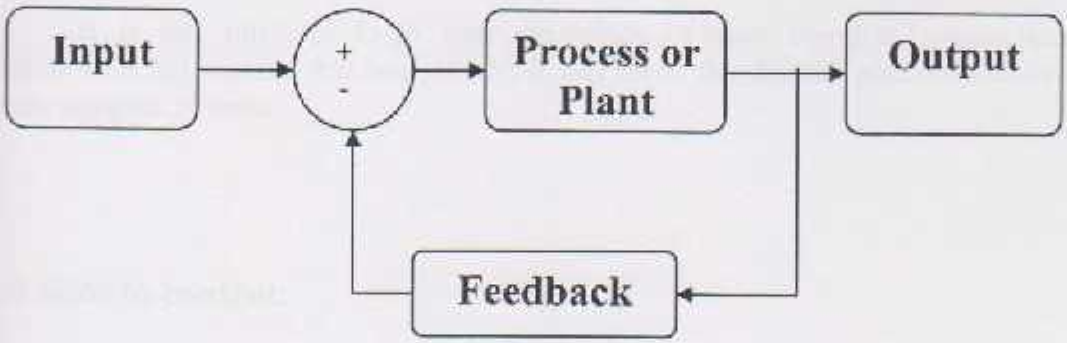


Figure (4-1) shows flow chart without controller

Figure (4-1) represents the main components of control operations, the signal is given at the input and then processed and sent to the output and returns a signal through the feedback for comparison with the input and when the feedback signal is equal with the input this means that the target is reached.

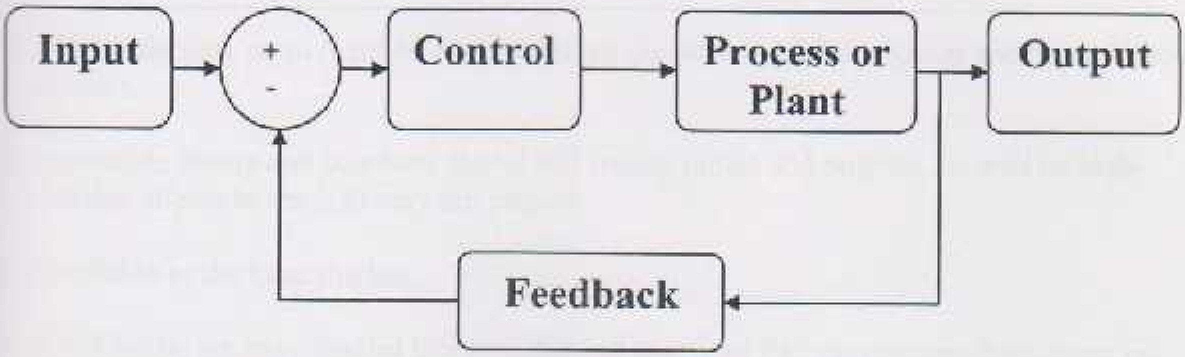


Figure (4-2) flow chart represents the system with controller

Figure(4-2) represents another image to control is that for every system has equations of motion of its own based on its physical characteristics including the weight of the system and moment of inertia, natural frequency, and things vary according to the system and these equations fixed, they cannot change equivalents to achieve the desired goal (because the coefficient of any change means change in the system) so they are working to introduce the concept of the controller through which they can change the roots of equations of the system and thus control the response of the system and speed .

In this project they used a feedback control to connect the output signal from the sensors, and make the operation of the signal and compare them with the save real value (saved in the microcontroller),and depended for this value the microcontroller get the output signal .

It is not intended to go into the details of more complex system because our project does not require this complexity; it can reach the desired goal without resorting to more complex systems.

4.2 How to control:

Process control is performed through the received data input from the system and logical calculations through the program stored in advance and then output the data fit with the input of the system.

This is done through the controller where the controller is working to coordinate the functions of parts of the program through its own as it should be noted here that there is to prepare many types of controllers but we have chosen to microcontroller (PIC18F4550) this project for several reasons including:

1. The availability of an (MPlab) through which the writing of the program and upload it to the controller.

2. It contains timers and counters, digital and analog inputs and outputs. As well its high-speed that allows to use it in very our project.

3. Available in the local market.

4. Knowledge, we have studied theoretically and practiced PIC programing throughout our study at PPU
5. The cost

The following figure (4-3) shows the inputs and outputs of the controller.

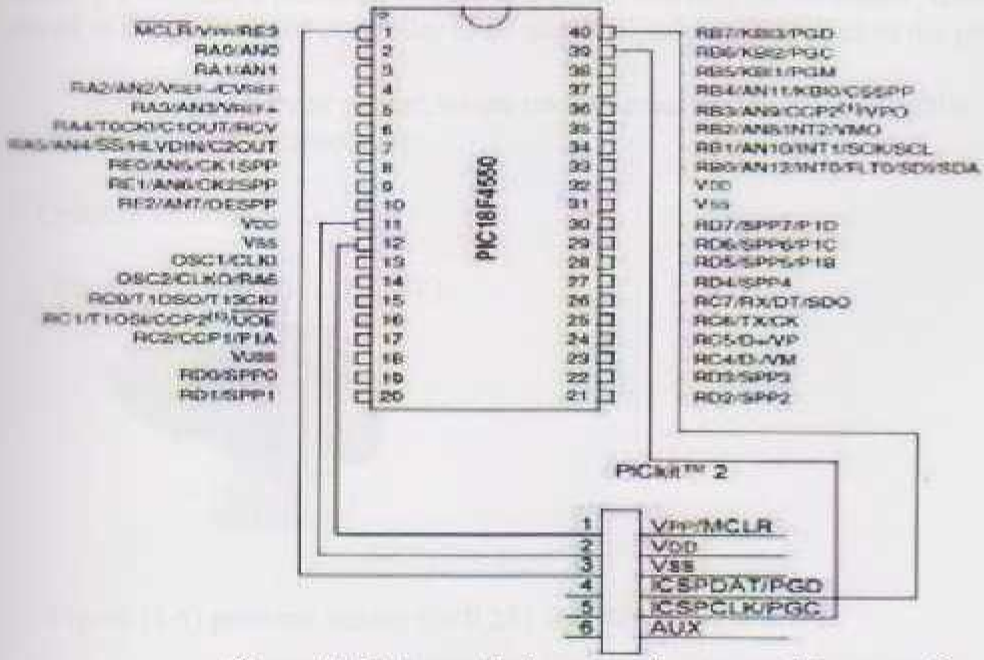


Figure (4-3) shows the inputs and outputs of the controller

The program is stored on the controller memory and you must make sure that each pin is connected to the programmed position.

Figure (4-4) shows the programmer

4.3 Sensors

Sensors collect information and convert it to the controller, to the data sheet for the sensor we can find a relationship between inputs and outputs for sensor, these relations are stored in the program of controller to be used properly and required in the project.

In this project three sensor, where used to measure the input variables and send signals to the controller. These sensors are:

1. Pressure sensors

Range (50...600 kpa), (0...5 V)

Figure (4-5) pressure sensor 6 6 0 281 002 420

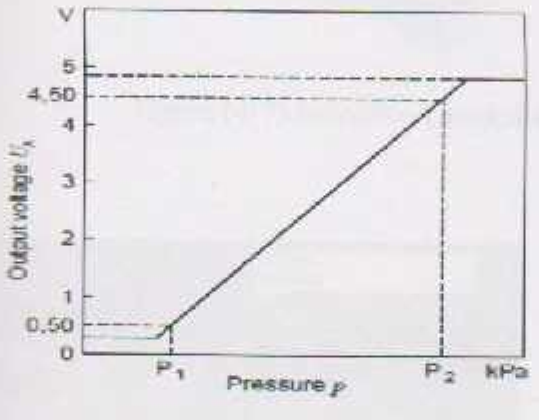


Figure (4-6) shows the relation between pressure and voltage

From the liner relation between pressure and voltage we find the slop value

$$S= \blacktriangle P/\blacktriangle V = (P-P1)/ (V-V1)$$

(4.1)

$P-P1= (P2-P1)(V-V1)/(V2-V1)$

$P= ((P2-P1)(V-V1)/(V2-V1))+P1$

But, $N= 2^{10} /(Vref+ - Vref-)$ (4.2)

Precision: if N=1, dVin= (Vref+ - Vref-)/1023

V=N*(5/1023) (4.3)

$$\boxed{P(N)=(2750/4095)N+0.05} \tag{4.4}$$

2 .inductive crankshaft sensor

Figure (4-7) Inductive Crankshaft Sensor IA B 261 209 519-01)

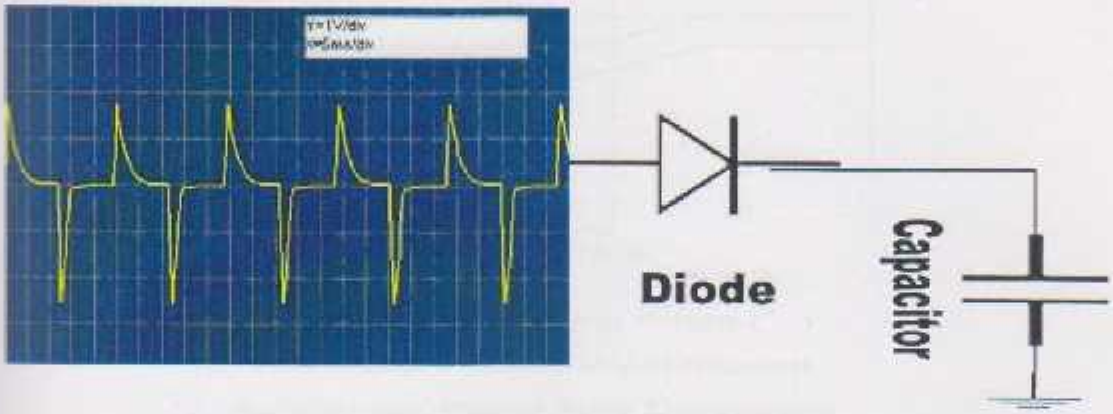


Figure (4-8) Signal Of Crankshaft Sensor And How To Treatment The Signal

from the output signal show in figure(4-8),we find the voltage range between (+ 5V_- 5V),we take this signal and input to the diode to make cancellation for the negative region signal , and contacted this signal to a (100 Micro Farad),and used the voltage regulator (5V) to protect (the PIC).

$N = 2^{10} / (Vref+ - Vref-)$

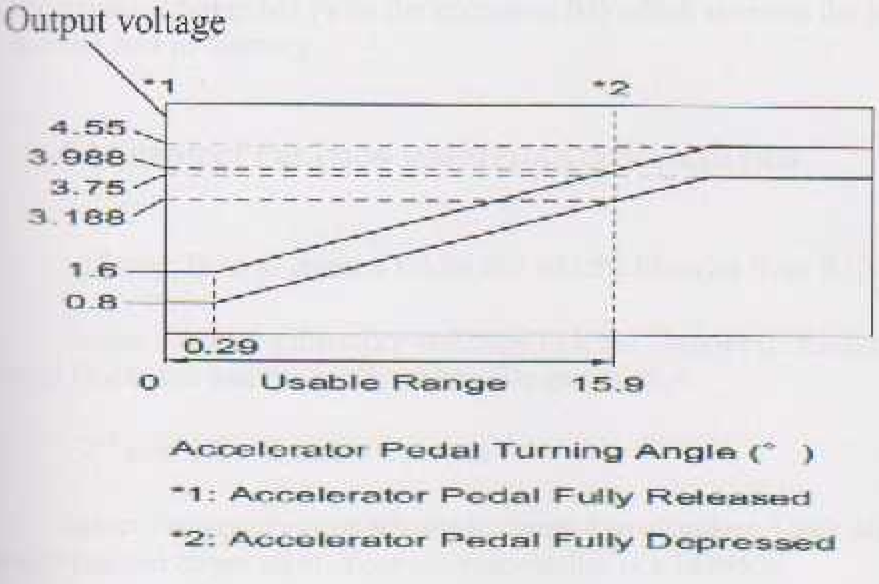
Precision: if N=1, $dVin = (Vref+ - Vref-)/1023$

$V = N * (5/1024)$

$$\boxed{N = 1023V/5} \qquad (4.5)$$

3. Accelerator pedal sensor

igure (40-9)APPS



From the liner relation between pressure and voltage we find the slop value

$S = \blacktriangle \varnothing / \blacktriangle V = (\varnothing - \varnothing 1)/(V - V1)$

$\varnothing - \varnothing 1 = (\varnothing 2 - \varnothing 1)(V - V1)/(V2 - V1)$

Ø= ((Ø2- Ø1)(V-V1)/(V2-V1))+ Ø1
But, N= 2^10 /(Vref+ - Vref-)
Precision: if N=1, dVin= (Vref+ - Vref-)/1023
V=N*(5/1023)

$$\boxed{\mathbf{\varnothing(N)=(0.02033)N - 3.04}} \qquad (4.6)$$

4.5 Denvelopment tools

To program the microcontroller, we use tools from Microchip:
⇨ Integrated Development Environment *MPLAB IDE v7.31*
⇨ C Compiler *MPLAB C18 Compiler v3.0*
⇨ Programmer / Debugger *MPLAB ICD2*

MPLAB IDE is a user friendly interface for editing, compiling, programming and debugging code. It supports ICD2 programmer/debugger and C source level debugging.

A project consists in a collection of files: the main program, libraries (source to be compiled), a linker file (with the extension *lkr*) which contains the location of the program and the data in memory.

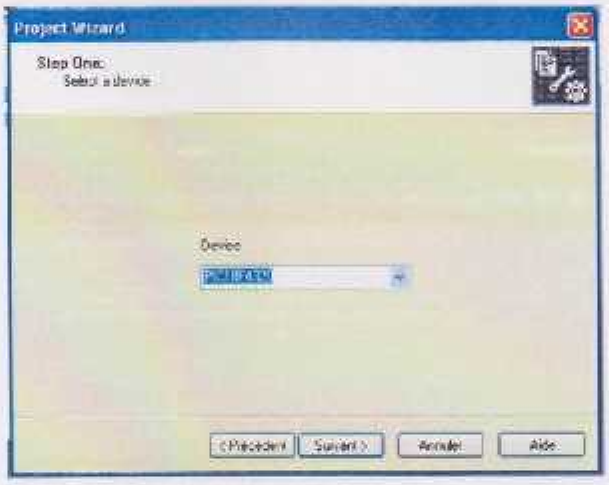
4.4.1 PROJECT CREATION AND MPLAB CONFIGURATION

1st step: How to create a folder and add the libraries from IUT Cachan

Create a working directory and copy in it the libraries (C files, *gamelcd_v3.c*), you would like to use and the configuration file gameinit.*h*

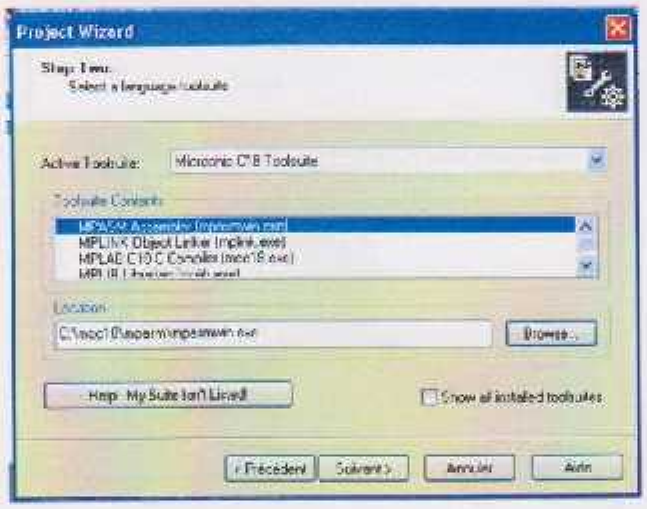
2nd step: How to create a project ?

Select *Project>Project Wizard* to create a new project. Click on *next*. Choose the *device* (named *target* also). Your microcontroller is a 18F4550.



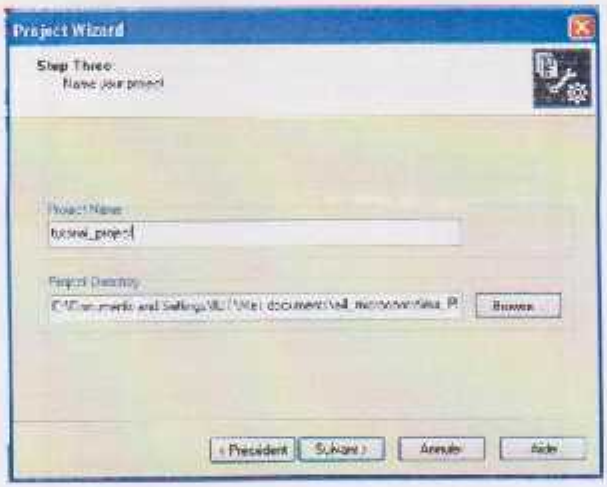
Click Next, choose Microchip C18 Toolsuite compiler. The elements of the compiler are in Toolsuite Contents. Indicate the location of each element on the hard disk:

⇨ MPASM (Assembler): c:\mcc18\mpasm\mpasmwin.exe
⇨ MPLINK (Linker) : c:\mcc18\bin\mplink.exe
⇨ MPLAB C18 (C compilater) : c:\mcc18\bin\mcc18.exe
⇨ MPLIB (Microchip libraries): c:\mcc18\bin\mplib.exe



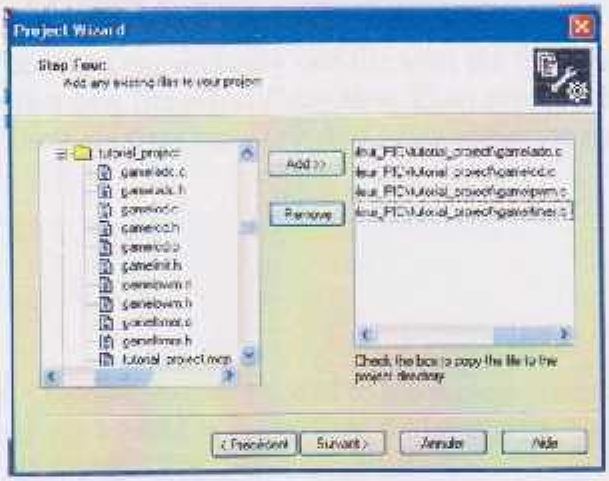
Click next.

In this new window, indicate the name of your project and its location on the hard disk (Browse)



Project Name: tutorial_project

Click next.
Add the source C files containing the functions used in your project (*gamelcd_v3.c*)



Click next and finish.

3rd step: How to configure the compilation options for your project

Select Project>Build Options>Project. Type the path of the header **.h* Microchip files (c:\mcc18\include), of the already compiled library **.o* Microchip files (c:\mcc18\lib) and of the linker **.lkr* Microchip files (d:\mcc18\lkr) as indicated below:

Output Directory, $(BINDIR):

Intermediates Directory, $(TMPDIR):

Assembler Include Path, $(AINDIR):

Include Path, $(INCDIR): d:\mcc18\h

Library Path, $(LIBDIR): d:\mcc18\lib

Linker-Script Path, $(LKRDIR): d:\mcc18\lkr

To add a file to the project

The project must contains one and only one file with the function main*()* (entry point of the program). To create a new file select *File>New*. Then save it with the extension **.c*. To add this file to the project choose *project* → *Add Files* or use the right button of the mouse.

Remarks:

- The header files mustn't be compiled and added to the project. They are just declared with *#include < xxx.h >* if they are located in the include folder or with *#include " xxx.h "* if they are located in the working folder.

- The Mplink linker, which builds your project needs a script file. Select *Linker Scripts* with the right button and *Add Files*. Look for *18f4550i.lkr* in *c:\mcc18\lkr*.

4.4.2 BUILDING THE PROJECT:

Select *Project>Build All* to build (that is to say compile and link) the project. Warning and error messages may appear in the output window (*Output*). Otherwise the message BUILD SUCCEEDED is displayed in this window. You may see it with *View>Output*.

4.4.3 EXECUTION AND DEBUGGING WITH MPLAB ICD 2:

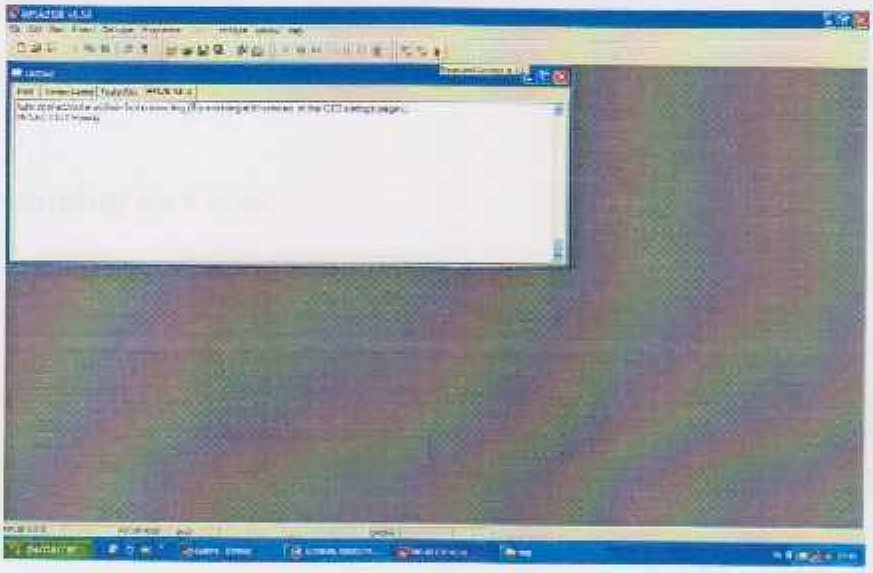
The goal of debugging is to check the execution of the program with the PC. This means step by step, execution, watching variables, and settings of breakpoints. The communication between the PC and the microcontroller is, in that case, very important; It's managed by the debugger MPLAB ICD2 which is used also to load the program into the microcontroller.

1st step: How to select the debugger

Select *Debugger>Select Tool>MPLAB ICD 2* to choose the tool ICD2 to communicate with the microcontroller. This tool bar should appear:

2nd step: Connection with the microcontroller

Select *Debugger>Connect* or the icon ●



The results of tests are displayed in the output window. The word READY means everything is OK.

3rd step: Programmation

To program the microcontroller select *Debugger>Program* or the icon

4th step : Running the program

Select *Debugger>Run*, or the icon ▶

5th step : How to debug

To test and correct your program you may choose the following debugging facilities :

⏸ Halt (F5) to stop the execution. A green arrow is displayed in front of the instruction which was about to be executed.

4.5 Programming and code

Programming is the most important steps in the design of the controller because it is the language of communication between different parts of the machine, so that the system performs the functions assigned to it in an orderly and complementary process to reach the desired goal.

With the presence of multiple programming languages had a C language compatibility with most programming language controlled, the following flow chart in Figure (4-8), where put the program based upon.

Note :

In this project they applied the equation in the motor without load ,and when find the value of parameter (x, y, z) by using the multimeter they found:

x : (output voltage of inductive crankshaft sensor) = 2.5v

X = (2.5*1023)/5 = 512

y : (output voltage of accelerator pedal sensor) = 4v

Y = (4.5*1023)/5 = 818

z : (output voltage of pressure sensors) = 1.1v

Z = (1.1*1023)/5 = 225

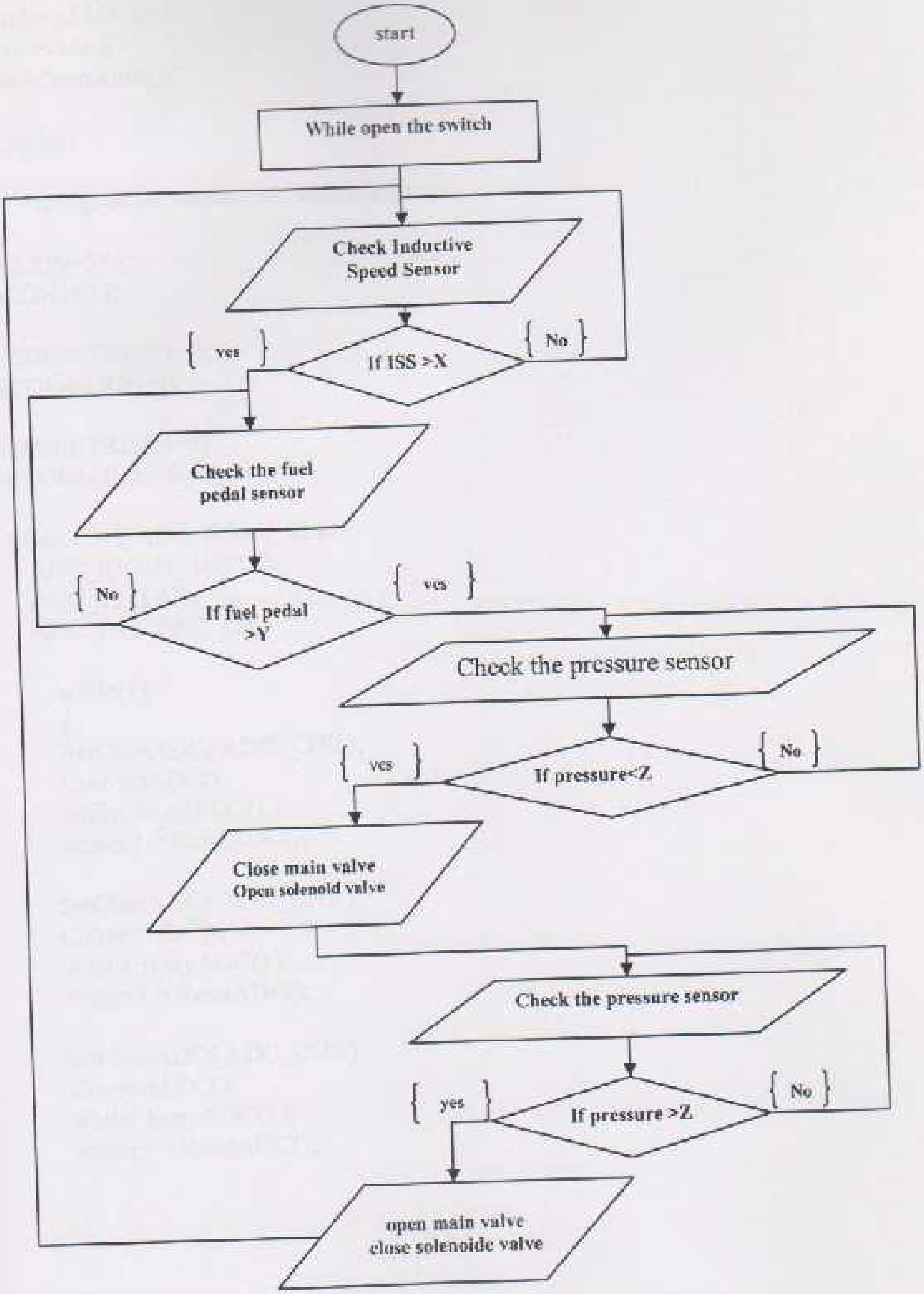


Figure (4-8) flow chart of system

The code:-

```
#include<p18f4550.h>
#include<adc.h>
#include"gamelinit.h"

void main()
{
        unsigned int sensor1,sensor2,sensor3;

 OSCCON=255;
 ADCON1=12;

 TRISBbits.TRISB1=0;
 PORTBbits.RB1=0;

TRISDbits.TRISD5=0;
 PORTDbits.RD5=0;

    OpenADC( ADC_FOSC_32 &
      ADC_RIGHT_JUST &
      ADC_12_TAD,
      ADC_INT_OFF, 12);

         while(1)
         {
         SetChanADC( ADC_CH0 );
         ConvertADC();
         while( BusyADC() );
         sensor1 = ReadADC();

        SetChanADC( ADC_CH1 );
        ConvertADC();
         while( BusyADC() );
         sensor2 = ReadADC();

        SetChanADC( ADC_CH2 );
         ConvertADC();
         while( BusyADC() );
         sensor3 = ReadADC();




if(sensor1>511 && sensor2>818 && sensor3<225)
{
```

```
PORTBbits.RB1=1;
PORTDbits.RD5=1;
}
else if(sensor1>511 && sensor2<818 && sensor3>225)
{
PORTBbits.RB1 =0;
PORTDbits.RD5=0;

}
}
}
```

Chapter

Five

Appling system and results

5.1 Introduction:

In the previous chapters we discussed the operating of turbo supercharging, and the parts of the anti lag in the turbo system.

And once again the mean of turbo lag is that Turbo rely on the flow of the exhaust gas through the turbine housing, As the engine RPMs increases, the turbo spools up and starts to build boost, The delay between pushing the accelerator pedal and the turbo spinning and producing boost is known as 'turbo lag'.

To improve best known a good boost, the system will be able to prevent that unwanted lag.

5.2 Components of Turbo anti lag system:

1. Air injection unit
2. High pressure air tank and mechanical pressure sensor.
3. High pressure air compressor

5.2.1 Air injection unit shown in figure (5-1)

Consists of:

a) Pressure sensors:

There are two main sensors, the first one reads the pressure of the manifold and transfer it to the engine ECU as shown in figure (5-2).

The other sensor is connected to the controller and reads the pressures at the exit of the turbo charger know when to inject the high pressure air to the manifold shown in figure (5-3).

Figure (5-1) shows the assembled air injection unit.

Figure (5-2) shows the boost pressure sensor.

Figure (5-3) shows the turbo pressure sensor.

b) Air pressure reducer:

It is located on the air injection unit and its main function is to reduce the pressure coming from the storage tank at a pressure of 8 bar to the recommended pressure at the intake manifold at 2 bar as shown in figure (5-4).

Figure (5-4) the pressure reducer

It has a pressure regulator to adjust the desired pressure and it has a gauge to know the essure that is been regulated.

c) Multi-function vacuum air flap:

Its main function is to close the path between the turbo pressure and the air injection unit shown in figure (5-5).

Figure (5-5) shows the air vacuum flap

Air injection solenoid valve:

This component takes a voltage signal from the controller to pass the pressurized air from the tank to the air injection unit then to the engine manifold as shown in figure (5-6).

Figure (5-6) shows the air injection solenoid valve and its location on the injection unit

5.2.2 High pressure air tank with mechanical pressure sensor:

It accumulates the air under 8 bar pressure and its volume 40 liter consists of pressure gauge and pressure sensor. The pressure sensor function is to prevent pressure to increase rather than 8 bar.

It cut-out the voltage on the compressor and cut-in again when the pressure is less than 4 bars.

Figure (5-7) shows the used air tank and mechanical pressure sensor

5.2.3 High pressure air compressor:

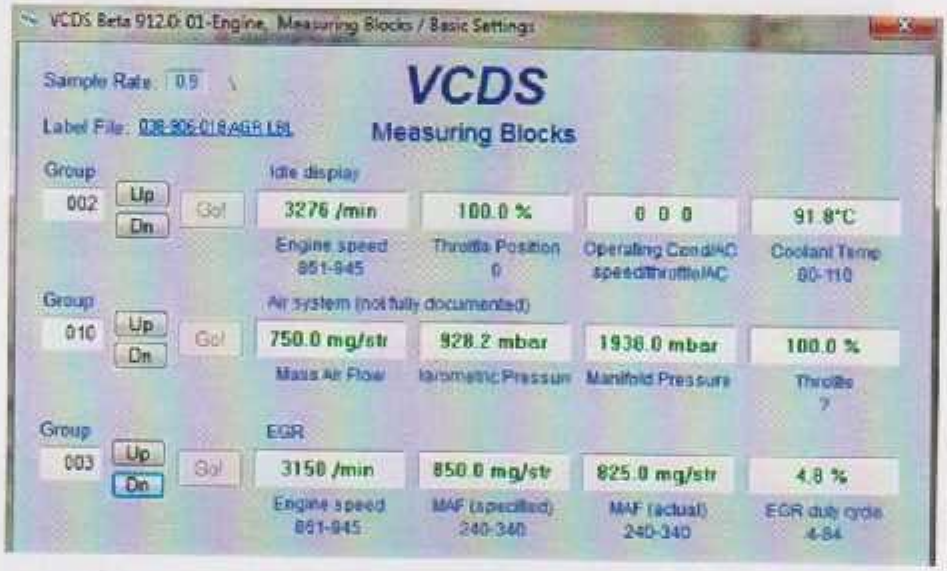
The compressor that is used is similar to the AC compressor in the car which allow charging the air inside the tank under high pressure and in a little time.

Figure (5-8) shows the compressor

5.3 Results:

Now by assembling all these components on a car and having a road test using a scan tool like the VAG the results would be as shown:

5.3.1 Testing the car without the system (using the normal turbo boosting):



Sample Rate: 0.9

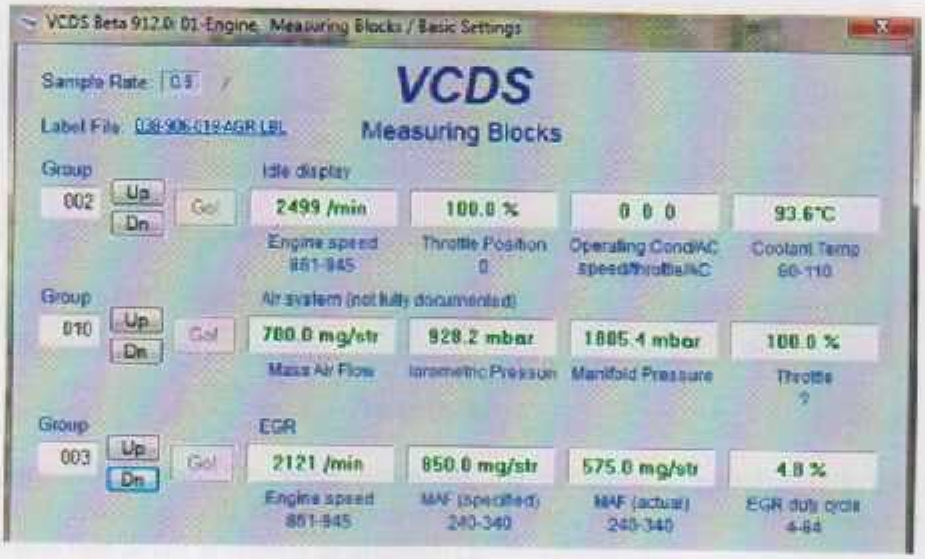
Label File: 038-906-018-AGR.LBL

Group 002 — Idle display
- 3276 /min — Engine speed 851-945
- 100.0 % — Throttle Position 0
- 0 0 0 — Operating Cond/AC speed/throttle/AC
- 91.8°C — Coolant Temp 80-110

Group 010 — Air system (not fully documented)
- 750.0 mg/str — Mass Air Flow
- 928.2 mbar — Barometric Pressur
- 1938.0 mbar — Manifold Pressure
- 100.0 % — Throttle ?

Group 003 — EGR
- 3150 /min — Engine speed 851-945
- 850.0 mg/str — MAF (specified) 240-340
- 825.0 mg/str — MAF (actual) 240-340
- 4.8 % — EGR duty cycle 4-84

Figure (5-9a)



Sample Rate: 0.9

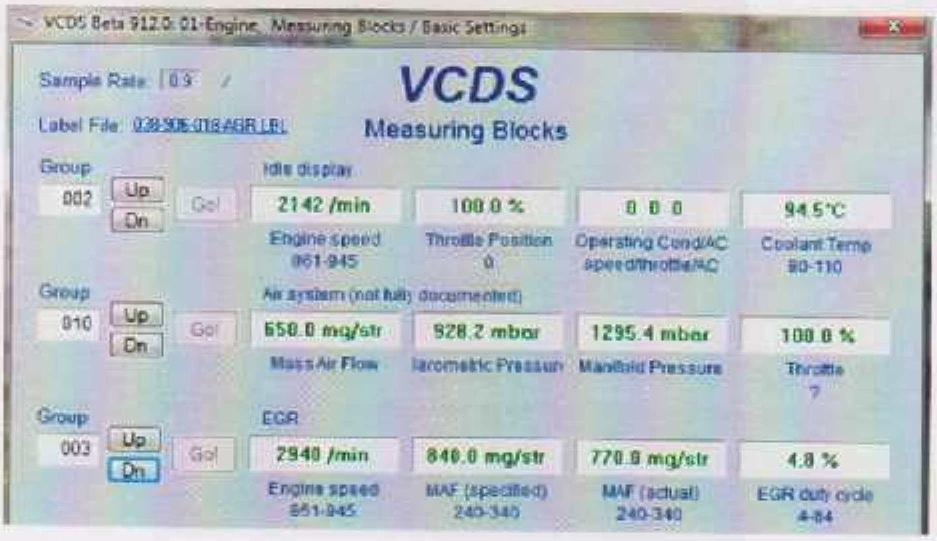
Label File: 038-906-018-AGR.LBL

Group 002 — Idle display
- 2499 /min — Engine speed 851-945
- 100.0 % — Throttle Position 0
- 0 0 0 — Operating Cond/AC speed/throttle/AC
- 93.6°C — Coolant Temp 80-110

Group 010 — Air system (not fully documented)
- 780.0 mg/str — Mass Air Flow
- 928.2 mbar — Barometric Pressur
- 1885.4 mbar — Manifold Pressure
- 100.0 % — Throttle ?

Group 003 — EGR
- 2121 /min — Engine speed 851-945
- 850.0 mg/str — MAF (specified) 240-340
- 575.0 mg/str — MAF (actual) 240-340
- 4.8 % — EGR duty cycle 4-84

Figure (5-9b)


VCDS Beta 912.0: 01-Engine, Measuring Blocks / Basic Settings

VCDS

Measuring Blocks

Sample Rate: 0.9

Label File: 038-906-019-AGR.LBL

Group 002 — Idle display

2142 /min	100.0 %	0 0 0	94.5°C
Engine speed 861-945	Throttle Position 0	Operating Cond/AC speed/throttle/AC	Coolant Temp 80-110

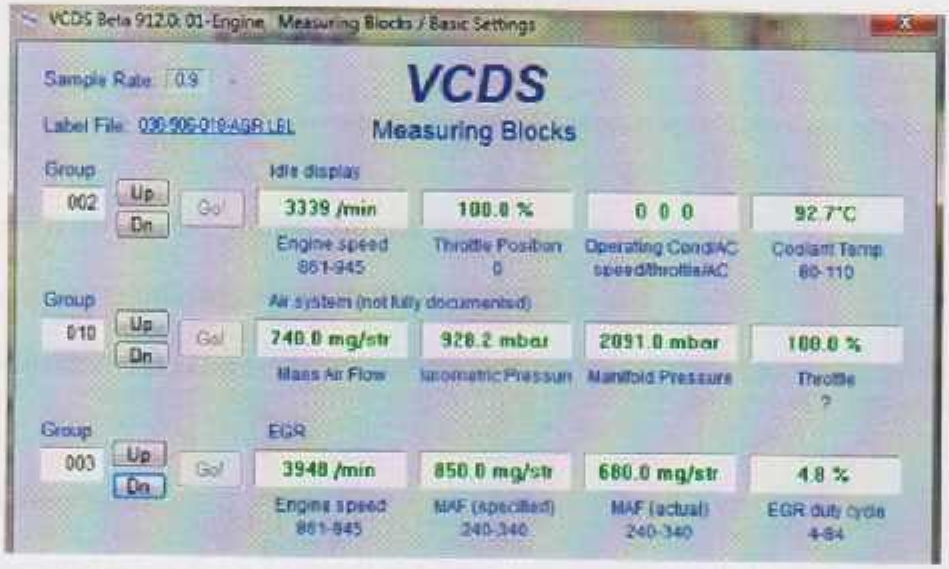
Group 010 — Air system (not fully documented)

650.0 mg/str	928.2 mbar	1295.4 mbar	100.0 %
Mass Air Flow	Barometric Pressure	Manifold Pressure	Throttle ?

Group 003 — EGR

2940 /min	840.0 mg/str	770.0 mg/str	4.8 %
Engine speed 861-945	MAF (specified) 240-340	MAF (actual) 240-340	EGR duty cycle 4-84

Figure (5-9c)


VCDS Beta 912.0: 01-Engine, Measuring Blocks / Basic Settings

VCDS

Measuring Blocks

Sample Rate: 0.9

Label File: 038-906-019-AGR.LBL

Group 002 — Idle display

3339 /min	100.0 %	0 0 0	92.7°C
Engine speed 861-945	Throttle Position 0	Operating Cond/AC speed/throttle/AC	Coolant Temp 80-110

Group 010 — Air system (not fully documented)

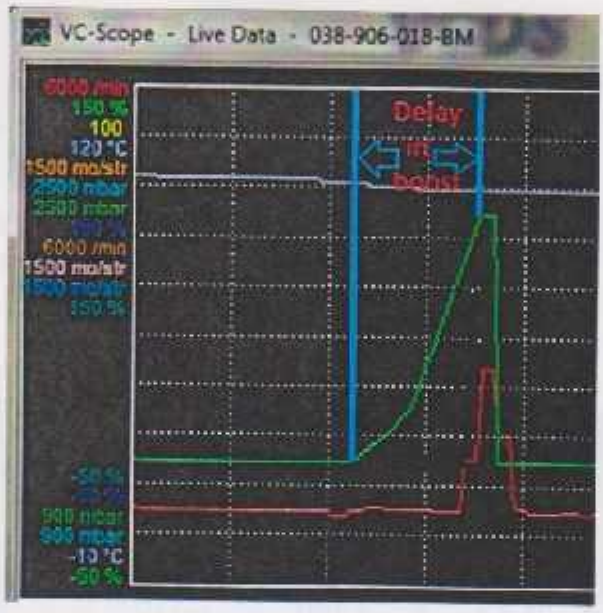
740.0 mg/str	928.2 mbar	2091.0 mbar	100.0 %
Mass Air Flow	Barometric Pressure	Manifold Pressure	Throttle ?

Group 003 — EGR

3948 /min	850.0 mg/str	680.0 mg/str	4.8 %
Engine speed 861-945	MAF (specified) 240-340	MAF (actual) 240-340	EGR duty cycle 4-84

Figure (5-9d)

From figure(5-9) when the driver press on the accelerator pedal 100% the boosting essure (manifold pressure) will be approximately 2 bar , but to build this pressure there is conds in time and this delay is shown in graph(5.1).



Graph (5-1) shows the system delay

The green line is the manifold pressure

The red line is the engine speed

From figures (9a,9b,9c,9d) the average of the mass air flow, manifold pressure and engine speed will be:

Mass air flow= (750+780+650+740)/4= 730 (mg/str) (5.1)

Manifold pressure= (1938+1805.4+1295.4+2091)/4= 1782.5 (mbar) (5.2)

Engine speed= (3150+2121+2940+3948)/4= 3039.8 (RPM) (5.3)

From previous graph:

The horizontal yellow line is 2 seconds or 1.3 mm (measured by a ruler), now by measuring the distance of the delay between two blue vertical lines it will be 1.6 mm, to determine the time delay:

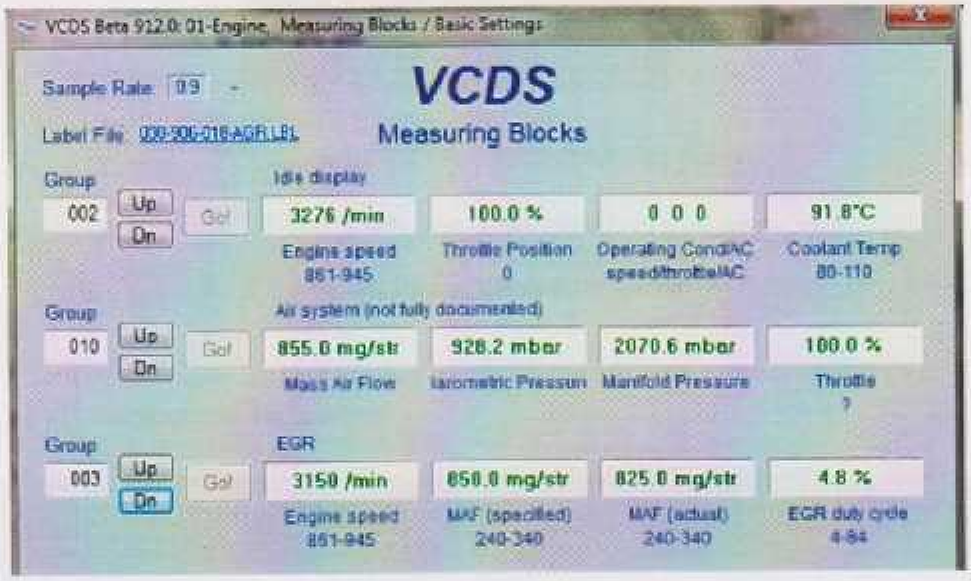
1.3 mm = 2 seconds

1.6 mm=??

(1.6 mm * 2 seconds)/1.3 mm = 2.46 seconds is the delay of the turbo boost at normal conditions at different road conditions.

5.3.2 Testing the car with the system:

This system will prove that the delay reduced which gives better performance when pressing on the accelerator pedal.



Sample Rate: 0.9

Label File: 038-906-016-AGR.LBL

Group 002 — Idle display
3276 /min — Engine speed 861-945
100.0 % — Throttle Position 0
0 0 0 — Operating Cond/AC speed/throttle/AC
91.8°C — Coolant Temp 80-110

Group 010 — Air system (not fully documented)
855.0 mg/str — Mass Air Flow
928.2 mbar — Barometric Pressure
2070.6 mbar — Manifold Pressure
100.0 % — Throttle ?

Group 003 — EGR
3150 /min — Engine speed 861-945
850.0 mg/str — MAF (specified) 240-340
825.0 mg/str — MAF (actual) 240-340
4.8 % — EGR duty cycle 4-84

Figure (5-10) shows measurements with system

Now, how air mass meter technique works?

By closing one side of the air injection unit and connecting the other side with the car air mass shown in figure (5-12) and look at the scan tool , by opening the air from the tank to the unit and closing the MFF and release it, a flow will be calculated and measured as shown in figure (5-11) .

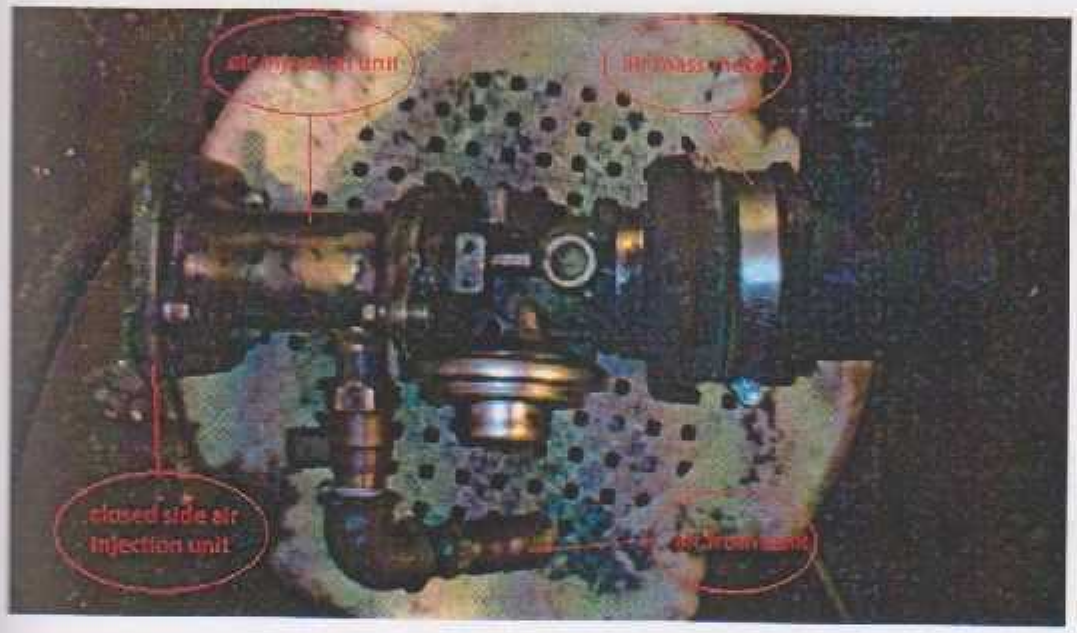


Figure (5-12) shows the assembled air mass

5.4 Recommendations and Conclusion:

1) The pic must know that the compressor must start to charge the tank when the vehicle is going downhill and that by taking a signal from the ABS (wheel speed sensor)and when the accelerator pedal is 0% and the gearbox is on the second or any gear.

2) Use an electronic pressure sensor located on the air tank which can determine the pressure and send it to the controller.

3) The system must work when the vehicle is moving and the engine is on, which means that the controller must have a signal from the ABS (wheel speed sensor) and the crankshaft sensor.

Conclusion

In the last , all the project parts has been assembled together, which it has been proved that the system is suitable for the engine to decrease the time needed to build up the pressure in the intake manifold which seems that the system gives a perfect response and high performance when applying the system.

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12) (http://en.wikipedia.org/wiki/Rotary_screw_compressor)
(11-1-2011/ 12:34 am)

13) http://en.wikipedia.org/wiki/Reciprocating_compressor (10-12-2011/12:27am)

14) http://en.wikipedia.org/wiki/Air_compressor
(10-12-2011/12:00am)

15) http://en.wikipedia.org/wiki/Pneumatics (10-12-2011/9:30pm)

16) http://en.wikipedia.org/wiki/Turbocharger (9-12-2011/ 9:00pm)

17) http://en.wikipedia.org/wiki/Turbocharger (9-12-2011/ 8:30pm)

Appendix

1.0 DEVICE OVERVIEW

This document contains device-specific information for the following devices:

- PIC18F2455
- PIC18F2550
- PIC18F4455
- PIC18F4550
- PIC18LF2455
- PIC18LF2550
- PIC18LF4455
- PIC18LF4550

This family of devices offers the advantages of all PIC18 microcontrollers – namely, high computational performance at an economical price – with the addition of high-endurance, Enhanced Flash program memory. In addition to these features, the PIC18F2455/2550/4455/4550 family introduces design enhancements that make these microcontrollers a logical choice for many high-performance, power sensitive applications.

1.1 New Core Features

1.1.1 nanoWatt TECHNOLOGY

All of the devices in the PIC18F2455/2550/4455/4550 family incorporate a range of features that can significantly reduce power consumption during operation. Key items include:

- **Alternate Run Modes:** By clocking the controller from the Timer1 source or the internal oscillator block, power consumption during code execution can be reduced by as much as 90%.
- **Multiple Idle Modes:** The controller can also run with its CPU core disabled but the peripherals still active. In these states, power consumption can be reduced even further, to as little as 4%, of normal operation requirements.
- **On-the-Fly Mode Switching:** The power-managed modes are invoked by user code during operation, allowing the user to incorporate power-saving ideas into their application's software design.
- **Low Consumption in Key Modules:** The power requirements for both Timer1 and the Watchdog Timer are minimized. See **Section 28.0 "Electrical Characteristics"** for values.

1.1.2 UNIVERSAL SERIAL BUS (USB)

Devices in the PIC18F2455/2550/4455/4550 family incorporate a fully featured Universal Serial Bus communications module that is compliant with the USB Specification Revision 2.0. The module supports both low-speed and full-speed communication for all supported data transfer types. It also incorporates its own on-chip transceiver and 3.3V regulator and supports the use of external transceivers and voltage regulators.

1.1.3 MULTIPLE OSCILLATOR OPTIONS AND FEATURES

All of the devices in the PIC18F2455/2550/4455/4550 family offer twelve different oscillator options, allowing users a wide range of choices in developing application hardware. These include:

- Four Crystal modes using crystals or ceramic resonators.
- Four External Clock modes, offering the option of using two pins (oscillator input and a divide-by-4 clock output) or one pin (oscillator input, with the second pin reassigned as general I/O).
- An internal oscillator block which provides an 8 MHz clock (±2% accuracy) and an INTRC source (approximately 31 kHz, stable over temperature and VDD), as well as a range of 6 user-selectable clock frequencies, between 125 kHz to 4 MHz, for a total of 8 clock frequencies. This option frees an oscillator pin for use as an additional general purpose I/O.
- A Phase Lock Loop (PLL) frequency multiplier, available to both the High-Speed Crystal and External Oscillator modes, which allows a wide range of clock speeds from 4 MHz to 48 MHz.
- Asynchronous dual clock operation, allowing the USB module to run from a high-frequency oscillator while the rest of the microcontroller is clocked from an internal low power oscillator.

Besides its availability as a clock source, the internal oscillator block provides a stable reference source that gives the family additional features for robust operation:

- **Fail-Safe Clock Monitor:** This option constantly monitors the main clock source against a reference signal provided by the internal oscillator. If a clock failure occurs, the controller is switched to the internal oscillator block, allowing for continued low-speed operation or a safe application shutdown.
- **Two-Speed Start-up:** This option allows the internal oscillator to serve as the clock source from Power-on Reset, or wake-up from Sleep mode, until the primary clock source is available.

1.2 Other Special Features

- **Memory Endurance:** The Enhanced Flash cells for both program memory and data EEPROM are rated to last for many thousands of erase/write cycles – up to 100,000 for program memory and 1,000,000 for EEPROM. Data retention without refresh is conservatively estimated to be greater than 40 years.
- **Self-Programmability:** These devices can write to their own program memory spaces under internal software control. By using a bootloader routine, located in the protected Boot Block at the top of program memory, it becomes possible to create an application that can update itself in the field.
- **Extended Instruction Set:** The PIC18F2455/2550/4455/4550 family introduces an optional extension to the PIC18 instruction set, which adds 8 new instructions and an Indexed Literal Offset Addressing mode. This extension, enabled as a device configuration option, has been specifically designed to optimize re-entrant application code originally developed in high-level languages such as C.
- **Enhanced CCP Module:** In PWM mode, this module provides 1, 2 or 4 modulated outputs for controlling half-bridge and full-bridge drivers. Other features include auto-shutdown for disabling PWM outputs on interrupt or other select conditions and auto-restart to reactivate outputs once the condition has cleared.
- **Enhanced Addressable USART:** This serial communication module is capable of standard RS-232 operation and provides support for the LIN bus protocol. The TX/CK and RX/DT signals can be inverted, eliminating the need for inverting buffers. Other enhancements include Automatic Baud Rate Detection and a 16-bit Baud Rate Generator for improved resolution. When the microcontroller is using the internal oscillator block, the EUSART provides stable operation for applications that talk to the outside world without using an external crystal (or its accompanying power requirement).
- **10-Bit A/D Converter:** This module incorporates programmable acquisition time, allowing for a channel to be selected and a conversion to be initiated without waiting for a sampling period and thus, reducing code overhead.
- **Dedicated ICD/ICSP Port:** These devices introduce the use of debugger and programming pins that are not multiplexed with other microcontroller features. Offered as an option in select packages, this feature allows users to develop I/O intensive applications while retaining the ability to program and debug in the circuit.

1.3 Details on Individual Family Members

Devices in the PIC18F2455/2550/4455/4550 family are available in 28-pin and 40/44-pin packages. Block diagrams for the two groups are shown in Figure 1-1 and Figure 1-2.

The devices are differentiated from each other in six ways:

1. Flash program memory (24 Kbytes for PIC18FX455 devices, 32 Kbytes for PIC18FX550 devices).
2. A/D channels (10 for 28-pin devices, 13 for 40/44-pin devices).
3. I/O ports (3 bidirectional ports and 1 input only port on 28-pin devices, 5 bidirectional ports on 40/44-pin devices).
4. CCP and Enhanced CCP implementation (28-pin devices have two standard CCP modules, 40/44-pin devices have one standard CCP module and one ECCP module).
5. Streaming Parallel Port (present only on 40/44-pin devices).

All other features for devices in this family are identical. These are summarized in Table 1-1.

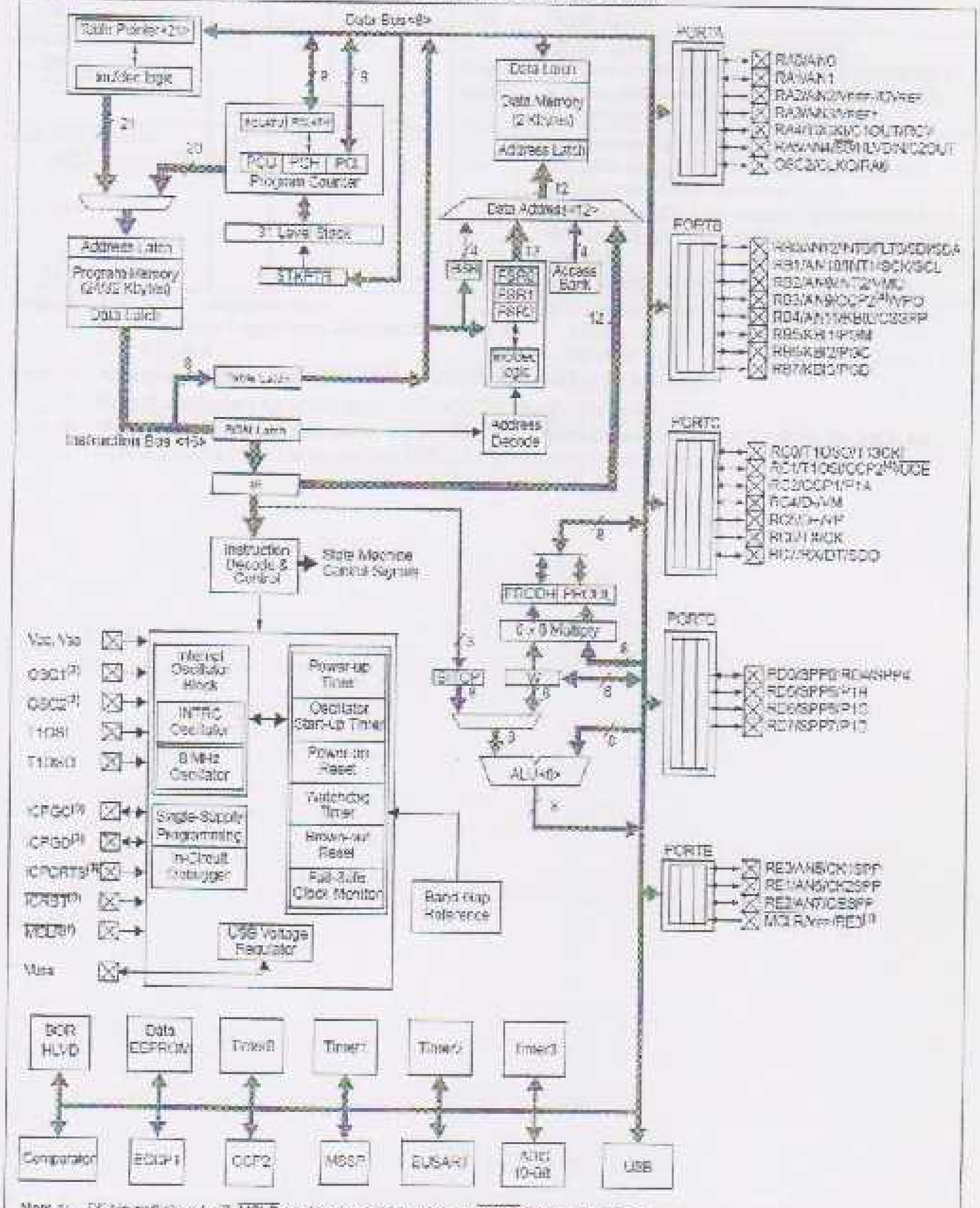
The pinouts for all devices are listed in Table 1-2 and Table 1-3.

Like all Microchip PIC18 devices, members of the PIC18F2455/2550/4455/4550 family are available as both standard and low-voltage devices. Standard devices with Enhanced Flash memory, designated with an "F" in the part number (such as PIC18F2550), accommodate an operating VDD range of 4.2V to 5.5V. Low-voltage parts, designated by "LF" (such as PIC18LF2550), function over an extended VDD range of 2.0V to 5.5V.

TABLE 1-1: DEVICE FEATURES

Features	PIC18F2455	PIC18F2550	PIC18F4455	PIC18F4550
Operating Frequency	DC – 48 MHz	DC – 48 MHz	DC – 48 MHz	DC – 48 MHz
Program Memory (Bytes)	24576	32768	24576	32768
Program Memory (Instructions)	12288	16384	12288	16384
Data Memory (Bytes)	2048	2048	2048	2048
Data EEPROM Memory (Bytes)	256	256	256	256
Interrupt Sources	19	19	20	20
I/O Ports	Ports A, B, C, (E)	Ports A, B, C, (E)	Ports A, B, C, D, E	Ports A, B, C, D, E
Timers	4	4	4	4
Capture/Compare/PWM Modules	2	2	1	1
Enhanced Capture/ Compare/PWM Modules	0	0	1	1
Serial Communications	MSSP, Enhanced USART	MSSP, Enhanced USART	MSSP, Enhanced USART	MSSP, Enhanced USART
Universal Serial Bus (USB) Module	1	1	1	1
Streaming Parallel Port (SPP)	No	No	Yes	Yes
10-Bit Analog-to-Digital Module	10 Input Channels	10 Input Channels	13 Input Channels	13 Input Channels
Comparators	2	2	2	2
Resets (and Delays)	POR, BOR, RESET Instruction, Stack Full, Stack Underflow (PWRT, OST), $\overline{\text{MCLR}}$ (optional), WDT	POR, BOR, RESET Instruction, Stack Full, Stack Underflow (PWRT, OST), $\overline{\text{MCLR}}$ (optional), WDT	POR, BOR, RESET Instruction, Stack Full, Stack Underflow (PWRT, OST), $\overline{\text{MCLR}}$ (optional), WDT	POR, BOR, RESET Instruction, Stack Full, Stack Underflow (PWRT, OST), $\overline{\text{MCLR}}$ (optional), WDT
Programmable Low-Voltage Detect	Yes	Yes	Yes	Yes
Programmable Brown-out Reset	Yes	Yes	Yes	Yes
Instruction Set	75 Instructions; 83 with Extended Instruction Set enabled	75 Instructions; 83 with Extended Instruction Set enabled	75 Instructions; 83 with Extended Instruction Set enabled	75 Instructions; 83 with Extended Instruction Set enabled
Packages	28-Pin PDIP 28-Pin SOIC	28-Pin PDIP 28-Pin SOIC	40-Pin PDIP 44-Pin QFN 44-Pin TQFP	40-Pin PDIP 44-Pin QFN 44-Pin TQFP

FIGURE 1-2: PIC18F4455/4550 (40/44-PIN) BLOCK DIAGRAM



Note 1: RE3 is multiplexed with $\overline{MCLR}$ and is only available when the $\overline{MCLR}$ Resets are disabled.

2: OSC1/CLKI and OSC2/CLKO are only available in select oscillator modes and when these pins are not being used as digital I/O. Refer to Section 2.0 "Oscillator Configurations" for additional information.

3: These pins are only available on 44-pin TQFP packages under certain conditions. Refer to Section 25.9 "Special ICPORT Features (44-Pin TQFP Package Only)" for additional information.

4: RB3 is the alternate pin for CCP2 multiplexing.

TABLE 1-3: PIC18F4455/4550 PINOUT I/O DESCRIPTIONS

Pin Name	Pin Number			Pin Type	Buffer Type	Description
	PDIP	QFN	TQFP			
MCLR/V_{PP}/RE3	1	18	18			Master Clear (input) or programming voltage (input).
MCLR				I	ST	Master Clear (Reset) input. This pin is an active-low Reset to the device.
V_{PP}				P		Programming voltage input.
RE3				I	ST	Digital input.
OSC1/CLKI	13	32	30			Oscillator crystal or external clock input.
OSC1				I	Analog	Oscillator crystal input or external clock source input.
CLKI				I	Analog	External clock source input. Always associated with pin function OSC1. (See OSC2/CLKO pin.)
OSC2/CLKO/RA6	14	33	31			Oscillator crystal or clock output.
OSC2				O	—	Oscillator crystal output. Connects to crystal or resonator in Crystal Oscillator mode.
CLKO				O	—	In RC mode, OSC2 pin outputs CLKO which has 1/4 the frequency of OSC1 and denotes the instruction cycle rate.
RA6				I/O	TTL	General purpose I/O pin.

Legend:
TTL = TTL compatible input
ST = Schmitt Trigger input with CMOS levels
O = Output
CMOS = CMOS compatible input or output
I = Input
P = Power

Note 1: Alternate assignment for CCP2 when CCP2MX Configuration bit is cleared.

2: Default assignment for CCP2 when CCP2MX Configuration bit is set.

3: These pins are No Connect unless the $\overline{\text{ICPRT}}$ Configuration bit is set. For NC/ICPORTS, the pin is No Connect unless ICPRT is set and the $\overline{\text{DEBUG}}$ Configuration bit is cleared.

TABLE 1-3: PIC18F4455/4550 PINOUT I/O DESCRIPTIONS (CONTINUED)

Pin Name	Pin Number			Pin Type	Buffer Type	Description
	PDIP	QFN	TQFP			
						PORTA is a bidirectional I/O port.
RA0/AN0	2	19	19			
RA0				I/O	TTL	Digital I/O.
AN0				I	Analog	Analog input 0.
RA1/AN1	3	20	20			
RA1				I/O	TTL	Digital I/O.
AN1				I	Analog	Analog input 1.
RA2/AN2/VREF-/CVREF	4	21	21			
RA2				I/O	TTL	Digital I/O.
AN2				I	Analog	Analog input 2.
VREF-				I	Analog	A/D reference voltage (low) input.
CVREF				O	Analog	Analog comparator reference output.
RA3/AN3/VREF+	5	22	22			
RA3				I/O	TTL	Digital I/O.
AN3				I	Analog	Analog input 3.
VREF+				I	Analog	A/D reference voltage (high) input.
RA4/T0CKI/C1OUT/RCV	6	23	23			
RA4				I/O	ST	Digital I/O.
T0CKI				I	ST	Timer0 external clock input.
C1OUT				O	—	Comparator 1 output.
RCV				I	TTL	External USB transceiver RCV input.
RA5/AN4/$\overline{SS}$/HLVDIN/C2OUT	7	24	24			
RA5				I/O	TTL	Digital I/O.
AN4				I	Analog	Analog input 4.
$\overline{SS}$				I	TTL	SPI slave select input.
HLVDIN				I	Analog	High/Low-Voltage Detect input.
C2OUT				O	—	Comparator 2 output.
RA6	—	—	—	—	—	See the OSC2/CLKO/RA6 pin.

Legend: TTL = TTL compatible input CMOS = CMOS compatible input or output
ST = Schmitt Trigger input with CMOS levels I = Input
O = Output P = Power

Note 1: Alternate assignment for CCP2 when CCP2MX Configuration bit is cleared.

2: Default assignment for CCP2 when CCP2MX Configuration bit is set.

3: These pins are No Connect unless the ICPRT Configuration bit is set. For NC/ICPORTS, the pin is No Connect unless ICPRT is set and the $\overline{DEBUG}$ Configuration bit is cleared.

TABLE 1-3: PIC18F4455/4550 PINOUT I/O DESCRIPTIONS (CONTINUED)

Pin Name	Pin Number			Pin Type	Buffer Type	Description
	PDIP	QFN	TQFP			
						PORTB is a bidirectional I/O port. PORTB can be software programmed for internal weak pull-ups on all inputs.
RB0/AN12/INT0/FLT0/SDI/SDA	33	9	8			
RB0				I/O	TTL	Digital I/O.
AN12				I	Analog	Analog input 12.
INT0				I	ST	External interrupt 0.
FLT0				I	ST	Enhanced PWM Fault input (ECCP1 module).
SDI				I	ST	SPI data in.
SDA				I/O	ST	I²C™ data I/O.
RB1/AN10/INT1/SCK/SCL	34	10	9			
RB1				I/O	TTL	Digital I/O.
AN10				I	Analog	Analog input 10.
INT1				I	ST	External interrupt 1.
SCK				I/O	ST	Synchronous serial clock input/output for SPI mode.
SCL				I/O	ST	Synchronous serial clock input/output for I²C mode.
RB2/AN8/INT2/VMO	35	11	10			
RB2				I/O	TTL	Digital I/O.
AN8				I	Analog	Analog input 8.
INT2				I	ST	External interrupt 2.
VMO				O	—	External USB transceiver VMO output.
RB3/AN9/CCP2/VPO	36	12	11			
RB3				I/O	TTL	Digital I/O.
AN9				I	Analog	Analog input 9.
CCP2[1]				I/O	ST	Capture 2 input/Compare 2 output/PWM2 output.
VPO				O	—	External USB transceiver VPO output.
RB4/AN11/KBI0/CSSPP	37	14	14			
RB4				I/O	TTL	Digital I/O.
AN11				I	Analog	Analog input 11.
KBI0				I	TTL	Interrupt-on-change pin.
CSSPP				O	—	SPP chip select control output.
RB5/KBI1/PGM	38	15	15			
RB5				I/O	TTL	Digital I/O.
KBI1				I	TTL	Interrupt-on-change pin.
PGM				I/O	ST	Low-Voltage ICSP™ Programming enable pin.
RB6/KBI2/PGC	39	16	16			
RB6				I/O	TTL	Digital I/O.
KBI2				I	TTL	Interrupt-on-change pin.
PGC				I/O	ST	In-Circuit Debugger and ICSP programming clock pin.
RB7/KBI3/PGD	40	17	17			
RB7				I/O	TTL	Digital I/O.
KBI3				I	TTL	Interrupt-on-change pin.
PGD				I/O	ST	In-Circuit Debugger and ICSP programming data pin.

Legend: TTL = TTL compatible input CMOS = CMOS compatible input or output
ST = Schmitt Trigger input with CMOS levels I = Input
O = Output P = Power

Note 1: Alternate assignment for CCP2 when CCP2MX Configuration bit is cleared.
2: Default assignment for CCP2 when CCP2MX Configuration bit is set.
3: These pins are No Connect unless the ICPRT Configuration bit is set. For NC/ICPORTS, the pin is No Connect unless ICPRT is set and the $\overline{\text{DEBUG}}$ Configuration bit is cleared.

TABLE 1-3: PIC18F4455/4550 PINOUT I/O DESCRIPTIONS (CONTINUED)

Pin Name	Pin Number			Pin Type	Buffer Type	Description
	PDIP	QFN	TQFP			
						PORTC is a bidirectional I/O port.
RC0/T1OSO/T13CKI	15	34	32			
RC0				I/O	ST	Digital I/O.
T1OSO				O	—	Timer1 oscillator output.
T13CKI				I	ST	Timer1/Timer3 external clock input.
RC1/T1OSI/CCP2/UOE	16	35	35			
RC1				I/O	ST	Digital I/O.
T1OSI				I	CMOS	Timer1 oscillator input.
CCP2$^{(1)}$				I/O	ST	Capture 2 input/Compare 2 output/PWM2 output.
UOE				O	—	External USB transceiver OE output.
RC2/CCP1/P1A	17	36	36			
RC2				I/O	ST	Digital I/O.
CCP1				I/O	ST	Capture 1 input/Compare 1 output/PWM1 output.
P1A				O	TTL	Enhanced CCP1 PWM output, channel A.
RC4/D-/VM	23	42	42			
RC4				I	TTL	Digital input.
D-				I/O	—	USB differential minus line (input/output).
VM				I	TTL	External USB transceiver VM input.
RC5/D+/VP	24	43	43			
RC5				I	TTL	Digital input.
D+				I/O	—	USB differential plus line (input/output).
VP				I	TTL	External USB transceiver VP input.
RC6/TX/CK	25	44	44			
RC6				I/O	ST	Digital I/O.
TX				O	—	EUSART asynchronous transmit.
CK				I/O	ST	EUSART synchronous clock (see RX/DT).
RC7/RX/DT/SDO	26	1	1			
RC7				I/O	ST	Digital I/O.
RX				I	ST	EUSART asynchronous receive.
DT				I/O	ST	EUSART synchronous data (see TX/CK).
SDO				O	—	SPI data out.

Legend:
TTL = TTL compatible input
ST = Schmitt Trigger input with CMOS levels
O = Output
CMOS = CMOS compatible input or output
I = Input
P = Power

Note 1: Alternate assignment for CCP2 when CCP2MX Configuration bit is cleared.

2: Default assignment for CCP2 when CCP2MX Configuration bit is set.

3: These pins are No Connect unless the ICPRT Configuration bit is set. For NC/ICPORTS, the pin is No Connect unless ICPRT is set and the $\overline{\text{DEBUG}}$ Configuration bit is cleared.

TABLE 1-3: PIC18F4455/4550 PINOUT I/O DESCRIPTIONS (CONTINUED)

Pin Name	Pin Number			Pin Type	Buffer Type	Description
	PDIP	QFN	TQFP			
						PORTE is a bidirectional I/O port.
RE0/AN5/CK1SPP RE0 AN5 CK1SPP	8	25	25	 I/O I O	 ST Analog —	 Digital I/O. Analog input 5. SPP clock 1 output.
RE1/AN6/CK2SPP RE1 AN6 CK2SPP	9	26	26	 I/O I O	 ST Analog —	 Digital I/O. Analog input 6. SPP clock 2 output.
RE2/AN7/OESPP RE2 AN7 OESPP	10	27	27	 I/O I O	 ST Analog —	 Digital I/O. Analog input 7. SPP output enable output.
RE3	—	—	—	—	—	See $\overline{\text{MCLR}}$/V_{PP}/RE3 pin.
V_{SS}	12, 31	6, 30, 31	6, 29	P	—	Ground reference for logic and I/O pins.
V_{DD}	11, 32	7, 8, 28, 29	7, 28	P	—	Positive supply for logic and I/O pins.
V_{USB}	18	37	37	P	—	Internal USB 3.3V voltage regulator output, positive supply for the USB transceiver.
NC/ICCK/ICPGC(3) ICCK ICPGC	—	—	12	 I/O I/O	 ST ST	No Connect or dedicated ICD/ICSP™ port clock. In-Circuit Debugger clock. ICSP programming clock.
NC/ICDT/ICPGD(3) ICDT ICPGD	—	—	13	 I/O I/O	 ST ST	No Connect or dedicated ICD/ICSP port clock. In-Circuit Debugger data. ICSP programming data.
NC/$\overline{\text{ICRST}}$/ICV_{PP}(3) $\overline{\text{ICRST}}$ ICV_{PP}	—	—	33	 I P	 — —	No Connect or dedicated ICD/ICSP port Reset. Master Clear (Reset) input. Programming voltage input.
NC/ICPORTS(3) ICPORTS	—	—	34	P	—	No Connect or 28-pin device emulation. Enable 28-pin device emulation when connected to V_{SS}.
NC	—	13	—	—	—	No Connect.

Legend:

TTL	= TTL compatible input	CMOS	= CMOS compatible input or output
ST	= Schmitt Trigger input with CMOS levels	I	= Input
O	= Output	P	= Power

Note 1: Alternate assignment for CCP2 when CCP2MX Configuration bit is cleared.

2: Default assignment for CCP2 when CCP2MX Configuration bit is set.

3: These pins are No Connect unless the ICPRT Configuration bit is set. For NC/ICPORTS, the pin is No Connect unless ICPRT is set and the $\overline{\text{DEBUG}}$ Configuration bit is cleared.

2.0 OSCILLATOR CONFIGURATIONS

2.1 Overview

Devices in the PIC18F2455/2550/4455/4550 family incorporate a different oscillator and microcontroller clock system than previous PIC18F devices. The addition of the USB module, with its unique requirements for a stable clock source, make it necessary to provide a separate clock source that is compliant with both USB low-speed and full-speed specifications.

To accommodate these requirements, PIC18F2455/2550/4455/4550 devices include a new clock branch to provide a 48 MHz clock for full-speed USB operation. Since it is driven from the primary clock source, an additional system of prescalers and postscalers has been added to accommodate a wide range of oscillator frequencies. An overview of the oscillator structure is shown in Figure 2-1.

Other oscillator features used in PIC18 enhanced microcontrollers, such as the internal oscillator block and clock switching, remain the same. They are discussed later in this chapter.

2.1.1 OSCILLATOR CONTROL

The operation of the oscillator in PIC18F2455/2550/4455/4550 devices is controlled through two Configuration registers and two control registers. Configuration registers, CONFIG1L and CONFIG1H, select the oscillator mode and USB prescaler/postscaler options. As Configuration bits, these are set when the device is programmed and left in that configuration until the device is reprogrammed.

The OSCCON register (Register 2-2) selects the Active Clock mode; it is primarily used in controlling clock switching in power-managed modes. Its use is discussed in **Section 2.4.1 "Oscillator Control Register"**.

The OSCTUNE register (Register 2-1) is used to trim the INTRC frequency source, as well as select the low-frequency clock source that drives several special features. Its use is described in **Section 2.2.5.2 "OSCTUNE Register"**.

2.2 Oscillator Types

PIC18F2455/2550/4455/4550 devices can be operated in twelve distinct oscillator modes. In contrast with previous PIC18 enhanced microcontrollers, four of these modes involve the use of two oscillator types at once. Users can program the FOSC3:FOSC0 Configuration bits to select one of these modes.

1.	XT	Crystal/Resonator
2.	HS	High-Speed Crystal/Resonator
3.	HSPLL	High-Speed Crystal/Resonator with PLL Enabled
4.	EC	External Clock with Fosc/4 Output
5.	ECIO	External Clock with I/O on RA6
6.	ECPLL	External Clock with PLL Enabled and Fosc/4 Output on RA6
7.	ECPIO	External Clock with PLL Enabled, I/O on RA6
8.	INTHS	Internal Oscillator used as Microcontroller Clock Source, HS Oscillator used as USB Clock Source
9.	INTIO	Internal Oscillator used as Microcontroller Clock Source, EC Oscillator used as USB Clock Source, Digital I/O on RA6
10.	INTCKO	Internal Oscillator used as Microcontroller Clock Source, EC Oscillator used as USB Clock Source, Fosc/4 Output on RA6

2.2.1 OSCILLATOR MODES AND USB OPERATION

Because of the unique requirements of the USB module, a different approach to clock operation is necessary. In previous PIC® devices, all core and peripheral clocks were driven by a single oscillator source; the usual sources were primary, secondary or the internal oscillator. With PIC18F2455/2550/4455/4550 devices, the primary oscillator becomes part of the USB module and cannot be associated to any other clock source. Thus, the USB module must be clocked from the primary clock source; however, the microcontroller core and other peripherals can be separately clocked from the secondary or internal oscillators as before.

Because of the timing requirements imposed by USB, an internal clock of either 6 MHz or 48 MHz is required while the USB module is enabled. Fortunately, the microcontroller and other peripherals are not required to run at this clock speed when using the primary oscillator. There are numerous options to achieve the USB module clock requirement and still provide flexibility for clocking the rest of the device from the primary oscillator source. These are detailed in **Section 2.3 "Oscillator Settings for USB"**.

FIGURE 2-1: PIC18F2455/2550/4455/4550 CLOCK DIAGRAM

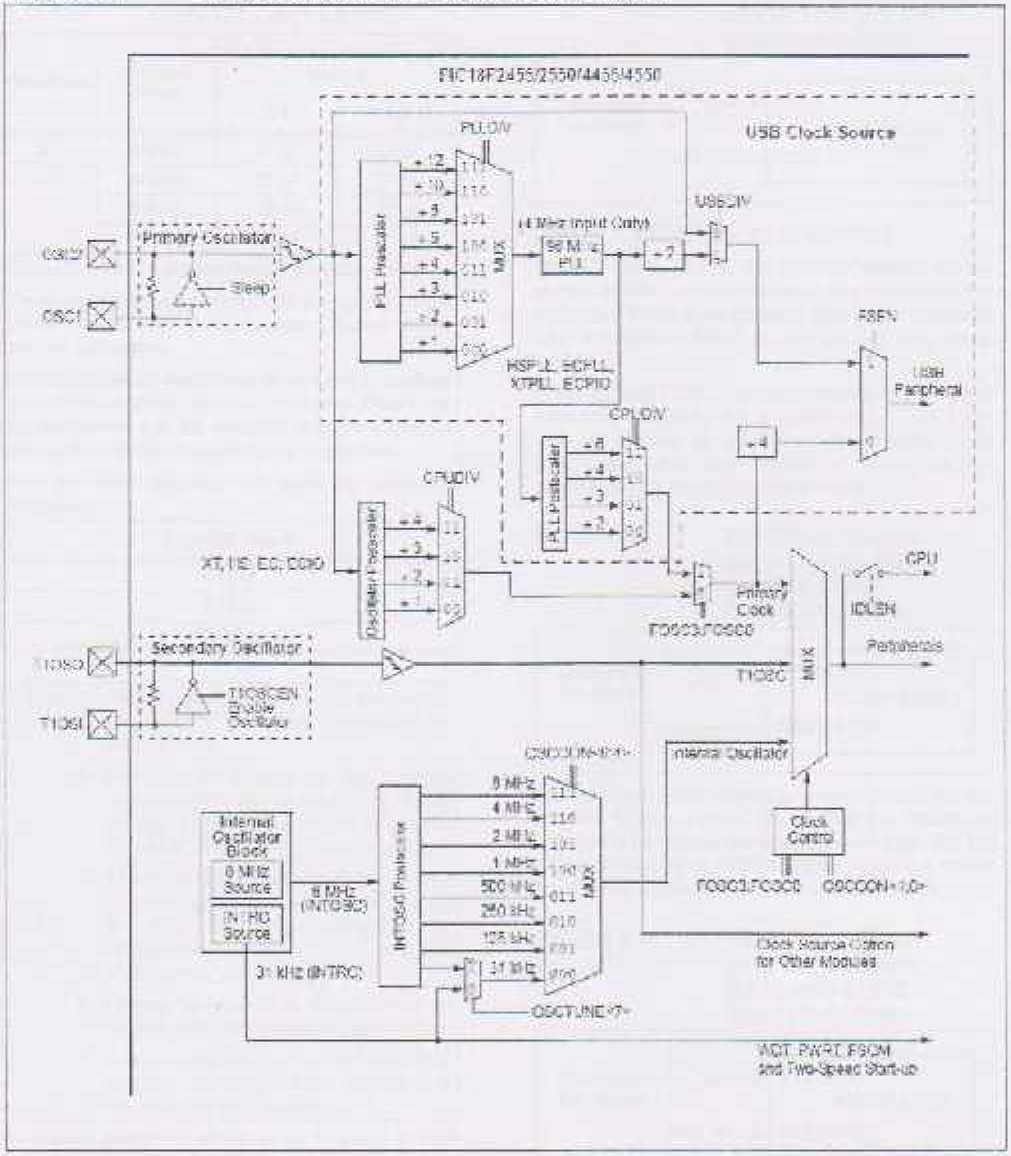


TABLE 2-2: CAPACITOR SELECTION FOR CRYSTAL OSCILLATOR

Osc Type	Crystal Freq	Typical Capacitor Values Tested:	
		C1	C2
XT	4 MHz	27 pF	27 pF
HS	4 MHz	27 pF	27 pF
	8 MHz	22 pF	22 pF
	20 MHz	15 pF	15 pF

Capacitor values are for design guidance only.

These capacitors were tested with the crystals listed below for basic start-up and operation. These values **are not optimized.**

Different capacitor values may be required to produce acceptable oscillator operation. The user should test the performance of the oscillator over the expected VDD and temperature range for the application.

See the notes following this table for additional information.

Crystals Used:
4 MHz
8 MHz
20 MHz

Note 1: Higher capacitance increases the stability of oscillator but also increases the start-up time.

2: When operating below 3V VDD, or when using certain ceramic resonators at any voltage, it may be necessary to use the HS mode or switch to a crystal oscillator.

3: Since each resonator/crystal has its own characteristics, the user should consult the resonator/crystal manufacturer for appropriate values of external components.

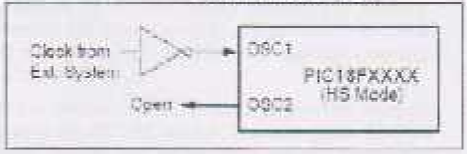
4: Rs may be required to avoid overdriving crystals with low drive level specification.

5: Always verify oscillator performance over the VDD and temperature range that is expected for the application.

An internal postscaler allows users to select a clock frequency other than that of the crystal or resonator. Frequency division is determined by the CPUDIV Configuration bits. Users may select a clock frequency of the oscillator frequency, or 1/2, 1/3 or 1/4 of the frequency.

An external clock may also be used when the microcontroller is in HS Oscillator mode. In this case, the OSC2/CLKO pin is left open (Figure 2-3).

FIGURE 2-3: EXTERNAL CLOCK INPUT OPERATION (HS OSC CONFIGURATION)

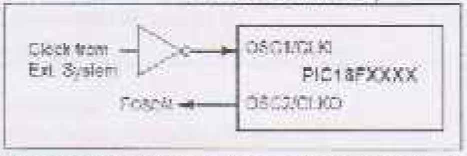


2.2.3 EXTERNAL CLOCK INPUT

The EC, ECIO, ECPLL and ECPIO Oscillator modes require an external clock source to be connected to the OSC1 pin. There is no oscillator start-up time required after a Power-on Reset or after an exit from Sleep mode.

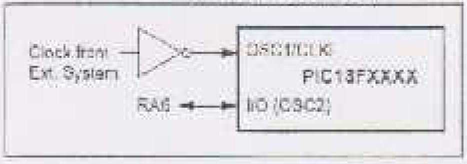
In the EC and ECPLL Oscillator modes, the oscillator frequency divided by 4 is available on the OSC2 pin. This signal may be used for test purposes or to synchronize other logic. Figure 2-4 shows the pin connections for the EC Oscillator mode.

FIGURE 2-4: EXTERNAL CLOCK INPUT OPERATION (EC AND ECPLL CONFIGURATION)



The ECIO and ECPIO Oscillator modes function like the EC and ECPLL modes, except that the OSC2 pin becomes an additional general purpose I/O pin. The I/O pin becomes bit 6 of PORTA (RA6). Figure 2-5 shows the pin connections for the ECIO Oscillator mode.

FIGURE 2-5: EXTERNAL CLOCK INPUT OPERATION (ECIO AND ECPIO CONFIGURATION)



The internal postscaler for reducing clock frequency in XT and HS modes is also available in EC and ECIO modes.

2.2.5.2 OSCTUNE Register

The internal oscillator's output has been calibrated at the factory but can be adjusted in the user's application. This is done by writing to the OSCTUNE register (Register 2-1). The tuning sensitivity is constant throughout the tuning range.

The INTOSC clock will stabilize within 1 ms. Code execution continues during this shift. There is no indication that the shift has occurred.

The OSCTUNE register also contains the INTSRC bit. The INTSRC bit allows users to select which internal oscillator provides the clock source when the 31 kHz frequency option is selected. This is covered in greater detail in **Section 2.4.1 "Oscillator Control Register"**.

2.2.5.3 Internal Oscillator Output Frequency and Drift

The internal oscillator block is calibrated at the factory to produce an INTOSC output frequency of 8.0 MHz. However, this frequency may drift as VDD or temperature changes, which can affect the controller operation in a variety of ways.

The low-frequency INTRC oscillator operates independently of the INTOSC source. Any changes in INTOSC across voltage and temperature are not necessarily reflected by changes in INTRC and vice versa.

REGISTER 2-1: OSCTUNE: OSCILLATOR TUNING REGISTER

R/W-0	U-0	U-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
INTSRC		—	TUN4	TUN3	TUN2	TUN1	TUN0
bit 7							bit 0

Legend:			
R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'	
-n = Value at POR	'1' = Bit is set	'0' = Bit is cleared	x = Bit is unknown

bit 7 **INTSRC:** Internal Oscillator Low-Frequency Source Select bit
1 = 31.25 kHz device clock derived from 8 MHz INTOSC source (divide-by-256 enabled)
0 = 31 kHz device clock derived directly from INTRC internal oscillator

bit 6-5 **Unimplemented:** Read as '0'

bit 4-0 **TUN4:TUN0:** Frequency Tuning bits
01111 = Maximum frequency
• •
• •
00001
00000 = Center frequency. Oscillator module is running at the calibrated frequency.
11111
• •
• •
10000 = Minimum frequency

2.3 Oscillator Settings for USB

When these devices are used for USB connectivity, they must have either a 6 MHz or 48 MHz clock for USB operation, depending on whether Low-Speed or Full-Speed mode is being used. This may require some forethought in selecting an oscillator frequency and programming the device.

The full range of possible oscillator configurations compatible with USB operation is shown in Table 2-3.

2.3.1 LOW-SPEED OPERATION

The USB clock for Low-Speed mode is derived from the primary oscillator chain and not directly from the PLL. It is divided by 4 to produce the actual 6 MHz clock. Because of this, the microcontroller can only use a clock frequency of 24 MHz when the USB module is active and the controller clock source is one of the primary oscillator modes (XT, HS or EC, with or without the PLL).

This restriction does not apply if the microcontroller clock source is the secondary oscillator or internal oscillator block.

2.3.2 RUNNING DIFFERENT USB AND MICROCONTROLLER CLOCKS

The USB module, in either mode, can run asynchronously with respect to the microcontroller core and other peripherals. This means that applications can use the primary oscillator for the USB clock while the microcontroller runs from a separate clock source at a lower speed. If it is necessary to run the entire application from only one clock source, full-speed operation provides a greater selection of microcontroller clock frequencies.

TABLE 2-3: OSCILLATOR CONFIGURATION OPTIONS FOR USB OPERATION

Input Oscillator Frequency	PLL Division (PLLDIV2:PLLDIV0)	Clock Mode (FOSC3:FOSC0)	MCU Clock Division (CPUDIV1:CPUDIV0)	Microcontroller Clock Frequency
48 MHz	N/A[1]	EC, ECIO	None (00)	48 MHz
			÷2 (01)	**24 MHz**
			÷3 (10)	16 MHz
			÷4 (11)	12 MHz
48 MHz	÷12 (111)	EC, ECIO	None (00)	48 MHz
			÷2 (01)	24 MHz
			÷3 (10)	16 MHz
			÷4 (11)	12 MHz
		ECPLL, ECPIO	÷2 (00)	48 MHz
			÷3 (01)	32 MHz
			÷4 (10)	24 MHz
			÷6 (11)	16 MHz
40 MHz	÷10 (110)	EC, ECIO	None (00)	40 MHz
			÷2 (01)	20 MHz
			÷3 (10)	13.33 MHz
			÷4 (11)	10 MHz
		ECPLL, ECPIO	÷2 (00)	48 MHz
			÷3 (01)	32 MHz
			÷4 (10)	**24 MHz**
			÷6 (11)	16 MHz
24 MHz	÷6 (101)	HS, EC, ECIO	None (00)	**24 MHz**
			÷2 (01)	12 MHz
			÷3 (10)	8 MHz
			÷4 (11)	6 MHz
		HSPLL, ECPLL, ECPIO	÷2 (00)	48 MHz
			÷3 (01)	32 MHz
			÷4 (10)	**24 MHz**
			÷6 (11)	16 MHz

Legend: All clock frequencies, except 24 MHz, are exclusively associated with full-speed USB operation (USB clock of 48 MHz). Bold is used to highlight clock selections that are compatible with low-speed USB operation (system clock of 24 MHz, USB clock of 6 MHz).

Note 1: Only valid when the USBDIV Configuration bit is cleared.

TABLE 2-3: OSCILLATOR CONFIGURATION OPTIONS FOR USB OPERATION (CONTINUED)

Input Oscillator Frequency	PLL Division (PLLDIV2:PLLDIV0)	Clock Mode (FOSC3:FOSC0)	MCU Clock Division (CPUDIV1:CPUDIV0)	Microcontroller Clock Frequency
20 MHz	÷5 (100)	HS, EC, ECIO	None (00)	20 MHz
			÷2 (01)	10 MHz
			÷3 (10)	6.67 MHz
			÷4 (11)	5 MHz
		HSPLL, ECPLL, ECPIO	÷2 (00)	48 MHz
			÷3 (01)	32 MHz
			÷4 (10)	**24 MHz**
			÷6 (11)	16 MHz
16 MHz	÷4 (011)	HS, EC, ECIO	None (00)	16 MHz
			÷2 (01)	8 MHz
			÷3 (10)	5.33 MHz
			÷4 (11)	4 MHz
		HSPLL, ECPLL, ECPIO	÷2 (00)	48 MHz
			÷3 (01)	32 MHz
			÷4 (10)	**24 MHz**
			÷6 (11)	16 MHz
12 MHz	÷3 (010)	HS, EC, ECIO	None (00)	12 MHz
			÷2 (01)	6 MHz
			÷3 (10)	4 MHz
			÷4 (11)	3 MHz
		HSPLL, ECPLL, ECPIO	÷2 (00)	48 MHz
			÷3 (01)	32 MHz
			÷4 (10)	**24 MHz**
			÷6 (11)	16 MHz
8 MHz	÷2 (001)	HS, EC, ECIO	None (00)	8 MHz
			÷2 (01)	4 MHz
			÷3 (10)	2.67 MHz
			÷4 (11)	2 MHz
		HSPLL, ECPLL, ECPIO	÷2 (00)	48 MHz
			÷3 (01)	32 MHz
			÷4 (10)	**24 MHz**
			÷6 (11)	16 MHz
4 MHz	÷1 (000)	XT, HS, EC, ECIO	None (00)	4 MHz
			÷2 (01)	2 MHz
			÷3 (10)	1.33 MHz
			÷4 (11)	1 MHz
		HSPLL, ECPLL, XTPLL, ECPIO	÷2 (00)	48 MHz
			÷3 (01)	32 MHz
			÷4 (10)	**24 MHz**
			÷6 (11)	16 MHz

Legend: All clock frequencies, except 24 MHz, are exclusively associated with full-speed USB operation (USB clock of 48 MHz). Bold is used to highlight clock selections that are compatible with low-speed USB operation (system clock of 24 MHz, USB clock of 6 MHz).

Note 1: Only valid when the USBDIV Configuration bit is cleared.

2.4.2 OSCILLATOR TRANSITIONS

PIC18F2455/2550/4455/4550 devices contain circuitry to prevent clock "glitches" when switching between clock sources. A short pause in the device clock occurs during the clock switch. The length of this pause is the sum of two cycles of the old clock source and three to four cycles of the new clock source. This formula assumes that the new clock source is stable.

Clock transitions are discussed in greater detail in **Section 3.1.2 "Entering Power-Managed Modes"**.

REGISTER 2-2: OSCCON: OSCILLATOR CONTROL REGISTER

R/W-0	R/W-1	R/W-0	R/W-0	R[1]	R-0	R/W-0	R/W-0
IDLEN	IRCF2	IRCF1	IRCF0	OSTS	IOFS	SCS1	SCS0
bit 7							bit 0

Legend:			
R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'	
-n = Value at POR	'1' = Bit is set	'0' = Bit is cleared	x = Bit is unknown

bit 7 **IDLEN:** Idle Enable bit
1 = Device enters Idle mode on `SLEEP` instruction
0 = Device enters Sleep mode on `SLEEP` instruction

bit 6-4 **IRCF2:IRCF0:** Internal Oscillator Frequency Select bits
111 = 8 MHz (INTOSC drives clock directly)
110 = 4 MHz
101 = 2 MHz
100 = 1 MHz[3]
011 = 500 kHz
010 = 250 kHz
001 = 125 kHz
000 = 31 kHz (from either INTOSC/256 or INTRC directly)[2]

bit 3 **OSTS:** Oscillator Start-up Time-out Status bit[1]
1 = Oscillator Start-up Timer time-out has expired; primary oscillator is running
0 = Oscillator Start-up Timer time-out is running; primary oscillator is not ready

bit 2 **IOFS:** INTOSC Frequency Stable bit
1 = INTOSC frequency is stable
0 = INTOSC frequency is not stable

bit 1-0 **SCS1:SCS0:** System Clock Select bits
1x = Internal oscillator
01 = Timer1 oscillator
00 = Primary oscillator

Note 1: Depends on the state of the IESO Configuration bit.
2: Source selected by the INTSRC bit (OSCTUNE<7>), see text.
3: Default output frequency of INTOSC on Reset.

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Rating	Symbol	1N4001	1N4002	1N4003	1N4004	1N4005	1N4006	1N4007	Unit
*Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	400	600	800	1000	Volts
*Non–Repetitive Peak Reverse Voltage (halfwave, single phase, 60 Hz)	V_{RSM}	60	120	240	480	720	1000	1200	Volts
*RMS Reverse Voltage	$V_{R(RMS)}$	35	70	140	280	420	560	700	Volts
*Average Rectified Forward Current (single phase, resistive load, 60 Hz, see Figure 8, $T_A = 75°C$)	I_O	1.0							Amp
*Non–Repetitive Peak Surge Current (surge applied at rated load conditions, see Figure 2)	I_{FSM}	30 (for 1 cycle)							Amp
Operating and Storage Junction Temperature Range	T_J T_{stg}	– 65 to +175							°C

ELECTRICAL CHARACTERISTICS*

Rating	Symbol	Typ	Max	Unit
Maximum Instantaneous Forward Voltage Drop ($i_F = 1.0$ Amp, $T_J = 25°C$) Figure 1	v_F	0.93	1.1	Volts
Maximum Full–Cycle Average Forward Voltage Drop ($I_O = 1.0$ Amp, $T_L = 75°C$, 1 inch leads)	$V_{F(AV)}$	—	0.8	Volts
Maximum Reverse Current (rated dc voltage) ($T_J = 25°C$) ($T_J = 100°C$)	I_R	 0.05 1.0	 10 50	μA
Maximum Full–Cycle Average Reverse Current ($I_O = 1.0$ Amp, $T_L = 75°C$, 1 inch leads)	$I_{R(AV)}$	—	30	μA

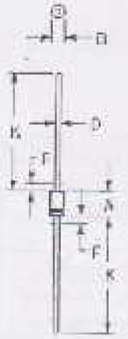
*Indicates JEDEC Registered Data

Preferred devices are Motorola recommended choices for future use and best overall value.

Rev 5

MOTOROLA

PACKAGE DIMENSIONS



NOTES:
1. ALL RULES AND NOTES ASSOCIATED WITH JEDEC DO-41 OUTLINE SHALL APPLY.
2. POLARITY DENOTED BY CATHODE BAND.
3. LEAD DIAMETER NOT CONTROLLED WITHIN F DIMENSION.

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	4.10	5.20	0.161	0.205
B	2.04	2.71	0.080	0.107
D	0.71	0.86	0.028	0.034
F	—	1.27	—	0.050
K	27.94	—	1.100	—

CASE 59–03
(DO–41)
ISSUE M

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MOTOROLA

RADIAL TYPE

TK Series Wide Temperature Range

SM ⇨ TK ⇨ TM

- High temperature 105°C and high reliability

SPECIFICATION

Item	Charecteristic		
Operation Temperature Range	-55 ~ +105°C	-40 ~ +105°C	-25 ~ +105°C
Rated Working Voltage	6.3 ~ 100VDC	160 ~ 400VDC	450VDC
Capacitance Tolerance (120Hz 20°C)	±20%(M)		
Leakage Current (20°C)	6.3~100 VDC I≦0.01CV or 4 (μA) *Whichever is greater after 3 minutes I : Leakage Current(μA) C : Rated Capacitance(μF) V : Working Voltage(V)	160~450 VDC I≦0.03CV +10 (μA)max	

Surge Voltage (20°C)

W.V.	6.3	10	16	25	35	50	63	100	160	200	250	350	400	450
S.V.	8	13	20	32	44	63	79	125	200	250	300	400	450	500

Dissipation Factor (tan δ) (120Hz 20°C)

Add 0.02 per 1000 μF for more than 1000 μF

W.V.	6.3	10	16	25	35	50	63	100	160	200	250	350	400	450
tan δ	0.24	0.20	0.17	0.15	0.12	0.10	0.10	0.08	0.15	0.15	0.15	0.20	0.20	0.20

Low Temperature Stability

Impedance ratio at 120Hz

Rated Voltage (V)	6.3	10	16	25	35~100	160~250	350~400	450
-25°C / +20°C	4	3	2	2	2	3	6	15
-40°C / +20°C	10	8	6	4	3	4	10	—

Load Life

After 2000 hours application of W.V. at +105°C, the capacitor shall meet the following limits

Capacitance Change	≦+25% of initial value for 6.3~16 W.V., ≦±20% of initial value for 25~450 W.V
Dissipation Factor	≦200% of initial specified value
Leakage current	≦initial specified value

Shelf Life

At +105°C no voltage application after 1000 hours the capacitor shall meet the limits for load life characteristics. (with voltage treatment)

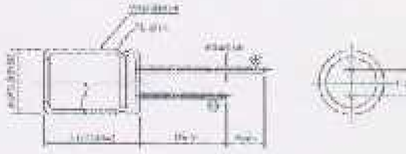
DIMENSIONS (mm)

φD	5	6.3	8	10	12.5	16	18	20	22	25
F	2.0	2.5	3.5	5.0	5.0	7.5	7.5	10.0	10.0	12.5
d	0.5	0.5	0.6	0.6	0.6	0.8	0.8	0.8	1.0	1.0
α	1.0	1.5	1.5	1.5	1.5	1.5	1.5	2.0	2.0	2.0

RIPPLE CURRENT COEFFICIENTS

Temperature(°C)	65	85	105
Multiplier	1.75	1.40	1.00

Frequency(Hz) W.V	60	120	1K	≥10K
	Multiplier			
6.3~25V	0.65	1.00	1.10	1.20
35~100V	0.80	1.00	1.15	1.25
160~250V	0.75	1.00	1.25	1.40
350~450V	0.70	1.00	1.30	1.50



CASE SIZE & MAX RIPPLE CURRENT

Case size D x L (mm)
Max ripple current mA(rms) 105°C 120Hz

μF	Code	6.3 (0J) DxL	6.3 (0J) R.C.	10 (1A) DxL	10 (1A) R.C.	16 (1C) DxL	16 (1C) R.C.
47	470				→	5x11	75
100	101	5x11	95	5x11	100	5x11	110
220	221	5x11	140	5x11	150	6.3x11	190
330	331	6.3x11	200	6.3x11	210	8x11.5	270
470	471	6.3x11	230	6.3x11	260	8x11.5	320
1000	102	8x11.5	400	10x12.5	460	10x18	590
2200	222	10x18	660	10x20	760	12.5x20	910
3300	332	10x20	880	12.5x20	890	12.5x25	1170
4700	472	12.5x20	1040	12.5x25	1230	16x25	1310
6800	682	12.5x25	1300	16x25	1390	16x31.5	1620
10000	103	16x25	1450	16x35.5	1790	16x35.5	1970
15000	153	16x35.5	1630	18x35.5	2090	20x40	2210
22000	223	18x40	2250	20x40	2160	22x50	2940
33000	333	22x50	2600	22x50	3020	25x50	3500

All blank voltage on sleeve marking is the same voltage as " → " point to.

μF	Code	25 (1E) DxL	25 (1E) R.C.	35 (1V) DxL	35 (1V) R.C.	50 (1H) DxL	50 (1H) R.C.
0.1	0R1				→	5x11	5
0.22	R22				→	5x11	7
0.33	R33				→	5x11	8
0.47	R47				→	5x11	10
1	010				→	5x11	15
2.2	2R2				→	5x11	22
3.3	3R3				→	5x11	27
4.7	4R7				→	5x11	32
10	100	5x11	38	5x11	42	5x11	46
22	220	5x11	65	5x11	65	5x11	70
33	330	5x11	70	5x11	75	5x11	85
47	470	5x11	80	5x11	90	6.3x11	110
100	101	6.3x11	140	6.3x11	150	8x11.5	190
220	221	8x11.5	240	8x11.5	290	10x12.5	330
330	331	8x11.5	280	10x12.5	340	10x16	410
470	471	10x12.5	360	10x16	450	10x20	540
1000	102	10x20	650	12.5x20	770	12.5x25	950
2200	222	12.5x25	1060	16x25	1160	16x35.5	1400
3300	332	16x25	1240	18x35.5	1570	18x35.5	1750
4700	472	16x31.5	1520	18x35.5	1940		
6800	682	18x35.5	1890				
10000	103	20x40	2270				
15000	153	22x50	2860				
22000	223	25x50	3210				

Zener diode

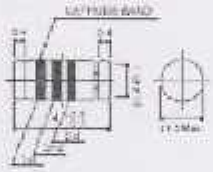
RLZ Series

●Applications
Constant voltage control.

●Features
1) Small surface mounting type. (LLDS)
2) High reliability.

●Construction
Silicon epitaxial planar

●External dimensions (Units : mm)



ROHM : LLDS
EIAJ :
JEDEC : LL-34

●Cathode band colors

Type	1st color band	2nd color band	3rd color band	Type	1st color band	2nd color band	3rd color band
RLZ 3.6B	Black	Purple	Green	RLZ 12B	Red	Black	Green
RLZ 3.9B	Black	Gray		RLZ 13B	Red	Brown	
RLZ 4.3B	Black	White		RLZ 15B	Red	Red	
RLZ 4.7B	Brown	Black		RLZ 16B	Red	Orange	
RLZ 5.1B	Brown	Brown		RLZ 18B	Red	Yellow	
RLZ 5.6B	Brown	Red		RLZ 20B	Red	Green	
RLZ 6.2B	Brown	Orange		RLZ 22B	Red	Blue	
RLZ 6.8B	Brown	Yellow		RLZ 24B	Red	Purple	
RLZ 7.5B	Brown	Green		RLZ 27B	Red	Gray	
RLZ 8.2B	Brown	Blue		RLZ 30B	Red	White	
RLZ 9.1B	Brown	Purple		RLZ 33B	Orange	Black	
RLZ 10B	Brown	Gray		RLZ 36B	Orange	Brown	
RLZ 11B	Brown	White		RLZ 39B	Orange	Red	

●Absolute maximum ratings (Ta=25°C)

Parameter	Symbol	Limits	Unit
Power dissipation	P	500	mW
Junction temperature	T_j	175	°C
Storage temperature	T_{stg}	-65~+175	°C

●Electrical characteristics (T_a=25°C)

Type	Zener voltage V_Z (V)			Operating resistance Z_Z (Ω)		Rising operating resistance Z_{ZK} (Ω)		Reverse current I_R (μA)	
	Min.	Max.	I_Z (mA)	Max.	I_Z (mA)	Max.	I_Z (mA)	Max.	V_R (V)
RLZ 3.6B	3.600	3.845	20	60	20	1000	1	10	1.0
RLZ 3.9B	3.89	4.16	20	50	20	1000	1	5	1.0
RLZ 4.3B	4.17	4.43	20	40	20	1000	1	5	1.0
RLZ 4.7B	4.55	4.80	20	25	20	900	1	5	1.0
RLZ 5.1B	4.94	5.20	20	20	20	800	1	5	1.5
RLZ 5.6B	5.45	5.73	20	13	20	500	1	5	2.5
RLZ 6.2B	5.96	6.27	20	10	20	300	1	5	3.0
RLZ 6.8B	6.49	6.83	20	8	20	150	0.5	2	3.5
RLZ 7.5B	7.07	7.45	20	8	20	120	0.5	0.5	4.0
RLZ 8.2B	7.78	8.19	20	8	20	120	0.5	0.5	5.0
RLZ 9.1B	8.57	9.01	20	8	20	120	0.5	0.5	6.0
RLZ 10B	9.41	9.90	20	8	20	120	0.5	0.2	7.0
RLZ 11B	10.50	11.05	10	10	10	120	0.5	0.2	8.0
RLZ 12B	11.44	12.03	10	12	10	110	0.5	0.2	9.0
RLZ 13B	12.55	13.21	10	14	10	110	0.5	0.2	10
RLZ 15B	13.89	14.62	10	16	10	110	0.5	0.2	11
RLZ 16B	15.26	16.04	10	18	10	150	0.5	0.2	12
RLZ 18B	16.82	17.70	10	23	10	150	0.5	0.2	13
RLZ 20B	18.63	19.59	10	28	10	200	0.5	0.2	15
RLZ 22B	20.64	21.71	5	30	5	200	0.5	0.2	17
RLZ 24B	22.61	23.77	5	35	5	200	0.5	0.2	19
RLZ 27B	24.97	26.20	5	45	5	250	0.5	0.2	21
RLZ 30B	27.70	29.13	5	55	5	250	0.5	0.2	23
RLZ 33B	30.32	31.88	5	65	5	250	0.5	0.2	25
RLZ 36B	32.79	34.49	5	75	5	250	0.5	0.2	27
RLZ 39B	35.36	37.10	5	85	5	250	0.5	0.2	30

* The Zener voltage is measured 40ms after power is supplied.

- Electrical characteristic curves (Ta=25°C)

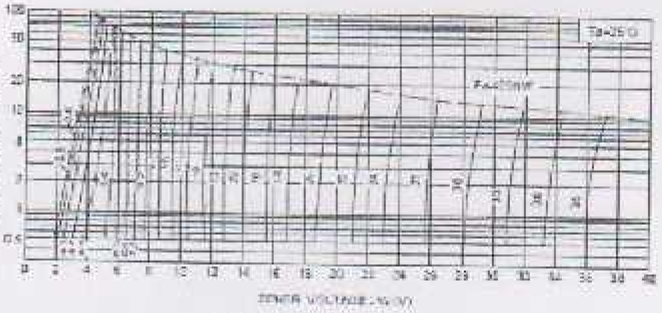


Fig.1 Zener characteristics

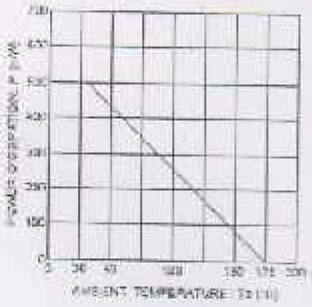


Fig.2 Derating curve

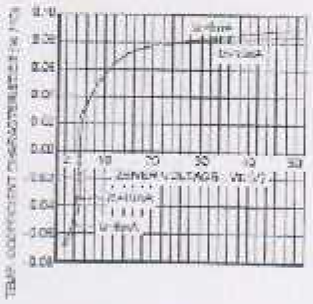


Fig.3 Zener voltage
temp.coefficient characteristics