Palestine Polytechnic University

College of Engineering and Technology
Mechanical Engineering Department

Graduation Project

Antilock Braking System: Monitoring & Simulation

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الملخص

نظرا للأهمية التي تكتسبها أنظمة الأمان في السيارات، وفي ظل الثورة التكنولوجية في مجالي الحاسوب والالكترونيات كان لا بد من إضافة أنظمة تحكم وأمان في السيارات مستفيدين من التطور الحاصل في هذه المجالات.

لقد غدا نظام منع الإقفال للكوابح (ABS) من اهم أنظمة التحكم في السيارة أثناء حركتها، وخاصة أثناء التوقف المفاجئ؛ ولقد اكتسب هذا النظام أهميته في السنوات الأخيرة نظرا للتطور المستمر في العلوم المختلفة، إضافة إلى زيادة معايير الأمان من قبل الجهات المختصة.

يهدف هذا المشروع إلى عمل حزمة تعليمية متكاملة خاصة بنظام منع الإقفال، بما فيها الجزء العملي وما يتصل به من مراقبة لمجموعة من الإشارات الأساسية التي توضح مبدأ عمل النظام، كما أنه من خلال برنامج المحاكاة سيصبح من الممكن تغيير بعض العوامل المؤثرة في عمل النظام متيحا بذلك إمكانيات أكثر لفهم وإزالة أي لبس يتعلق بمبدأ عمل النظام.

تم تقسيم العمل في المشروع إلى مرحلتين: حيث تمت في المرحلة الأولى مراقبة مجموعة من الإشارات الخاصة بهذا النظام وهي سرعة السيارة، والضغط الموجود في أنابيب الكوابح بالإضافة إلى الإشارة الصادرة من وحدة التحكم إلى الصمام الكهربائي؛ وذلك باستعمال نموذج لنظام منع الإقفال الموجود في مشغل السيارات التابع لجامعة بوليتكنك فلسطين، من خلال ربط هذا المجسم بجهاز الحاسوب، وتمت المراقبة باستعمال برنامج خاص هو LabVIEW، و كان الهدف من عملية مراقبة النظام هو تعميق الفهم لدى الطلاب لمبدأ عمل نظام منع الإقفال وذلك من خلال قياس و تحليل الإشارات.

أما في المرحلة الثانية من المشروع تم عمل برنامج محاكاة لنظام منع الإقفال باستخدام برنامجي LabVIEW & MATLAB، حيث تمت إتاحة الفرصة أمام المستخدم لتغيير بعض العوامل الخاصة بالنظام من خلال استعمال تلك البرامج مثل معامل الاحتكاك، ومقدار الانزلاق في النظام، و كان الهدف من ذلك هو توضيح الإشارات التي تؤخذ من النظام نظريا، ومقارنتها ببعض الإشارات والرسومات الموجودة في بعض المراجع، من اجل تعميق الفهم للنظام وإزالة جميع التساؤلات المتعلقة بمبدأ عمل النظام.

Abstract

ABS system has become a very important system in the control of vehicle motion, especially under severe braking conditions. ABS has gained much of its importance during the last decade from two aspects; with the aid of electronic science, which lay the foundation of the modern type of ABS, and with the increasingly standards of safety of vehicles.

In this project the signal that describe the principle of operation of the ABS system have been monitored, these signals are speed signal, brake pressure value and the Electronic Control Unit (ECU) signal to the solenoid valves, the ABS system already exists in the automotive workshop that belongs to "Palestine Polytechnic University".

In the second stage of project, a simulation program of an ABS system using an appropriate softwares "MATLAB & LabVIEW" have been built, all of this in order to clarify the various manipulations that occur inside the ECU, and removing of any confusion that remains after the monitoring stage, all of this in order to provide the user with an education package that will help him answer any question concerning the ABS system.

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W : The angular velocity of the wheel.

U : The linear velocity of the vehicle

P : The pressure in the brake line

M : Total mass of quarter car and wheel

V : Longitudinal velocity

ω : Angular velocity

τ_b : Braking torque applied by disk/drum brake

I : Wheel's moment of inertia

$\mu(s)$: Friction coefficient between tire and road

F_{Normal} : Vertical normal force on the road = Mg

R : Radius of wheel

c_x : Aerodynamic coefficient of the wheel

β : Friction coefficient of the wheel bearings

S : Slip ratio

v_b : Braking pressure from the braking pedal.

τ : Time constant.

K_b : Braking gain.

Chapter One

Introduction

Chapter One

Introduction

1.1 Project Idea

Antilock braking system (ABS) is an electronic system that monitors and controls wheel slip during vehicle braking. ABS can improve vehicle control during braking, and reduce stopping distances on slippery road surfaces by limiting wheel slip and minimizing lockup. Rolling wheels have much more traction than locked wheels. Reducing wheel slip improves vehicle stability and controllability during braking, since stability increases as wheel slip decreases.

ABS system has become a very important system in the control of vehicle motion, especially under severe braking conditions. ABS has gained much of its importance during the last decade from two aspects; with the aid of electronic science, which lay the foundation of the modern type of ABS, and with the increasingly standards of safety of vehicles and passengers.

Moving toward optimization of brake action; research centers simulate and monitors the ABS system in order to create the optimal brake system that will protect the drivers in nearly all conditions if possible. So this project is intended at the first place to monitor the ABS system which already exists in the automotive workshop that belongs to our university, in order to clarify the various input and output signals, in addition, to simulate an ABS system using an appropriate softwares such as "MATLAB" and/or LabVIEW, all of this in order to contribute in the tendency of development of safety automotive systems which is the main issue of the automotive research centers in the last years.

1.2 Importance of this project

Since the tendency in automotive manufacturing is to utilize ABS system on modern speedy vehicles, that is to increase safety and enhance breaking system action under sever operation conditions, a deep look should be taken at this system to know how it works and to clear up some confusion about it.

This project will be implemented and served for students in the laboratory to give them a chance to apply what they have learned in the courses, and make a sense about it. Also the project is intended to give students a closer look and a clear vision about the system signals and the manipulations that occur on these signals in the controller; through monitors attached to the system hardware, also the programming of simulation package, with graphical user interface (GUI), all of these-monitor, simulation- will give students a clear understanding of the ABS behavior and gives the ability to test the system before going to verify results through the hardware.

1.3 Literature review of ABS system

This section illustrates the development of ABS system, also it describes some theses that emphasize the importance of ABS system, and simulation programs found in the markets that are used either to study the ABS system or to test existing ABS systems.

Anti-lock braking systems were first developed for aircraft. An early system was Dunlop's Maxaret system, introduced in the 1950s and still in use on some aircraft models. This was a fully mechanical system. It saw limited automobile use in the 1960s in the Ferguson P99 racing car, the Jensen FF and the experimental all wheel drive Ford Zodiac, but saw no further use; the system proved expensive and in automobile use somewhat unreliable. A purely mechanical system developed and sold by Lucas Girling was factory-fitted to the Ford Fiesta Mk III. It was called the Stop Control System

More than two-thirds of all new vehicles worldwide are now fitted with ABS and in Europe every car from the middle of 2004 was fitted with ABS. The German firm of Robert Bosch GmbH had been developing anti-lock braking technology since the 1930s, but the first production cars using Bosch's electronic system became available in 1978. The rest of vehicle companies followed in recognizing the importance of the ABS system and in the installation of it as years passed, here is some statistics:

- BMW applied ABS to its road cars in 1979. Then motorcycles in 1987.
- Bosch launched the modern computerized ABS in the early 80s. Mercedes and BMW included it as option of their top of the range.
- In 1985, Ford Granada Scorpio took it as standard equipment.
- In the mid-80s, Lucas Girling and AP also developed their low price ABS for cars like Ford Escort and Fiat Uno. Both served only the front wheels.
- Today, even mini cars offer ABS as standard.

Now the papers discussing the ABS system advantages combined with other vehicle systems are presented

Nonlinear Control Design of Anti-lock Braking Systems Combined with Active Suspensions, Wei-En Ting and Jung-Shan Lin, Department of Electrical Engineering National Chi Nan University:

This paper develops the anti-lock braking control system integrated with active suspensions applied to a quarter- car model by employing the nonlinear back stepping design schemes. The goal of this paper is to take advantage of anti-lock braking systems combined with active suspensions to further reduce the vehicle braking time and distance.

The conclusion from this paper proves that ABS system is very important in reducing the stopping distance and time.

A Simulation Model for Vehicle Braking Systems Fitted with ABS, Terry D. Day Sydney G. Roberts, Engineering Dynamics Corporation, SAE 2002 world congress, March 2002:

This paper describes a new ABS model implemented in the Hybrid Vehicle Electric(HVE) simulation environment. Two ABS algorithms were implemented. These are the Tire Slip algorithm and the HVE Bosch Version 1 algorithm. These algorithms, the results from these two algorithms indicate that the first algorithm is simple and fast and more applicable to vehicles than the second one, and both show a decrease in stopping time and distance compared with systems that don't use ABS.

Many simulation programs for the vehicle electronic systems including ABS system are found in the market, the following will present two of these programs.

Simulink®, MatLab, © 1994-2006 The MathWorks, Inc

The world first modeling and simulation program, it's a general modular program that can provide the user with a variety of tools for modeling and simulating nearly every physical system, once the user had the model the MatLab provides the blocks representing the model then it generates the code and gives the solution for the model, the model can be expanded to include Hard Ware in the Loop(HWL), which can be used either to verify any design of ABS model or with the appropriate modeling can be used to test currently existing ABS systems.

acslXtreme, www.acslXtreme.com .

Using acslXtreme Block Diagram modeling tool, the components of an ABS system (the controller, hydraulic system, the wheels and the wheel/road interface) were computerized and modeled. The pressure applied to the brake is regulated by the controller as a function of the difference between vehicle velocity and wheel velocity subjected to some performance and time constants. These sub-systems and their time constants can be tuned and the effects on wheel and vehicle speed, vehicle position, as well as relative slip itself can be observed and recorded.

After building the model in acslXtreme, the compiled simulation can be integrated into existing controller system for further optimization of the ABS. acslXtreme open API allows the easy incorporation of the model into a number of other engineering software platforms for evaluation and analysis. Fig.1.2 below shows the platform of this program.

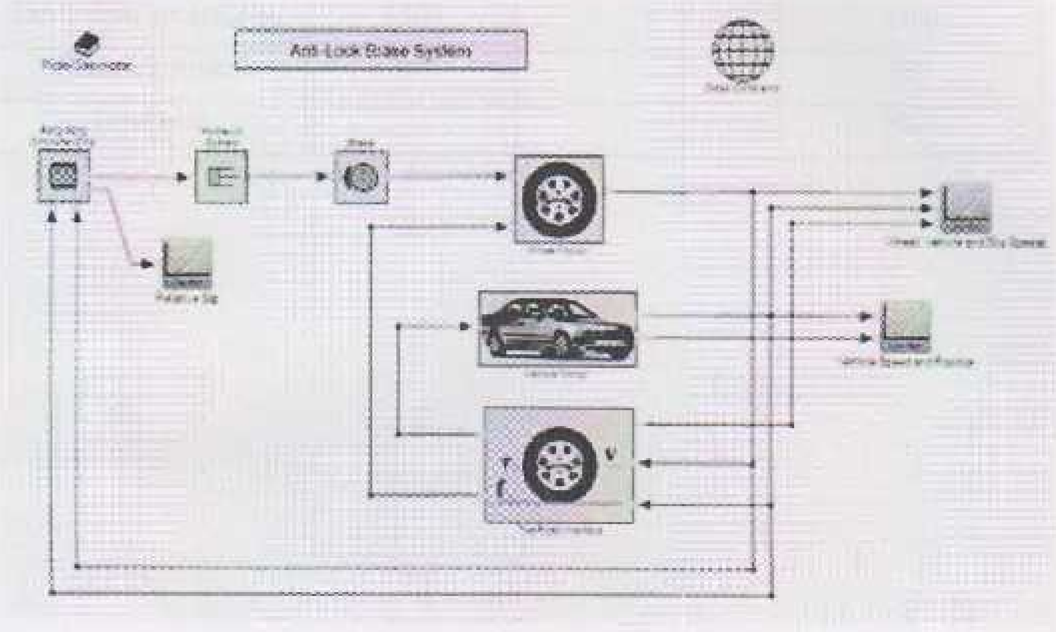

Figure 1.1: acslXtreme platform of ABS system.

1.4 Cost Estimation

Table 1.1: Cost Estimation

Part	Unit cost (NIS)	# of units	Total cost (NIS)
Pressure sensor	600	1	600
PC + Monitor	1500	1	1500
PC bench	100	1	100
DAQ with accessories	2500	1	2500
Other expenses	300		300
Total cost			5000

1.5 Outline of the Research

This research comes in six chapters:

- Chapter One — Introduction.
- Chapter Two — Theoretical Background.
- Chapter Three — Monitoring Stage.
- Chapter Four — Monitoring of ABS System.
- Chapter Five — Modeling and Simulation.
- Chapter Six — Conclusions and Recommendations.

Chapter Two

Theoretical Background

Chapter Two
Theoretical Background

2.1 Introduction

The objectives of this project are to monitor and simulate the ABS system, the use of some unknown expressions in this report, calls for the necessity of illustration of some related subjects to the project that will clarify some terms used during the project stages. And so, this chapter will give a theoretical background about some subjects related to the goals of this project.

This chapter is divided into two sections, the first section will briefly present the dynamics of vehicle tire that will lead to the definition of the slip ratio as an important variable used in the simulation stage, and which is also used by the Electronic Control Unit 'ECU' of the ABS system during calculations.

The second section describes the main components of the ABS system that signals are going to be obtained from during monitoring stage and their relation to the principle of operation of the ABS, however, the explanation of the stages that the ABS system undergoes during operation is important; because it will help in the analysis of the signals that are going to be obtained during monitoring or that going to be generated during simulation stage.

2.2 Dynamics of tire

In order to realize the operation of the ABS, it is essential to understand vehicle tire dynamics. Tires are involved with the transfer of accelerating and decelerating forces between the road surface and the vehicle. The grip exerted by tire on the road surface is measured in terms of coefficient of friction μ. The value of μ depends on the nature of two surfaces; for example, it reaches maximum of about 1.0 on dry tarmac road, falls to 0.7 on wet tarmac, but is only about 0.2 on snow-covered road. Thus the greater value of μ means more braking grip and a shorter stopping distance.

Tire grip also depends on the slip ratio; *the ratio of the tire speed to the road speed.* When the car is traveling at steady speed there is no slippage between the road and the tire, and so the slip ratio is zero. On the other hand, the application of powerful braking may cause the wheel to lock and the tire then has slip ratio of one. [4]

The amount of slip determines the braking force and lateral force. The slip, as a percentage of car speed, is given by

$$S = \frac{U - WR}{U} X\ 100\% \qquad 2.1$$

As can be seen from equation 2-1, a free rolling wheel has slip $S = 0$, and fully locked wheel has $S = 100\%$, R is the radius of the wheel, W is the angular velocity of the wheel, and U is the linear velocity of the vehicle. [5]

During gentle braking the tires are slowed to slightly less than the vehicle speed and so some slip occurs. The value of μ rises proportionately with this slip, reaching a maximum at slip ratio of about 0.15-0.30. After that with heavier braking μ falls sharply and so locking occurs. These characteristics are shown in fig. 2.1. [4]

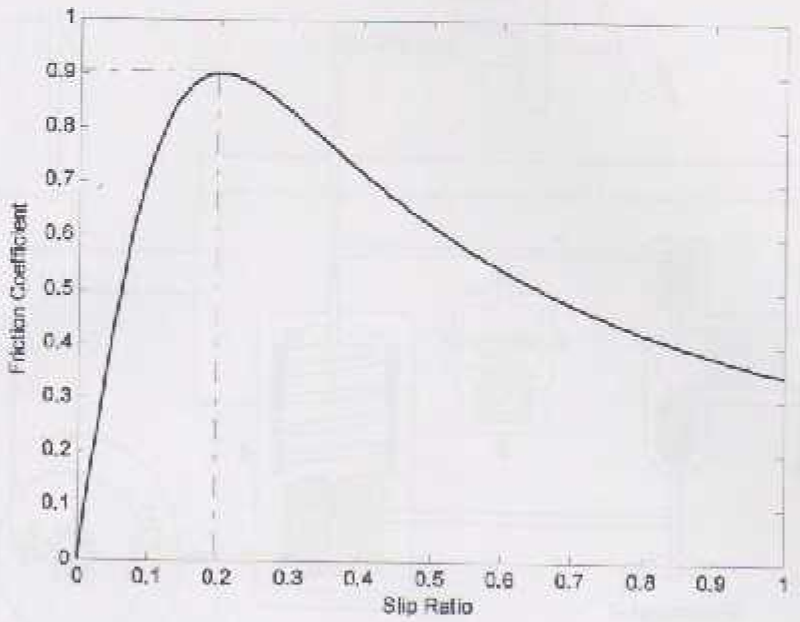

Figure 2.1: Braking characteristics versus tire slip. [5]

2.3 Main components of the ABS system

2.3.1 Hydraulic control circuit

The operation of hydraulic control circuit for a single wheel cylinder is illustrated in fig.2.2(a,b,c). When no energizing current is applied to solenoid valve (normal driving) it connects the brake wheel cylinder directly with the master cylinder, allowing conventional brake operations as in fig 2-2(a). Since the driver may readily increase the braking force via the brake pedal this is termed the pressure INCREASE position.

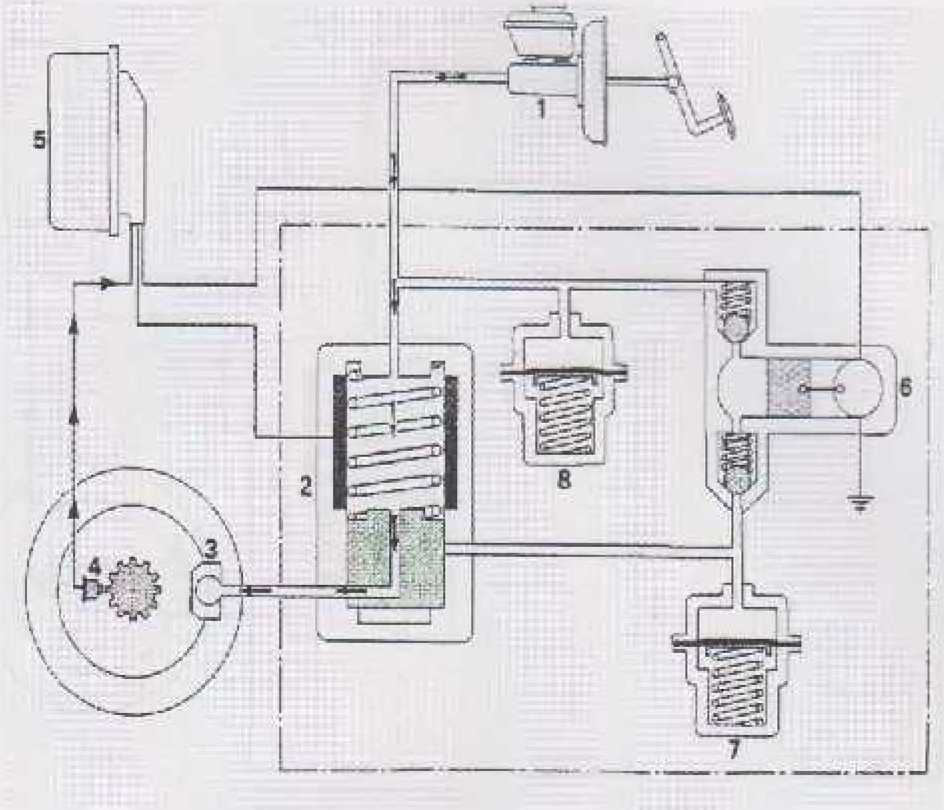

Figure 2.2: (a) Pressure INCREASE position.

Where (1): master cylinder, (2): solenoid valve, (3): brake piston, (4): wheel speed sensor, (5): ECU, (6): return pump, and (7, 8): accumulator.

If the ECU detects excessive wheel slip during braking, a low-level energizing current (about 2A) is applied to the solenoid valve (2) to move it to the pressure HOLD position fig 2.2(b). This isolates the wheel cylinder from the master cylinder and so maintains the fluid pressure in the wheel cylinder (therefore the braking force) at its previous value, any increase in braking force due to an increase in the driver's pedal pressure is thus prevented.

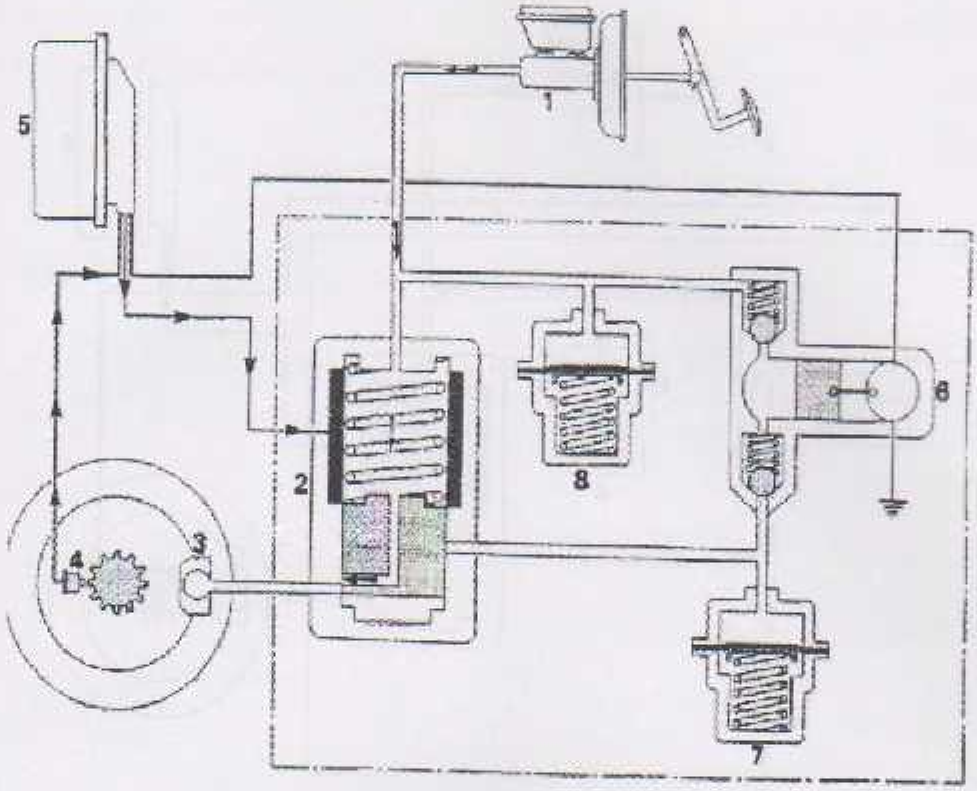

Figure 2.2: (b) Pressure HOLD position.

If the wheel slip continues at excessive rate then the ECU must reduce the braking force to avoid wheel locking. A higher energizing current (about 5A) is applied to the solenoid valve, moving it to the pressure DECREASE position fig. 2-2(c). The wheel cylinder is still isolated from master cylinder, but now connected to the return pump circuit. The pump is switched on by the ECU and draws fluid away from the wheel cylinder, pumping it back, via the accumulators, to the appropriate master cylinder circuit. In this way the braking force is reduced and fluid is returned to the master cylinder against pedal pressure. The driver feels the pedal rise slightly "Kickback" beneath his foot.

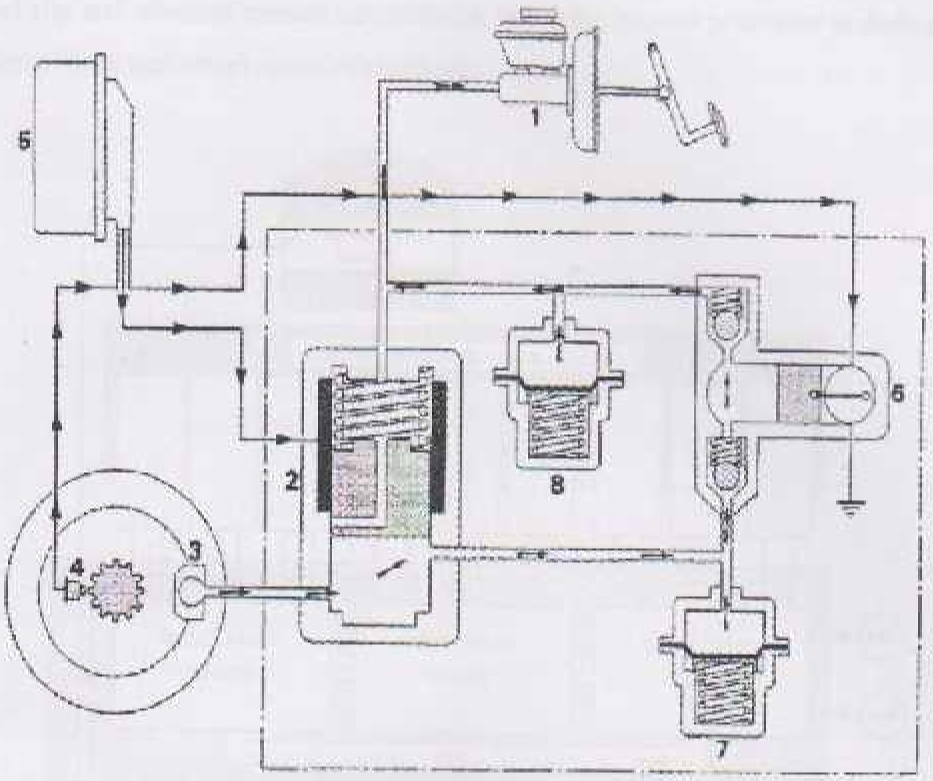

Figure 2.2: (c) Pressure REDUCE position.

The function of the accumulator is to momentarily hold the returning high pressure fluid before it flows into the master cylinder, thereby minimizing kickback and preventing heating and foaming of fluid.

2.3.2 Electronic control circuit

Most ABS ECUs are microcomputer-based controllers, incorporating ASICs and at least one microprocessor to ensure fast and reliable data processing. To illustrate the sophistication of modern ABS controllers, the Teves MK 20 ECU is taken as an example fig. 2.3. The ECU contains two microprocessors, processor 1 performs the wheel slip and solenoid control calculations, while the second processor is dedicated to signal input and wheel speed evaluations.

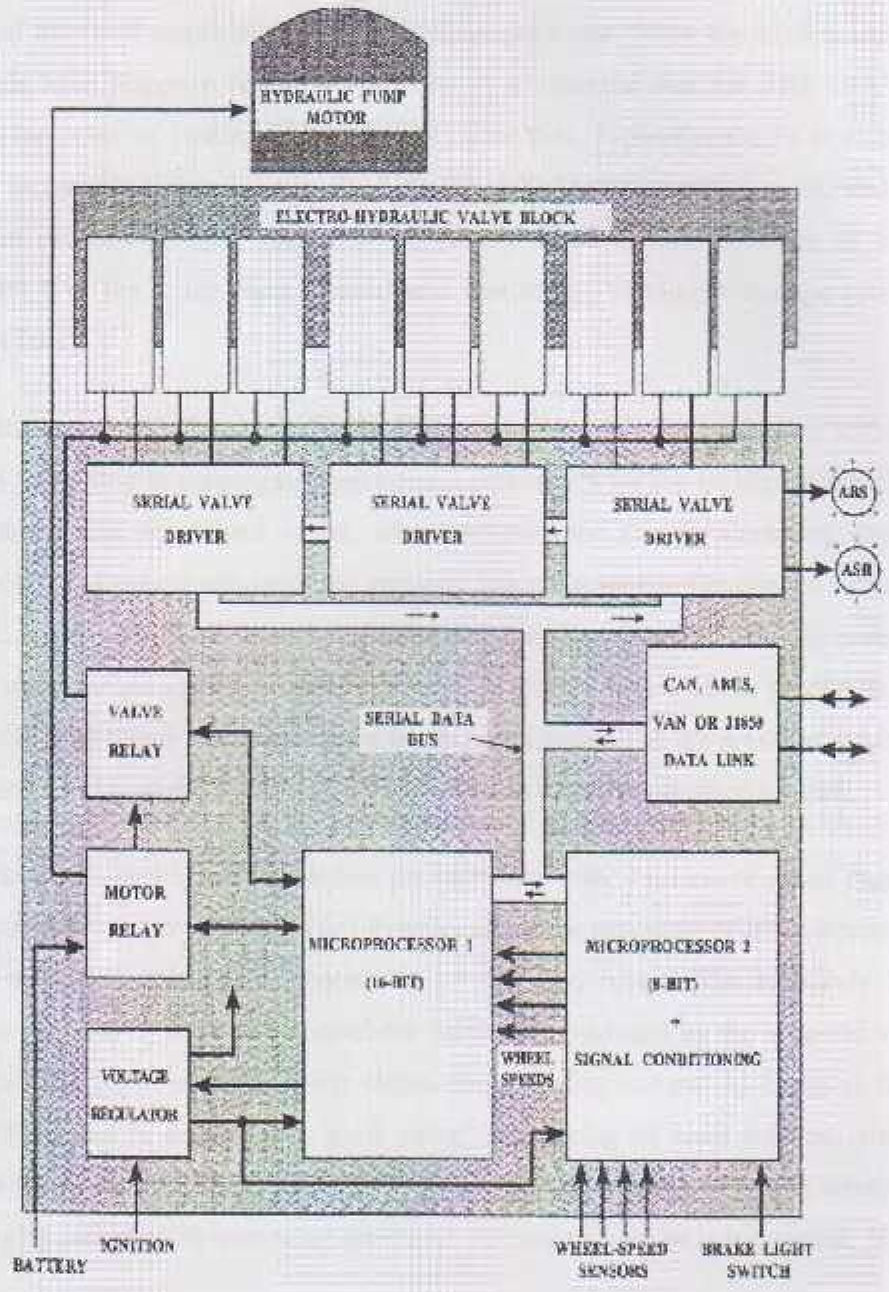

Figure 2.3: Block diagram of ABS ECU employing two microprocessors.

Data from the wheel speed sensor arrives at the ECU as sine-wave signals that have frequency and amplitude proportional to wheel speed. The wheel speed sensor interface circuit filters and amplifies these signals, and then converts it into digital pulses of the fixed amplitude, suitable for 8-bit processor. Since the ABS modulator solenoids have response times of 10-20 ms, it is essential that the ABS ECU can predict the onset of locking in shorter time than this. Typically, the ECU must be able to assess wheel speeds every 5-10 ms (i.e. 100-200 times each second) and it is the 8-bit processor which does this. Secondary functions are detection of brake operation (via the brake light switch) and monitoring of supply voltage (via the ignition feed).

Using the calculated wheel speeds, the 16-bit processor then carries out the anti-lock strategy according to preprogrammed control parameters for the particular vehicle. It computes values for wheel speed, wheel acceleration (or deceleration), control reference speed, wheel slip ratio and pressure reduction speed. The control reference speed is *a speed which decreases with time and represents the theoretically optimum deceleration for the vehicle*. It is indicative of a wheel rotating at the predetermined target slip ratio where tire grip is greatest. A wheel rotating at the pressure reduction speed is operating at the maximum permissible slip ratio, just short of locking.

If a measured wheel speed falls below the calculate control reference speed then the ABS intervenes to prevent the wheel from locking. The processor sends solenoid and motor control signals to the respective circuits and relays. The relatively high currents required by hydraulic modulator valves are produced by the solenoid valve drive circuits. These are high power stages, incorporating current regulators so that a constant current is delivered to each valve. Monitoring of each solenoid current enables short or open circuit faults to be detected. Also a communication circuit for exchanging information with other electronic controllers may be incorporated. [4]

The antilock brake system tests itself every time the vehicle is started and every time the brakes are applied. The system evaluates its own signals. If a defect is detected, the system then turns off, leaving normal braking unaffected. [3]

Fig. 2.4 shows the signals associated with an antilock control wheel of typical ABS system. When the brakes are first applied, the ECU uses wheel sensor data to calculate the actual vehicle speed, a hypothetical control reference speed and a pressure reduction speed.

As the brake is depressed, the fluid pressure quickly rises, braking force increases proportionately and wheel slip increases. If wheel speed falls below the control reference speed then the slip ratio is likely to become excessive and so the ECU sends a pressure HOLD signal to solenoid valve to prevent the wheel from locking.

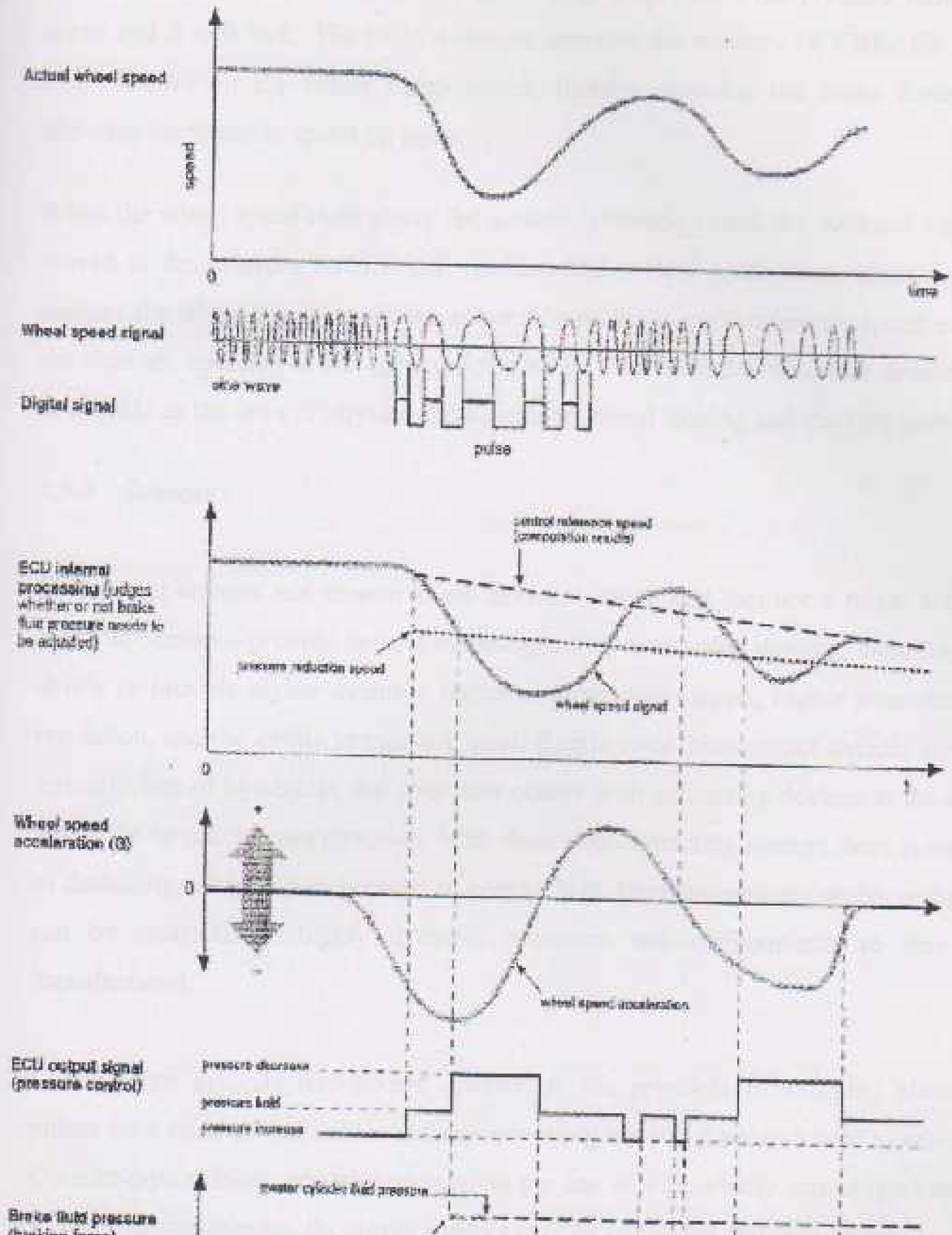

Figure 2.4: Anti-lock control cycle for a single wheel. [4]

If wheel continues to decelerate its speed will drop below the pressure reduction speed and it will lock. The ECU therefore operates the pressure DECREASE valve and switches on the return pump motor, thereby reducing the brake force and allowing the wheel to speed up again.

When the wheel speed rises above the control reference speed, the solenoid valve is moved to the pressure INCREASE position and control cycle starts again. In this manner the wheel speed oscillates either side of the control reference speed and so the tires are operated at the optimum slip ratio. The vehicle is therefore decelerated as quickly as the laws of physics allow, with no wheel locking and steering control.

2.3.3 Sensors

Noncontact sensors and measurement devices—those that monitor a target without physical contact—provide several advantages over contacting devices, including the ability to provide higher dynamic response to moving targets, higher measurement resolution, and the ability to measure small fragile parts. Noncontact sensors are also virtually free of hysteresis, the error that occurs with contacting devices at the point where the target changes direction. With these non-contacting sensors there is no risk of damaging a fragile part because of contact with the measurement probe, and parts can be measured in highly dynamic processes and environments as they are manufactured.

Counter-type velocity transducers operate on the principle of counting electrical pulses for a fixed amount of time, then converting the count per unit time to velocity. Counter-type velocity transducers rely on the use of a proximity sensor (pickup) or an incremental encoder. Proximity sensors may be one of the following types:

- Electro-optic
- Variable reluctance
- Hall effect.
- Inductance
- Capacitance

2.3.3.1 Capacitive Sensors

Capacitive sensors are noncontact devices used for precision measurement of a conductive target's position or a nonconductive material's thickness or density. When used with conductive targets they are not affected by changes in the target material; all conductors look the same to a capacitive sensor. Capacitive sensors sense the surface of the conductive target, so the thickness of the material is not an issue; even thin plating is a good target.

Capacitive displacement sensors are known for nanometer resolutions, frequency responses of 20 kHz and higher, and temperature stability. They typically have measurement ranges of 10 μm to 10 mm although in some applications much smaller or larger ranges can be achieved.

Capacitive sensors are sensitive to the material in the gap between the sensor and the target. For this reason, capacitive sensors will not function in a dirty environment of spraying fluid, dust, or metal chips. Generally the gap material is air.

2.3.3.2 Inductive Sensors

Inductive sensors, also known as eddy current sensors, are noncontact devices used for precision measurement of a conductive target's position. Unlike capacitive sensors, inductive sensors are not affected by material in the probe/target gap so they are well adapted to hostile environments where oil, coolants, or other liquids may appear in the gap. Inductive sensors are sensitive to the type of target material. Copper, steel, aluminum and others react differently to the sensor, so for optimum performance the sensor must be calibrated to the correct target material.

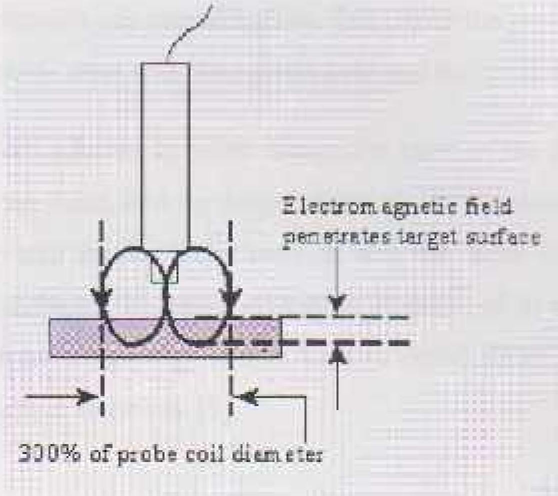

Figure 2.5: Inductive sensors use electromagnetic field.

Inductive sensors are known for nanometer resolutions, frequency responses of 80 kHz and higher, and immunity to contaminants in the measurement area.

They typically have measurement ranges of 0.5mm to 15mm although in some applications much smaller and larger ranges can be achieved. Inductive sensors' tolerance of contaminants make them excellent choices for hostile environments or even for operating while immersed in liquid.

An inductive sensor's magnetic field creates electrical currents within the target material and therefore the targets have a minimum thickness requirement.

Inductive Technology Fundamentals

While capacitive sensors use an electric field for sensing the surface of the target, inductive sensors use an *electromagnetic* field that penetrates into the target fig. 2.5. By passing an alternating current through a coil in the end of the probe, inductive sensors generate an alternating electromagnetic field around the end of the probe. When this alternating field contacts the target, small electrical currents are *induced* in the target material (eddy currents). These electrical currents, then, generate their own electromagnetic fields. These small fields react with the probe's field in such a way that the driver electronics can measure them. The closer the probe is to the target, the more the eddy currents react with the probes field and the greater the driver's output.

Inductive sensors are affected by three things: the sizes of the probe coil and target, the distance between them, and the target material. For displacement measurements the sensor is calibrated for the target material and the probe size remains constant, leaving the target/probe gap as the only variable. Because of its sensitivity to material changes, eddy current technology is also used to detect flaws, cracks, weld seams, and holes in conductive materials. [6]

2.3.4 Solenoid -Actuated valves

A very common way to actuate a spool valve is by using a solenoid, illustrated in Fig.2.6. As shown, when the electric coil (solenoid) is energized, it creates a magnetic force that pulls the armature into the coil. This causes the armature to push on the push rod to move the spool of the valve. [7]

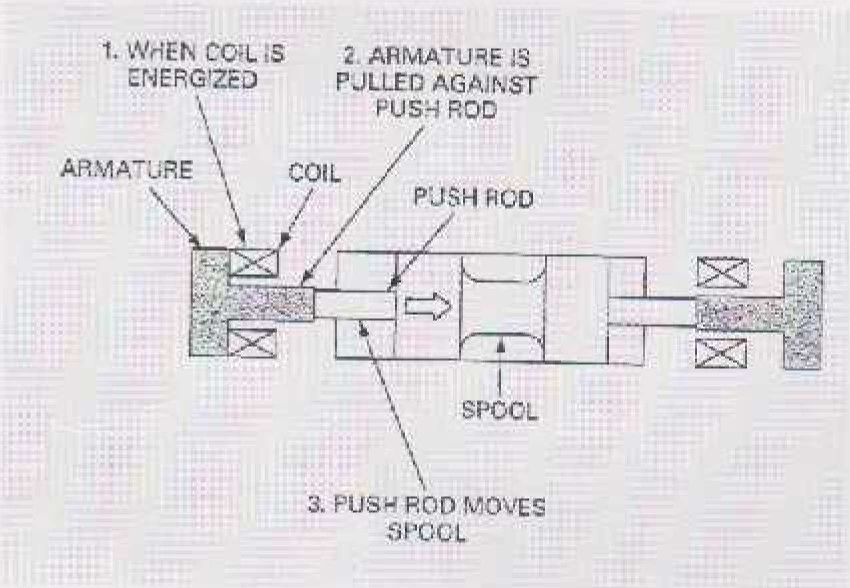

Figure 2.6: Operation of solenoid to shift spool of valve. [7]

Chapter Three

Monitoring Stage

Chapter Three
Monitoring Stage

3.1 Introduction

Monitoring system is a combination of hardware and software components used to read the real systems information and analyze it. The main parts of a monitoring system are:

- Sensors.
- Interfacing circuits.
- Data acquisition hardware.
- Software.
- Microprocessor or computer.
- Displaying hardware (computer display).

Fig.3.1 shows the relation that exists among the previous components.

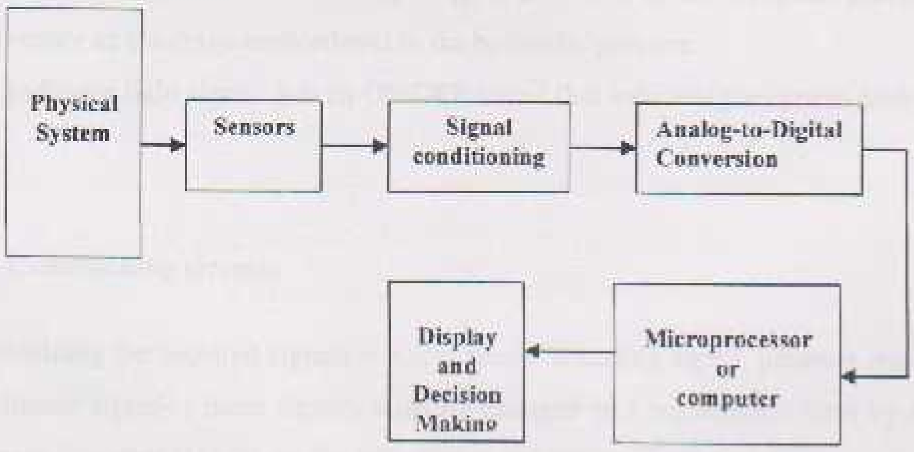

Figure 3.1: General block diagram.

In the following sections the technical considerations of use of these components is going to be illustrated according to the sequence shown in the general block diagram of monitoring fig.3.1. These considerations are accounted for when practical implementation is done.

3.2 Sensors

Transducers are used to sense the real world, convert the physical phenomena into signal, and help in gathering information about it. The produced signal can be analog, digital, or frequency signal.

In this project both analog and digital signals exist and they are:

1. Speed signal: it is an AC type signal delivered by wheel speed sensor as a voltage that has amplitude and frequency corresponding to the tire speed.
2. Solenoid signal: it is a DC signal delivered by the ECU to the solenoid valve, this signal is a voltage signal that is converted to one of three values; 0A, 2A or 5A through relays, corresponding to the desired position of the solenoid valve; increase, hold or decrease position respectively.
3. Pressure signal: it is an AC-type signal produced by an electrical pressure sensor as a voltage proportional to the hydraulic pressure.
4. Indicator light signal: it is an ON/OFF signal that indicates the system faults.

3.3 Conditioning circuits

After obtaining the required signals – wheel speed, actuating signal, pressure signal, and indicator signal- , these signals must be changed to a measurable form by the data acquisition card (DAQ), so the following consideration must be taken:

- The dynamic range of these signals after conditioning should be within the dynamic range of the DAQ.

- The source impedance of the input signal should be low enough so that it will not affect the input signal.
- The frequency of the DAQ must be chosen to be at least twice of frequency of the input signal.
- The input signal should be isolated, to protect the DAQ from damage, and this protection can be done using magnetic or optical isolation.
- Signal filtering in order to remove undesired signals or noise.

3.4 DAQ specifications and requirements

In this project the wheel sensor signal, the pressure sensor signal, and the ECU output signal to the solenoid valves will be monitored. The wheel sensor the pressure sensor, the ECU outputs are analog signals, so for monitoring these signals a three analog input channels DAQ is required, for the frequency the ECU it self monitors the wheel sensors about 5-10ms (i.e. 100-200 times each second), so the DAQ frequency should be at its minimum double the highest frequency present which is 200Hz: but any DAQ nowadays has at least more than 1 KHz as its sampling frequency.

So for monitoring these signals the 6034 NI-DAQ have been used, the National Instruments 6034 device is high-performance multifunction analog, digital, and timing I/O device for PCI. The NI 6034 features 16 channels (eight differential) of 16-bit analog input (AI), a 68-pin connector, and eight lines of digital I/O (DIO).

Analog input characteristics

Number of channels .... 16 single-ended or 8 differential
(software-selectable per channel)

Type of ADC.. Successive approximation

Resolution .... 16 bits, 1 in 65,536

Sampling rate .... 200 kS/s guaranteed

Input signal ranges................................ Bipolar only

Digital I/O characteristics

Number of channels ....8 input/output

Compatibility..TTL/CMOS

Table 3.1: Digital logic levels.

Level	Min	Max
Input low voltage	0 V	0.8 V
Input high voltage	2 V	5 V
Input low current (Vin = 0 V)	—	320 μ A
Input high current (Vin = 5 V)	—	10 μA
Output low voltage (IOL = 24 mA)	—	0.4 V
Output high voltage (IOH = 10 mA)	4.35 V	—

So when using this DAQ, three channels from the differential analog input are used for the wheel sensor and the pressure sensor and for the ECU output signal to the solenoid valve. Also, one output signal from the digital I/O at high level i.e. 5V, is used as power signal for the pressure sensor.

Finally for monitoring stage a Personal Computer PC is needed to mount the DAQ on it and to run the monitoring program, which is LabView 7.1 or later. [9]

3.5 Software

DAQ hardware without appropriate driving software has no meaning; the importance of having software comes from:

- Acquiring data at specified sampling rate.
- Acquiring data in the background while processing in foreground.

- Stream data to and from disk.
- Integrate different DAQ boards in a computer and use various functions of a DAQ board from a single user interface.

3.6 LabVIEW Software

In fig. 3.2 a complete DAQ system with LabVIEW is shown. The driver software is a lower level driver that interfaces LabVIEW software with the DAQ boards. As a user of LabVIEW one does not have to worry about configuration and control of components within DAQ boards. LabVIEW identifies each board by a device number and therefore one can have as many devices as many as the computer can accept on their expansion slots. LabVIEW can also combine and display inputs from various sources like inputs from serial and parallel port, data acquisition board(s), and GPIB boards on a single interface as shown in the figure below.

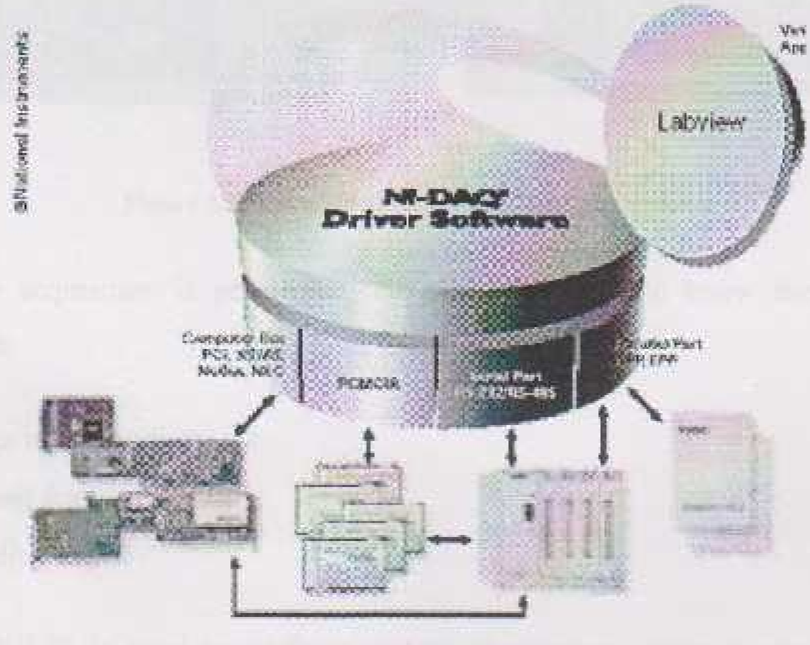

Figure 3.2: LabVIEW software and DAQ system.

LabVIEW is programmed with set of icons that represents controls and functions available in the menu of the software. The user interface which is called virtual instrument 'VI' consists of two parts- a front panel and a block diagram. This is similar to that of an instrument where a front panel is used for an input, output controls, and to display the data whereas the circuit resides on the circuit board. Similarly you can bring the buttons, indicators and graphing and display functions on the front panel as shown below:

Figure 3.3: Example of difference front panel vis.

When data acquisition is performed, the software needs to know the following information:

- Device number.
- Channel that is being used.
- Sampling Rate.

Often LabVIEW is used to perform system simulations, since it contains many commonly used filter, digital signal processing, and statistical functions. LabVIEW compiles almost as fast as C or Matlab and therefore one can perform complete simulation within a VI.

The detailed block diagram of the monitoring stage is shown in fig.3.4.

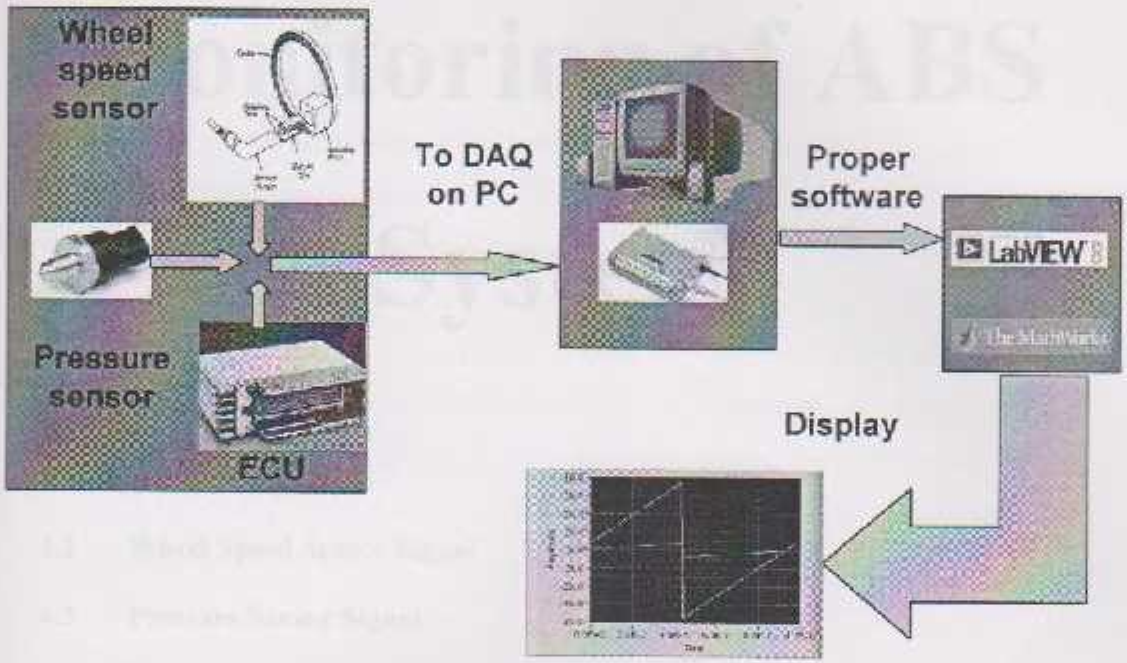

Figure 3.4: Detailed block diagram.

Chapter Four

Monitoring of ABS System

Chapter Four

Monitoring of ABS System

4.1 Introduction

In this chapter a full description of the monitoring stage will be introduced, including the signals acquired and their types, steps done to acquire these signals, and the manipulations on these signals. Where in the first section the speed signal is described from the aspects of operation of the ABS system with a brief illustration of properties of this signal. In the second section; the pressure signal is described, including a short description of the sensor used, the treatment of the signal and the hardware software filtering done on it. In the final section the ECU signal to the solenoid valve is described along with the characteristics of it and the software manipulations done on it.

4.2 Wheel Speed Sensor Signal

In this section the monitored wheel speed sensor signal will be shown, and then it will be dissected to obtain all necessary data to illustrate the internal operation of the ABS system.

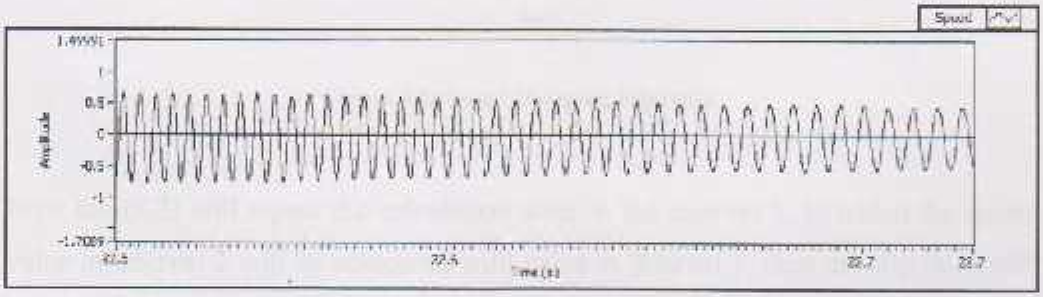

Figure 4.1: Wheel speed sensor signal.

The signal acquired from the wheel speed sensor is shown in fig.4.1, as shown the shape of this signal is sinusoidal signal, has a frequency and amplitude correspond to the wheel speed, as the speed decrease the frequency and amplitude will decrease.

This signal is very helpful to understand the principle of operation of the ABS system. If we look at fig.4.2 we will notice that there are three different intervals (denoted by the numbers written upper the speed signal), and the speed in each interval has a value different from the values in the other intervals. In interval 1 the ECU will calculate the value of the slip ratio depending on two speed values, the current speed value obtained from interval 1 and the previous speed value obtained from the interval comes before interval one. Then the ECU will send the suitable order for the hydraulic modulator. In this situation the ECU detects that the slip ratio is lower than the desired value so the decision taken by the ECU is to decrease the speed, which can be achieved by changing the position of the solenoid valve from the current position (pressure hold or decrease position depending on the previous state) to pressure increase position, so the speed will decrease as shown in the interval 2.

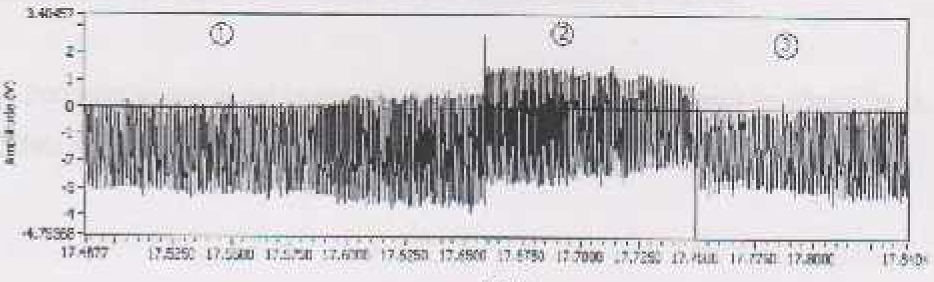

Figure 4.2: Speed changing Intervals.

Now the ECU will repeat the calculation done in the interval 1, in which the speed value in interval 2 will be compared with value in interval 1, then the slip ratio will be obtained in order to determine whether the speed in the third interval must be increased, decreased, or held the same. Here it is noticed that the speed in the third interval starts to increase which means that the calculated slip ratio is higher than the desired value, so there is an interesting interaction between the ECU and the different parts of the ABS system will be done through signals; the ECU says the current slip ratio is higher than the desired one so the braking force must be decreased, then the ECU will tell the 'solenoid valve': you must change your position from pressure increase to pressure decrease position, and you 'return pump' you have to work in order to return the brake fluid into the master cylinder. Then the ECU will ask over the 'wheel speed sensor' for the speed in order to decide the level of the next order.

4.3 Pressure Sensor Signal

In this section the pressure sensor signal is described, and the characteristics of it are illustrated, along with the hardware and software filtering done on it.

The pressure signal is the signal produced by the pressure sensor when the brake pedal is pressed, the monitoring of this signal is important from the aspect that it is used to explain the working cycle of the ABS system, in addition to that it gives an indication of the start of operation of the whole braking process.

The pressure sensor used is common rail sensor with data sheet in appendix B, from the data sheet the characteristic curve is shown in fig.4.3

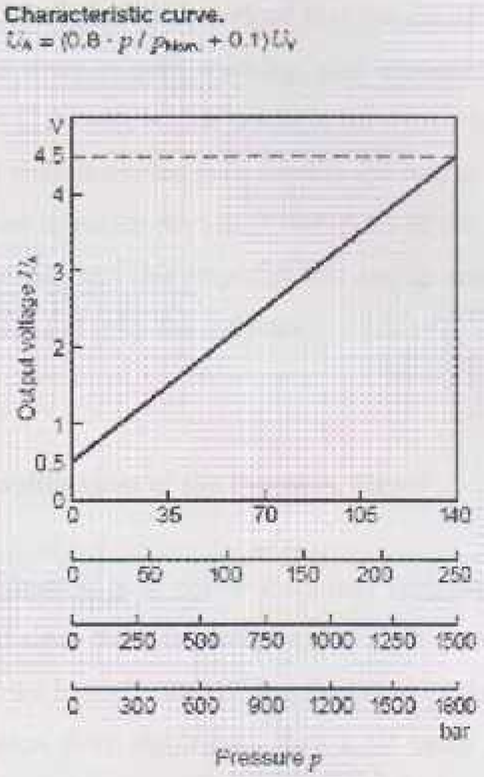

Figure 4.3: Common rail sensor characteristic.

The pressure sensor used is that with range of pressure (0-1500) bar, it is used to measure the pressure in the fuel-distributor rail of a gasoline direct-injection engine. As can be seen the change of the output voltage with respect to the range of the pressure sensor is small, and after measuring the pressure in our system, the change in the output voltage was from (.5-.57) volt, which is so small, indicating that the pressure in our system is about (26.25 bar), this value is obtained by interpolation as shown in Eq.4.1 by solving for P

$$\frac{1500-0}{1500-P}=\frac{4.5-0.5}{4.5-0.57} \qquad 4.1$$

Where P is the pressure in the brake line, in which the nominal pressure in the ABS system must be from (160-200 bar), this difference is caused since that the brake booster in our system unused.

From the data sheet of the sensor it is noticed that the sensor needs power supply of (5Vwith (5-9) mA) in order to start working, also according to the data sheet the output current is about (2.5 mA), which is within the dynamic range of the DAQ, i.e. from (0-20mA), so all what is needed is to amplify the output voltage signal from the pressure sensor in order to notice the small variations in the pressure as the rang of the output voltage is small, and this amplification can be achieved by two methods; first by hardware, the second is by the software.

4.3.1 Hardware Amplification of the Pressure Signal

The aim of the amplification is to notice the small variations in pressure value as mentioned before, and since there is always a (0.5V) in common to all voltages, to cancel this 0.5V value we begin by amplifying the pressure signal by a factor of 10 to make the signal variation more significant, then a 5V value added to the amplified signal using summer amplifier, to cancel the effect of the half volt ,and then all what is remained is to amplify the remaining part of the signal as long as we are within the dynamic range of the DAQ (-10 to 10)V, the circuit describing this manipulation is shown in fig.4.4.

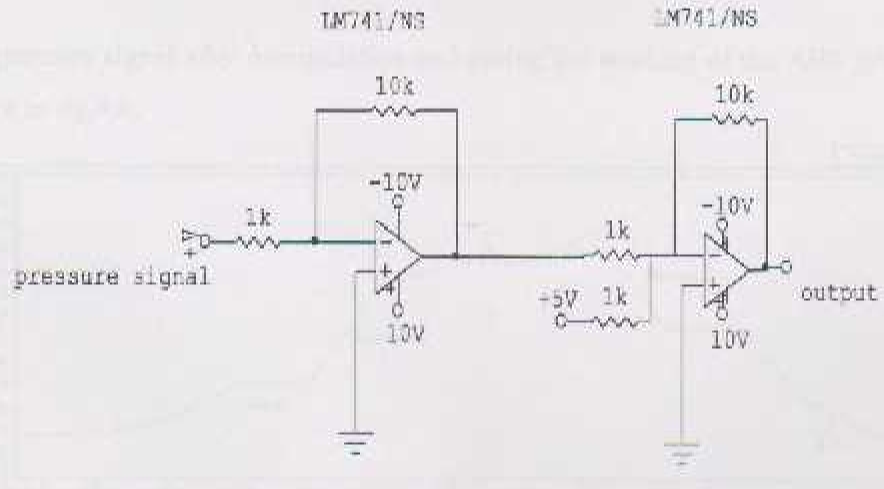

Figure 4.4: Pressure sensor interfacing circuit Schematic.

The drawbacks of this circuit is the grate noise that is present within the signal, also the difficulty to cancel the effects of temperature on the IC's used, all of this called for an alternative approach; that is to use the software amplification as will be explained next.

Note: this circuit works only in the range of operation $0.5 \leq V < 0.6$, and is indicated only for this case of manipulation of pressure signal.

4.3.2 Software Amplification of the Pressure Signal

In the software manipulation an already built in blocks in LabView are used to shift down the acquired signal half volt to let the total curve start from the origin, then the signal can be amplified with the desired value, without having the amount of noise that was present in the hardware manipulation of the pressure signal.

The blocks that are used and their configuration are shown in fig.4.5.

Figure 4.5: LabVIEW blocks used for pressure signal manipulation.

The pressure signal after manipulation and during the working of the ABS system is shown in fig.4.6.

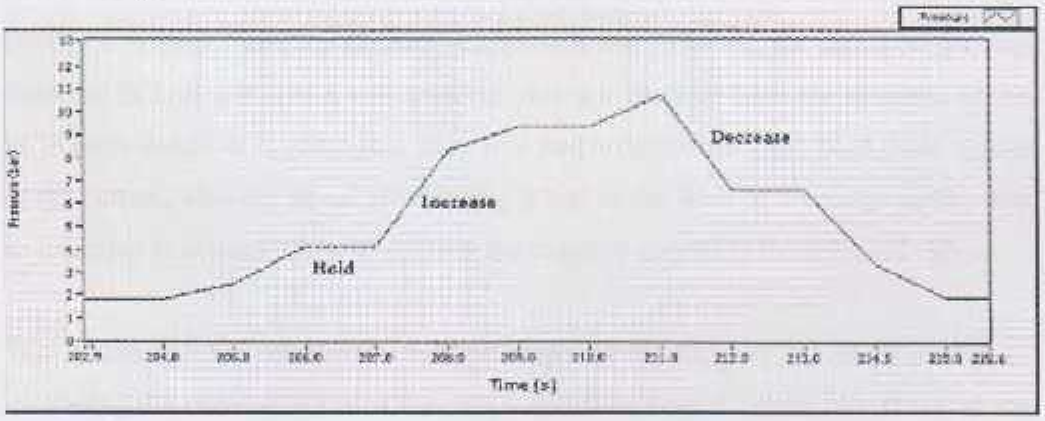

Figure 4.6: Pressure sensor signal.

It is noticed that the signal period is so small, so a zoom IN is used to clarify the cyclic operation of the ABS system.

As shown in fig.4.6 the three stages of ABS operation (pressure increase, hold, and decrease) can be clearly noticed.

But what will happen to the system in the three cases?
During pressure increase and pressure hold case the system speed will decrease, and as the pressure decreases the system speed will increase.

4.4 ECU Output Signal to the Solenoid Valves

This signal is produced when the ABS indicates that a slip is occurring and the system has reached a threshold slip or/and acceleration, as mentioned in chapter 2, there are three states for the solenoid valve; increase, hold, and decrease positions. The first position means no signal is coming from the ECU, the second is accompanied with 2A actuating signal, and the third position is achieved with a 5A actuating signal.

As the values of the signals are very high compared with the dynamic range of the DAQ; the signals need to be attenuated and converted to a form measurable by the DAQ, i.e. voltage form. An alternative approach was followed; the signal originating from the ECU it self is in a voltage form; this was obvious from the structure of the ECU from inside -it is composed from IC's and resistors that can't hold these values of the current, also the signal after testing it was in the form of a voltage signal; and so it is used to actuate relays to connect the required current to the solenoid valves.

This means that we can use the voltage output of the ECU to the relays instead of measuring the currents between the relays and the solenoid valves. For doing so we

have followed the electrical map of the ECU related to the type of the ABS and car used, this map is found in the Auto Data CD and is referenced in appendix C .
The configuration of blocks in LabView used to measure this signal is shown in fig.4.7.

Figure 4.7: LabVIEW blocks used for ECU signal manipulation.

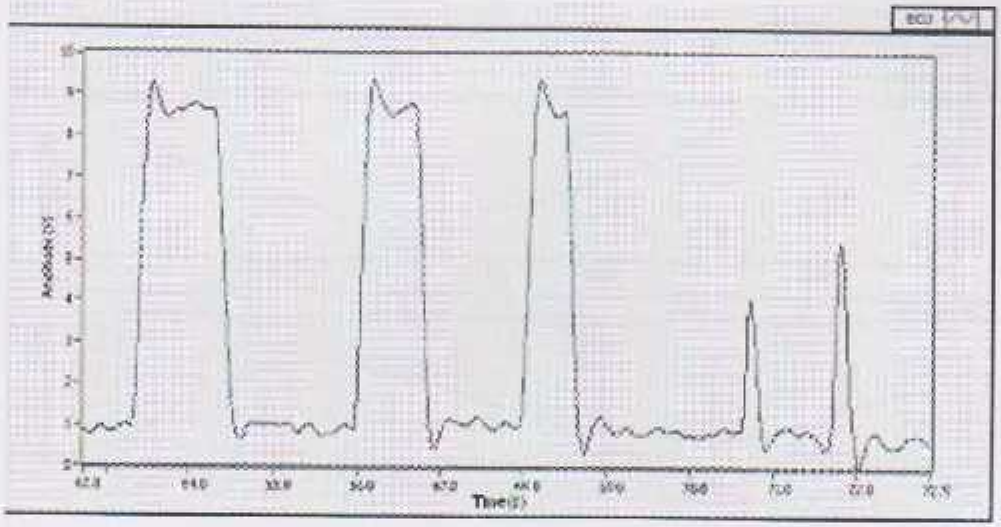

Figure 4.8: Zoomed view of the ECU output signal

From fig.4.8 as noticed, the output of the ECU takes only two values that corresponds to two states; either zero or decrease; this occurs due to the braking force in our system, which is sufficient to make the small inertia we have reach a value that necessitates the operation of the of the hydraulic pump. In other words, the holding position is passed very quickly as the system has small inertia and the value of pressure causes it to stop immediately so that a release in pressure is needed also immediately.

Now the three signals that where monitored are plotted all together in fig.4.9, it is noticed from the figure the interval of operation that indicate pressure increase combined with a pulse in the ECU signal combined with velocity decrease signal, and it can be also noticed that as the system has negligible inertia, the ECU signal passes the hold position very quickly from increase to decrease positions and vise versa in order to keep the slip ratio around the desired value and preventing wheel locking.

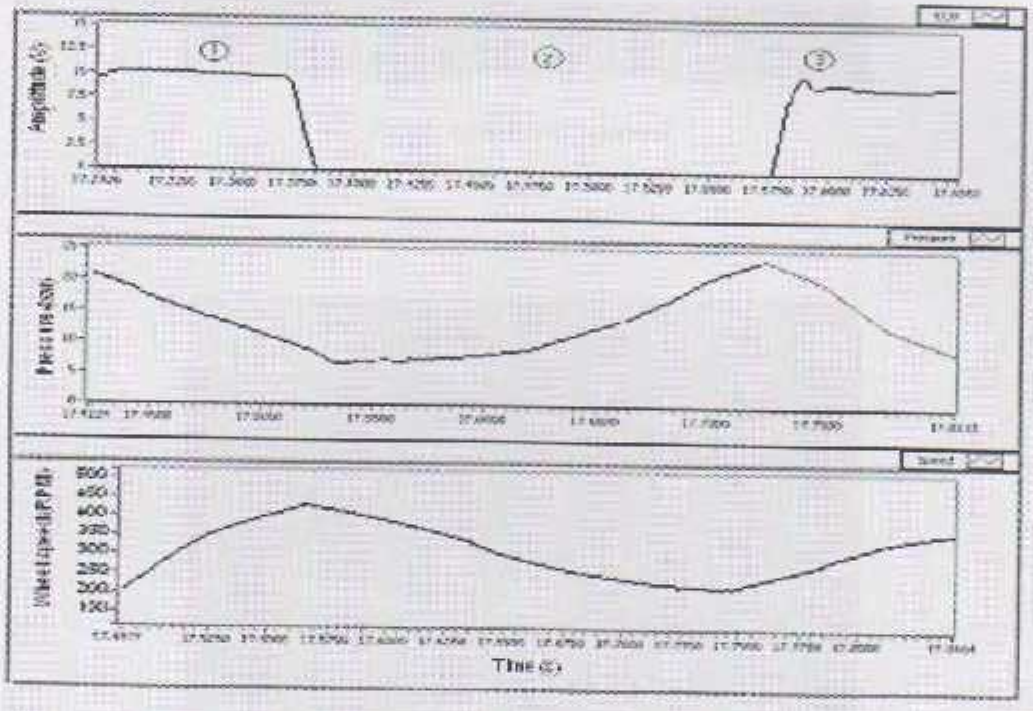

Figure 4.9: ECU, pressure, and speed signals.

The following figures shows the components that have been added to the ABS system model during the monitoring stage implementation in the automotive workshop, its worth noting that this stage took from working team about 150 hours of hard working.

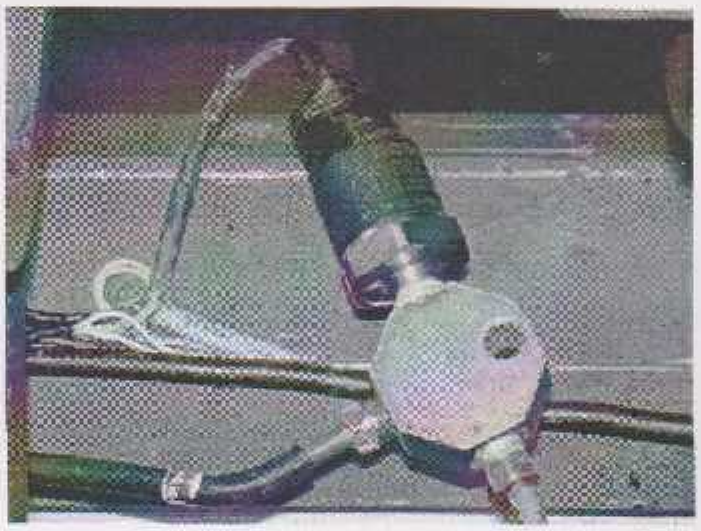

Figure 4.10: Pressure sensor.

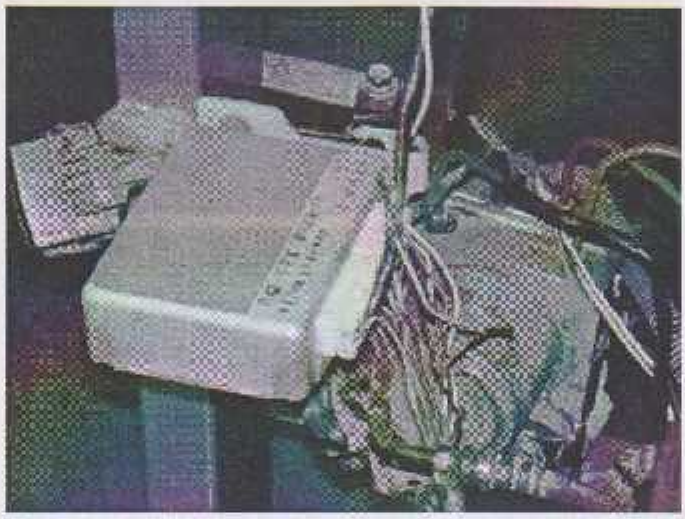

Figure 4.11: ABS system ECU with hydraulic modulator beside it.

Figure 4.12: Wheel speed sensor.

Figure 4.13: ABS system model combined with monitoring system.

Chapter Five

Modeling and Simulation

Chapter Five

Modeling and Simulation

5.1 Introduction

This chapter is devoted for the modeling and simulation of the ABS system, the first section illustrates the model of the ABS based on Newton's laws, which will guide us to the simulation section; as each equation in the model is going to be represented by blocks in the Simulink environment, the results are then explained, discussed, and commented. Section three covers the prerequisites needed for the operation of the simulation package, and in the final section the features and privileges of the designed software are presented.

5.2 Modeling of ABS System

The general braking model of quarter car can be shown as in fig5.1, with the aid of Newton's second law, the dynamic equations of this model are:

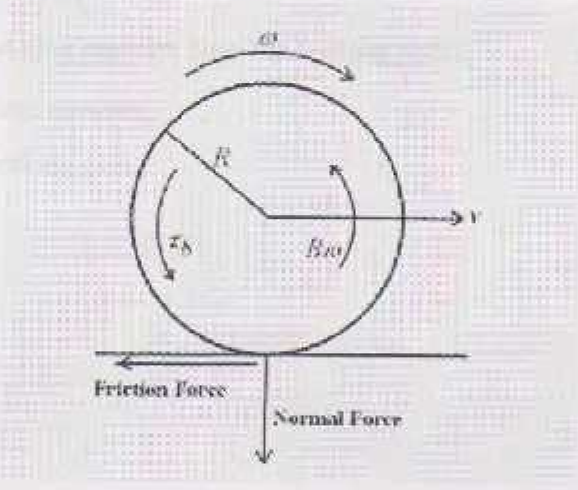

Figure 5.1: Quarter car braking model.

$$M\dot{v} = -\mu(s)F_{Normal} - c_x v^2 \quad 5.1$$

$$I\dot{\omega} = -B\omega + \mu(s)F_{Normal}R - \tau_b \quad 5.2$$

$$\dot{\tau}_b = \frac{-\tau_b + K_b v_b}{\tau} \quad 5.3$$

Note: - The boundaries of integration are from initial braking time to the final stopping time and will be dropped for simplicity.

Where:-

M	: Total mass of quarter car and wheel
V	: Longitudinal velocity
ω	: Angular velocity
τ_b	: Braking torque applied by disk/drum brake
I	: Wheel's moment of inertia
$\mu(s)$	: Friction coefficient between tire and road
F_{Normal}	: Vertical normal force on the road = Mg
R	: Radius of wheel
c_x	: Aerodynamic coefficient of the wheel
B	: Friction coefficient of the wheel bearings
S	: Slip ratio
v_b	: Braking pressure from the braking pedal.
τ	: Time constant.
K_b	: Braking gain.

Assumptions

1- Bearings' friction is assumed to be negligible compared with main force between road and tire.

2- Friction coefficient is a function of slip ratio (s) which is defined by

$$s = \frac{v - R\omega}{v} \tag{A}$$

The relationship between μ and s shown in fig5.2 can be approximated by the following function:

$$\mu(s) = 2\mu_0 \frac{s_0 s}{s_0^2 + s^2} \tag{B}$$

Where:

s_0 : The optimal slip ratio which yield the peak friction value μ_0

Note: - different values of μ_0 represent various road surfaces.

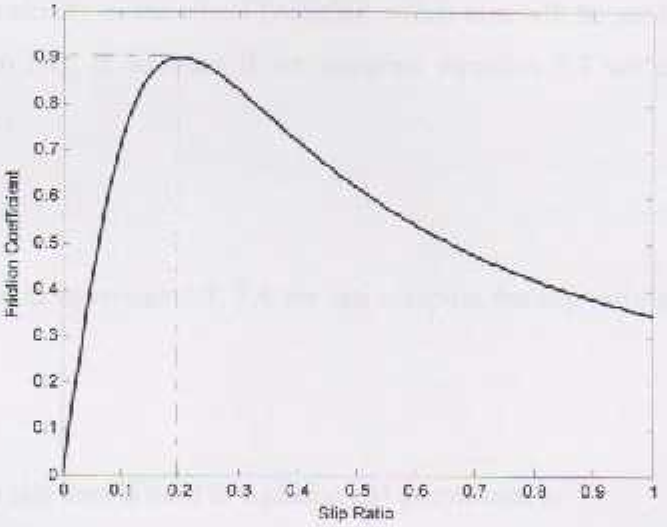

Figure 5.2: Braking characteristics versus tire slip.

Now equations 5.1 & 5.2 reduce to

$$M\dot{v} = -\mu(s)F_{Normal} - c_x v^2 \qquad 5.4$$

$$I\dot{\omega} = \mu(s)F_{Normal}R - \tau_b \qquad 5.5$$

Dividing equation 5.5 by (I)

$$\dot{\omega} = \frac{\mu(s)F_{Normal}R - \tau_b}{I} \qquad 5.6$$

Integrating equation 5.6

$$\omega = \int \dot{\omega} \qquad 5.7$$

This angular velocity is an indication of the wheel's angular velocity due to brake torque τ_b, and the reaction from road $\mu(s)F_{Normal}R$, and also will be used to evaluate $\mu(s)$ in equation (A).

Dividing equation 5.4 by M and integrating yields

$$v = \int \frac{-\mu(s)F_{Normal}}{M} \qquad 5.8$$

This the linear velocity of the wheel (vehicle), which also will be used in evaluating $\mu(s)$ in equation (A), in addition if we integrate equation 5.7 we can obtain the stopping distance

$$SD = \int v \qquad 5.9$$

Using the values in equations 5.7, 5.8 we can compute the slip ratio using equation (A)

$$s = \frac{v - R\omega}{v} \qquad (A)$$

The value of the slip then is used in equation (B) to evaluate μ

$$\mu(s) = 2\mu_0 \frac{s_0 s}{s_0^2 + s^2} \qquad (B)$$

This value of friction coefficient is then again used to compute ω & v in a loop as will be shown in simulation section.

The Braking torque is controlled by the braking pressure, according to equation 5.3, where the braking pressure is the result of manipulating the system equations.

5.3 Simulation of ABS System

Building the system model under MATLAB Simulink environment, and starting form equation 5.4, as shown in fig.5.3

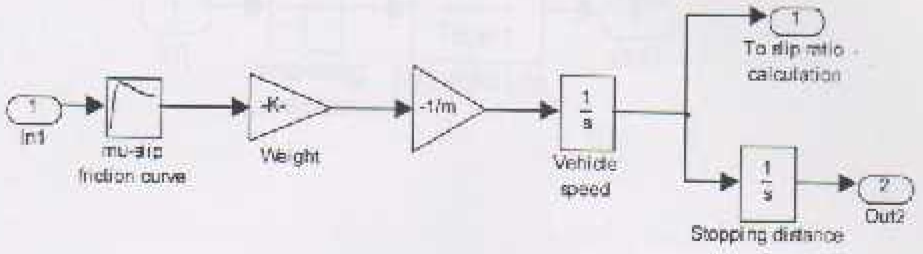

Figure 5.3: Simulink model of equation 5.4.

The vehicle speed obtained at the end of the loop is used to calculate slip ratio in equation 5.4, now from equation 5.5 we find the angular velocity which is the second variable needed to calculate the slip ratio; first we form the simulink model of the braking torque in equation 5.3, and is shown in fig.5.4

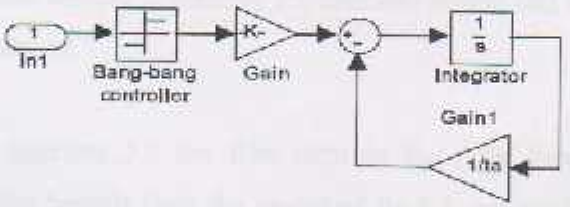

Figure 5.4: Simulink model of equation 5.3.

The closed loop can be reduced to obtain more compact form that will benefit us in the simulation model of the overall system, according to the equation in [14] the closed loop transfer function is

$$TF = \frac{G}{1+GH}$$

which results in the form shown in fig.5.5.

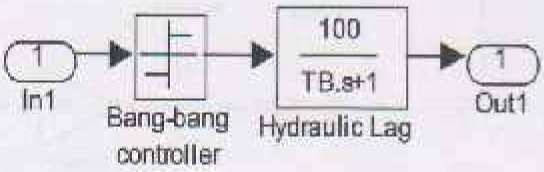

Figure 5.5: Simulink model of equation 5.3 'compact form'.

The function of the bang-bang controller is to provide the three logic states of the hydraulic solenoid valve, i.e. increase, hold, and decrease, which depends on the value of the relative slip, that is: if the relative slip is less than the desired value, the pressure is needed to be increased, if the relative slip value is equal to the desired value no action will be taken, and if the value of the relative slip is more than the desired slip then the vehicle is entering the unstable region and the value of pressure is needed to be reduced.

Following from equation 5.5 the first term in the right hand side needs to be computed, so taking benefit from the model of fig.5.3, we need just to multiply the friction force ($\mu * Mg$) with the radius of the wheel to form the reaction moment by the ground.

Then subtracting the term of braking torque and dividing the resulting signal by the inertia of the wheel, then integrating we obtain the angular velocity of the wheel which is the second variable in slip ratio equation ,i.e. equation .(A), as mentioned before, the simulink model is shown in fig.5.6 that illustrates the idea of the previous paragraph.

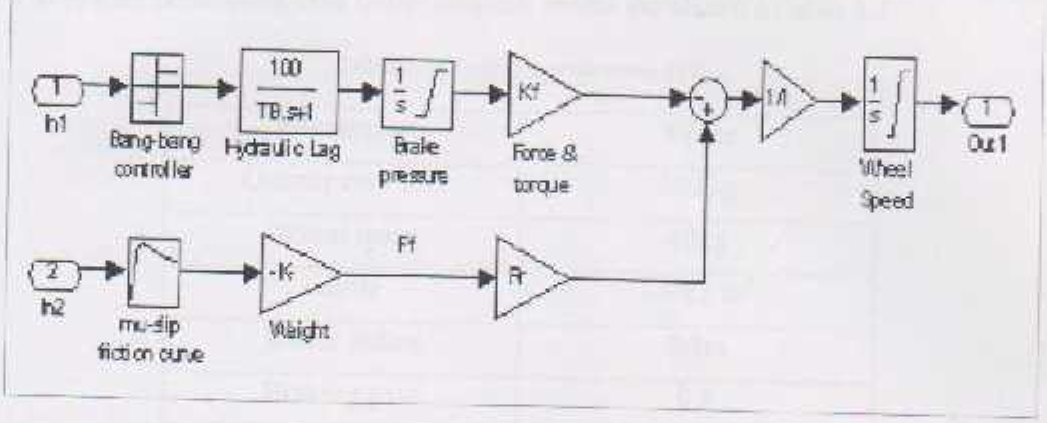

Figure 5.6: Simulink model to obtain the angular velocity.

Now as the whole terms needed to compute the slip ratio are found the overall system simulink model is built and is shown in fig.5.7.

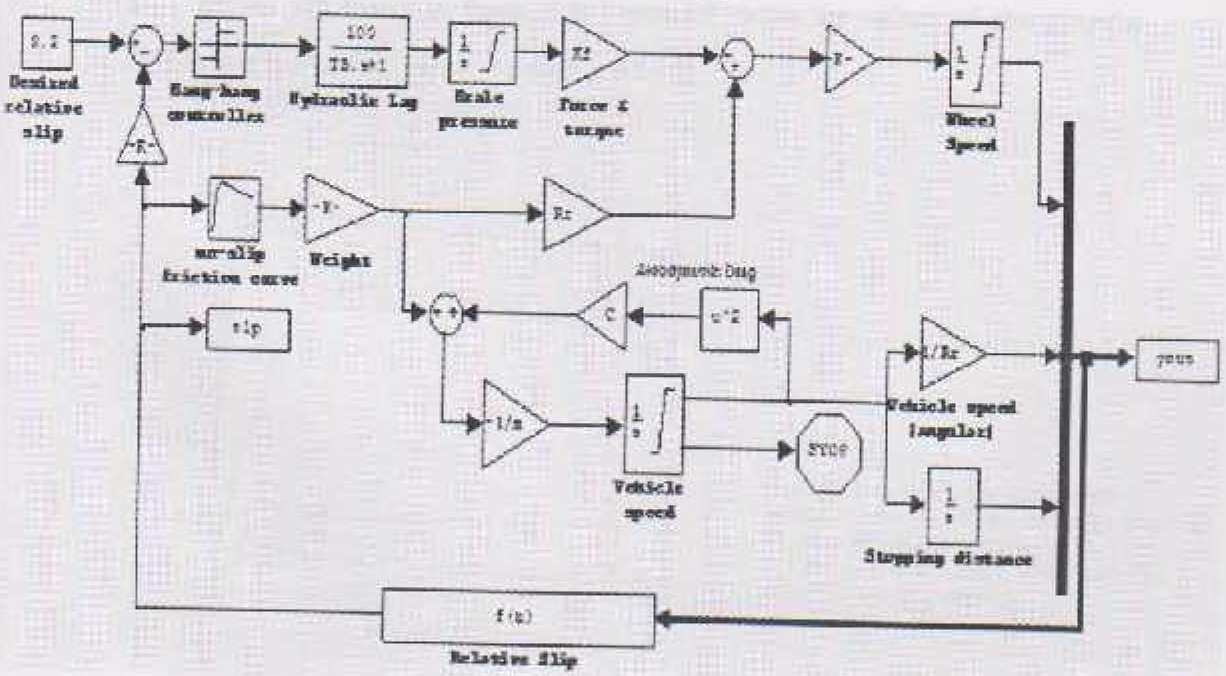

Figure 5.7: Simulink model of the overall system.

The translation of ABS simulink model to LabVIEW environment is done using the 'translation of simulation model' option, in which the ABS model is imported and converted to the corresponding blocks in LabVIEW.

The system parameters used in the simulink model are shown in table 5.1

Table 5.1: System parameters. [12]

Parameter	Value
Quarter car mass	440 kg
Wheel mass	40kg
Inertia	1.6 $kg.m^2$
Wheel radius	0.3m
Braking gain	0.8

Starting from testing the effects of changing the coefficient of friction by choosing one of the road surfaces in the combo box, these surfaces and there corresponding $\mu - s$ curves are shown in figure 5.8. Figure5.9 shows the effects of changing the surface that the vehicle passes on during driving.

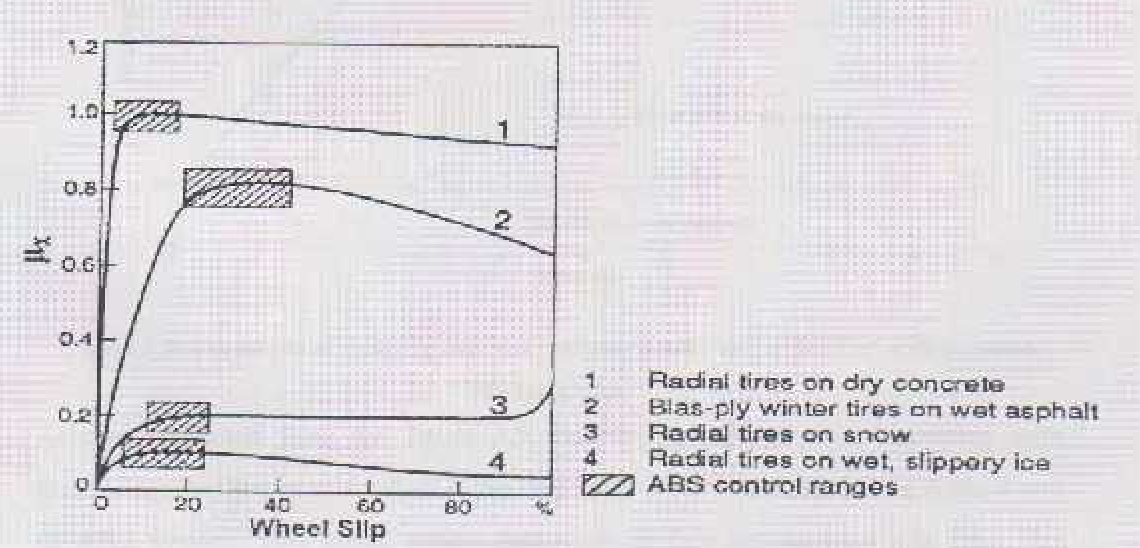

Figure 5.8: ABS control ranges as afunction of brake slip during staight-ahead braking.[11]

The road surfaces and there corresponding coefficient of friction are shown in table 5.2, these values of friction coefficients are obtained in the optimum range of slip ratio that the ABS forces the system to operate within. These values of μ_0 and slip ratio s_0 are used to obtain the friction coefficient $\mu(s)$ in eq.(B).

Table 5.2: Road surfaces and there corresponding coefficient of friction.

Road surface	Coefficient of friction	Optimal range of slip ratio
Radial tires on dry concrete	0.9	0.15-0.2
Bias-ply winter tires on wet asphalt	0.8	0.18-0.25
Radial tires on snow	0.2	0.17-0.21
Radial tires on wet, slippery ice	0.1	0.14-0.18

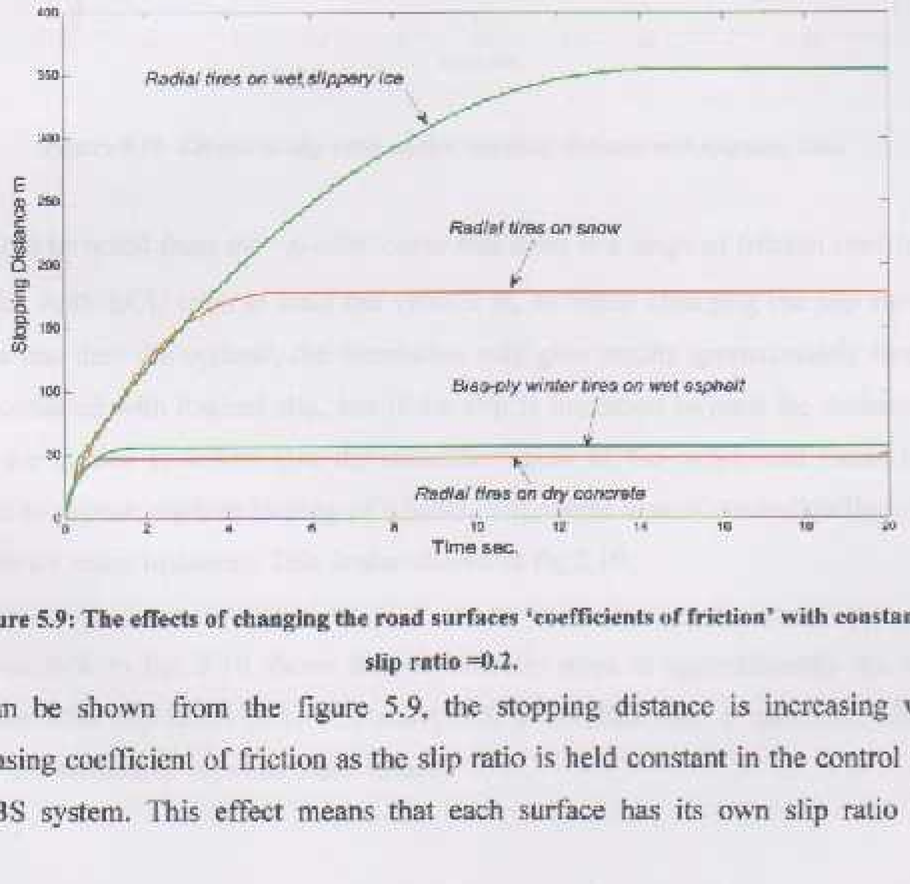

Figure 5.9: The effects of changing the road surfaces 'coefficients of friction' with constant slip ratio =0.2.

As can be shown from the figure 5.9, the stopping distance is increasing with decreasing coefficient of friction as the slip ratio is held constant in the control unit of ABS system. This effect means that each surface has its own slip ratio that corresponds to an optimum coefficient of friction which will eventually cause minimum stopping distance for that surface.

Also to explain the effects of slip ratio on stopping distance it is examined on the first surface, as can be shown in figure 5.10.

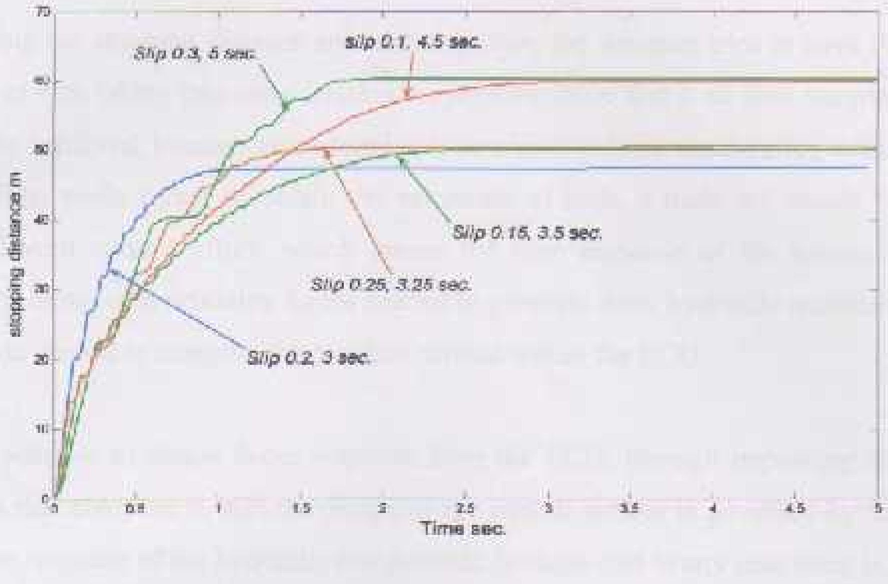

Figure 5.10: Effects of slip ratio on the stopping distance and stopping time.

It should be noted from the 'μ-slip' curve that there is a range of friction coefficient that the ABS ECU tries to hold the vehicle at, so when changing the slip ratio to values less than the optimal; the simulation may give results approximately like the ones obtained with desired slip, but if the slip is increased beyond the desired slip ratio the system is driven into the unstable region of the curve, and cause other effects to appear; such as locking of wheels, that means lose of controllability of the vehicle for some instances. This is also shown in fig.5.10.

A close lock to fig. 5.10 shows that the vehicle stops at approximately the same distance with slip ratios (0.1, 0.3) and (0.15, 0.25), this rises a question; what is really the difference between these values?

When a designer programs the ECU at a desired slip ratio, he/she thinks of many aspects at the same time, first reducing stopping distance, second reducing stopping time, the third is reducing the control effort, all of this while not allowing wheel lock up and so maintaining controllability of the vehicle.

For reducing the stopping distance and stopping time, the designer tries to have the minimum of both taking into consideration the physical laws; that is no zero stopping time can be achieved, because zero stopping time means infinite deceleration which is impossible, while trying to obtain the minimum of both, a trade off should be considered with control effort; which means the time response of the hydraulic components along with actuation forces needed to generate these hydraulic reactions, and the time needed to compute the required actions within the ECU.

While its possible to obtain faster response from the ECU; through improving the electronics that compose it, still the design of the overall system is governed by the slower time response of the hydraulic components, because still in any case there is a need for time to build up pressure, however, it is not allowed for pressure to reach values that may cause the wheel to lock up. So a good compromise between the three aspects should be adopted.

In order to clarify the image more, fig.5.11 shows the slip ratio fluctuations with time as the desired slip ratio is changed for the same surface, comparing these curves with the ones in fig.5.10, it is noticed that while slip ratios (0.1& 0.3) may have the same stopping distance and approximately stopping time, the system with (S=0.3) reaches high values of slip ratio indicating that the vehicle wheel locks up several times, however, looking at the curve of (S=0.1) the control signal and effort may cause a problem at the real system; because of high oscillations about the desired values=0.1. The same argument can be made for the pair of slip ratios (0.15& 0.25), indicating that the choice of the desired slip ratio to be =0.2, is an excellent choice,; because the three requirements have been achieved, also this is an indication that this point is the optimal working point for this surface and truly the highest friction is obtained at this point.

Another thing that can be concluded from fig. 5.11, is the stability range; as the most important purpose of ABS is to prevent wheels from locking up during braking, any wheel lock up during braking is considered as unstable, and the behavior of the system is not expected nor explained, and so, examining fig. 5.11 shows that both slip ratios (0.25& 0.3) cause wheel lock up at several occasions for several intervals of time, indicating that there is a high change in the wheel speed in a short time, which may physically damage the wheel components (axels, bearings, brake disk/drum,...etc), also from another point of view this action causes the lose of controllability of the vehicle, which the driver is indeed in need to bypass the panic situation and take the passengers to shore of safety.

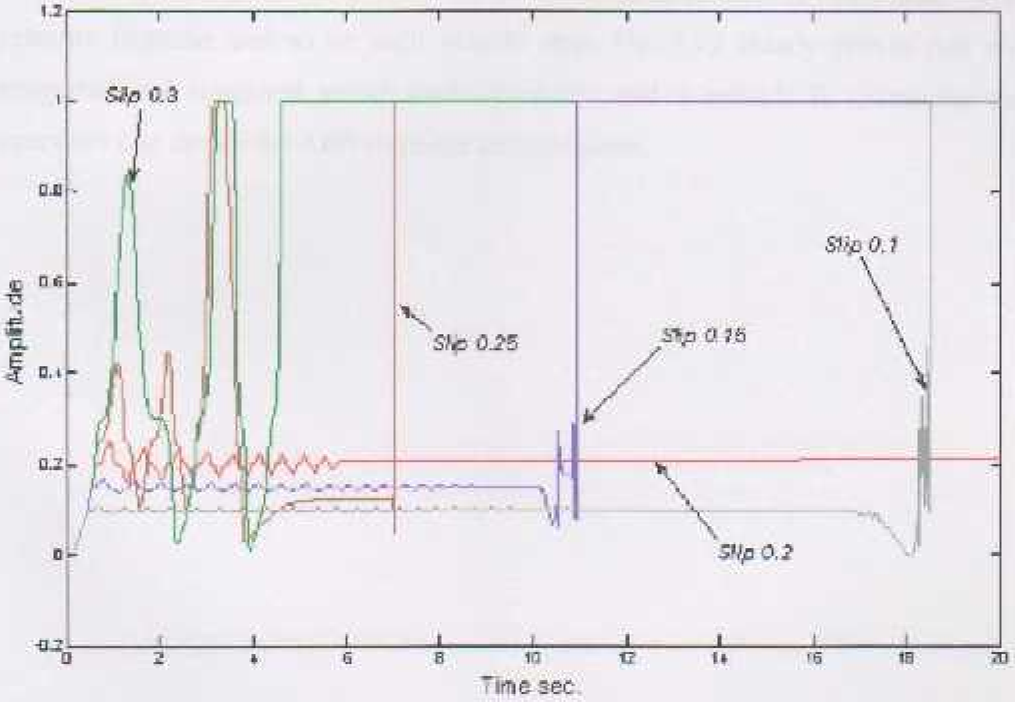

Figure 5.11: Desired Slip Ratio values on the same surface and its variations with time.

To illustrate the control cycle, i.e. ABS principle of operation, the three main signals indicating the operations of ABS are shown in fig. 5.12, the dashed lines are used to indicate the working phases of the ABS, i.e. increase, hold, and decrease.

From the figure it is noticed that in phase '1' a pressure increase is done from brake pedal, this is accompanied with a wheel speed drop until the system reaches the desired slip ratio, then the pressure enters the hold position indicated by phase '2'.

As the time passes the wheel speed drops more causing the slip to increase and the pressure to enter phase '3', in which a pressure decrease is performed until the system reaches the desired slip ratio, then phase '4' is performed with pressure hold and the wheel starts to accelerate again causing the slip ratio to drop below the desired value, as a consequence phase '5' is entered, in which another control cycle starts with pressure increase, and so on until vehicle stop. Fig. 5.12 clearly proves that our suggested and simulated model works properly, and is reliable in examining the operators that decide the ABS response and operation.

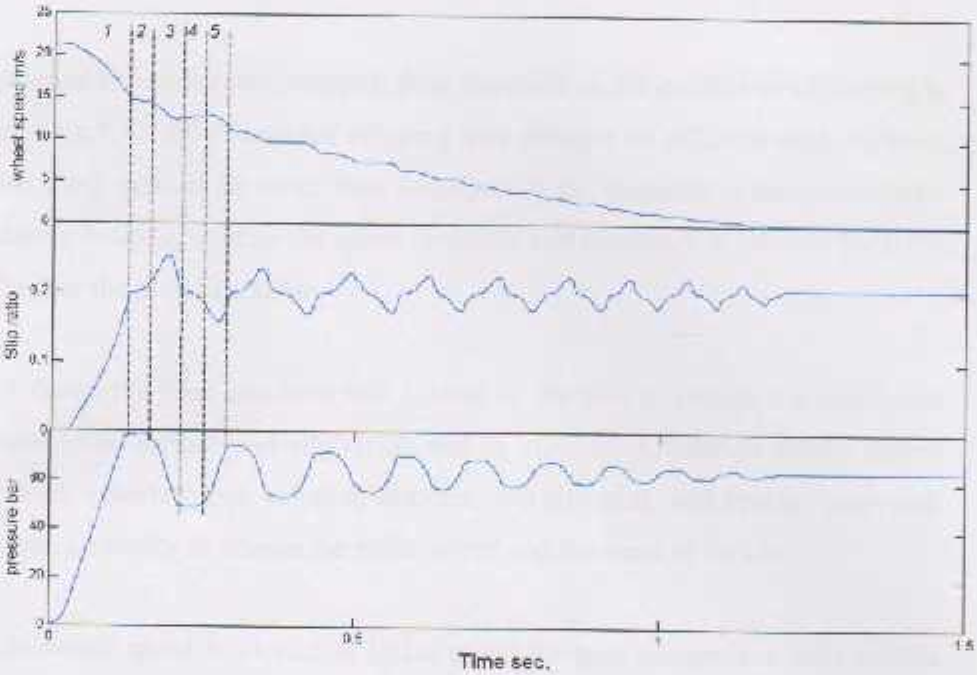

Figure 5.12: Control cycle of ABS system.

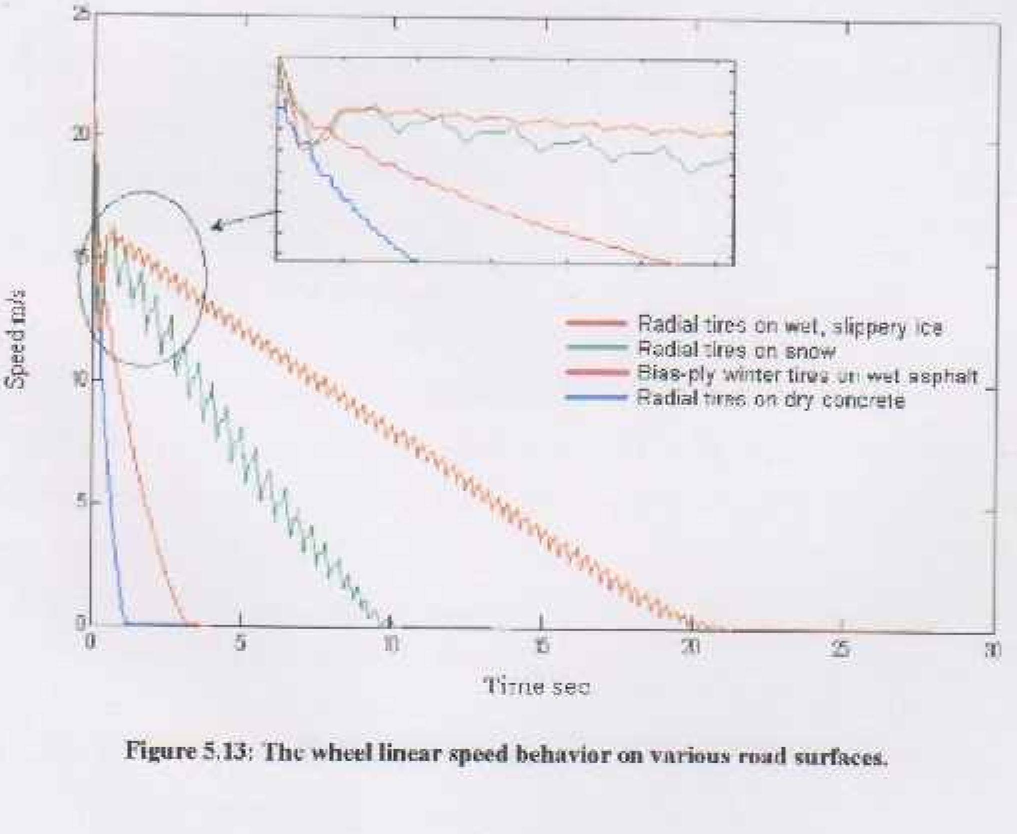

Figure 5.13: The wheel linear speed behavior on various road surfaces.

As mentioned before that the stopping time increases as the coefficient of friction is decreased, fig.5.13 shows how the stopping time changes on different road surfaces. The other thing that can be noted from this figure is the changing in the wheel linear speed during braking, as seen the speed increases and decreases in order to keep the slip ratio near the optimum value.

Fig.5.14 shows the final graphical that is used by the user to change the simulation parameters (road surface and slip ratio), and to view the simulation results (linear wheel speed, vehicle speed, stopping distance, slip changing, and braking pressure), there is also an ability to change the initial speed and the mass of the car.

Note: the wheel speed is plotted as linear speed for easy comparison with vehicle speed.

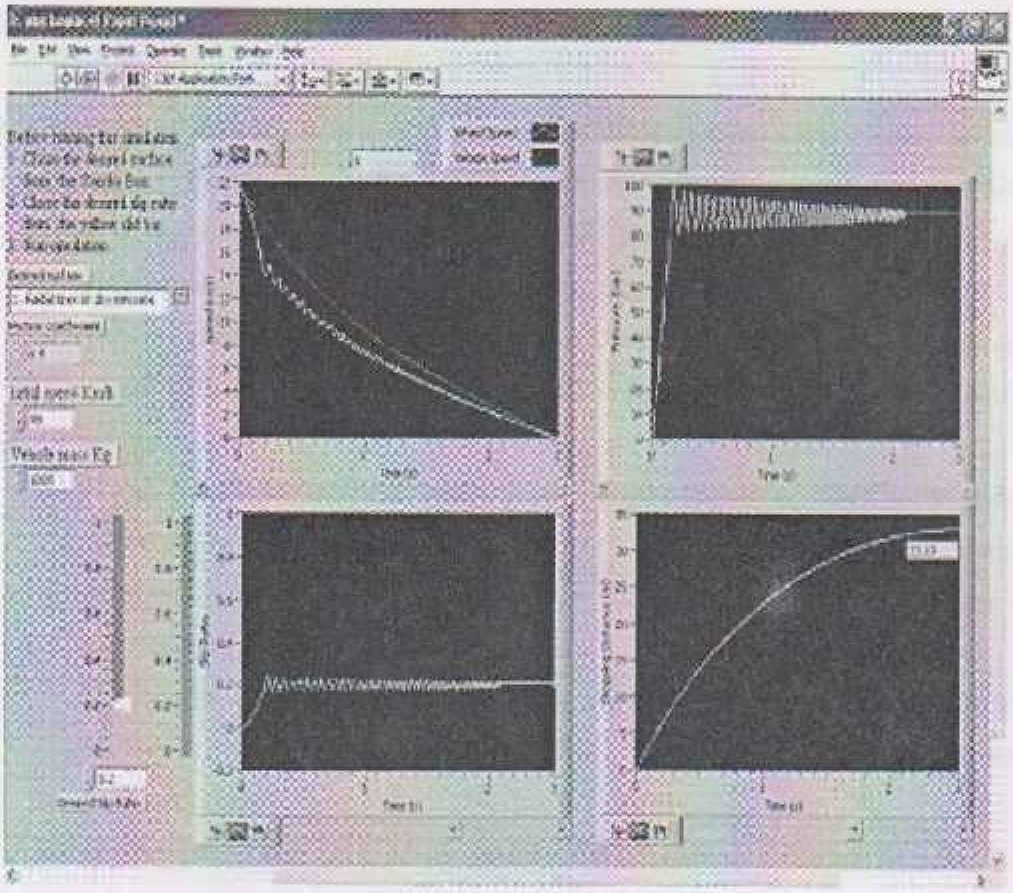

Figure 5.14: Graphical user interface.

5.4 Prerequisites of ABS simulation program

The model simulation of the ABS system is provided for the user as an" .EXE" type file, which enables for easy use of this software package, however, there are prerequisites that must exist for the program to operate efficiently and reliably, the minimum requirements are:

1- P4 1500 GHz , 256 RAM, 2 GB of H.D available space.

2- Operating system windows XP.

3- LabVIEW8.2 runtime engine.

4- To have the full preview of the program interface, screen resolution 1024*768 pixels.

5.5 Features of the ABS simulation program

The simulation software of the ABS provided with this project is considered as an reliable choice for the users who want to learn more about the ABS system, this reliability of the program is achieved through many features that include:

1- An easy access to the program through the EXE file.
2- This program covers almost all aspects related to the ABS system, i.e. wheel speed, vehicle speed, stopping time, stopping distance, pressure signal, and slip ratio curves.
3- For students who want to investigate the effects of changing some parameters on the behavior of the ABS and on the total response of the vehicle, they are allowed to change the slip ratio through the sliding bar, and also through choosing the surface coefficient of friction.
4- The results obtained are very reliable; because the references are curves plotted as results of an experimental work in the world first ABS system producer ***'Bosch'***.
5- This software can be used as an educational tool in the training schools, colleges and universities; through its user friendly interface and its presentation of true road surface situations, in other words, the real world is brought between the hands of the students.

Chapter Six

Conclusions and Recommendations

Chapter Six
Conclusions and Recommendations

6.1 Introduction

This chapter is devoted for the conclusions, remarks, problems faced, and future recommendations. Where in the first section, some of the results obtained during working on this project are presented, in the second section the problems raised during simulation and the hardware implementation are mentioned, finally, in section three the final recommendations about the system and its use will be introduced.

6.2 Conclusions and Remarks

During working on this project some remarks on the system hardware and simulation are noticed:-

1- The ABS system forms a step toward the auto-piloted vehicle which the automotive companies are competing to produce.

2- The major parameters that determine the operation of ABS in general are slip ratio and coefficient of friction, however, the control algorithm used has also an effect on the overall response of the vehicle.

3- This project has added to the knowledge of the working team, from the aspects of applying some concepts and theories gained through the academic life, looking for alternatives and solutions for the problems faced, and enhancing programming capabilities through dealing with new softwares that we didn't have any knowledge about.

4- In order to insure that students have gained all what is required from the ABS system; that is to be able to indicate the phases of operation of the ABS system, and the parameters that affects its operation, an experiment have been designed that will help students and instructor to evaluate all sides of the ABS system principle of operation. The experiment form is accompanied in appendix D.

6.3 Problems Faced

There are many difficulties that we have dealt with and managed to overcome while working on the project, these are:-

1- Some noise occurred in the signals measured, but the sever and dangerous one that almost destroyed the signal, is the one that occurred on the speed signal; because we are interested in the hole range of wheel angular speed, i.e. from approximately 0.0 Hz to 550 Hz, and the noise was covering almost the whole range, and the conventional (low-, high-, and band-pass) filters could not solve the problem, also the source of noise was unknown, so hardware elimination wasn't also possible, and so, a novel approach was adapted; in which we took advantage of the small amplitude of the noises compared to the original signal, and with another stage of signal averaging we were able to brought the signal to an acceptable form like it should be.

2- The unknown inertia and coefficient of friction of the hardware system in the automotive workshop, has prevented us from calibrating the system to a standard surface, however, the results obtained by simulation gives results similar to that from the hardware; indicating that our simulation software is working properly, eventually if a mean for estimating the inertia and coefficient of friction is found, the system can be calibrated to one of the standard surfaces and verified by simulation.

6.4 Future Recommendations

The ABS system can be combined and examined with other systems, such as active suspension system, and traction control system, this will give more interesting results concerning vehicle dynamics in acceleration, braking, and ride of the vehicle.

Its worth to note that with little reconfigurations this package can be brought to marketing especially for training schools, collages and universities.

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Appendices

Appendix A
Analog/Digital Input Signal Overview

A.1 Analog Input Signal Overview

The Connection of the analog input signals to the device depends on the type of input signal source and the configuration of the analog input channels you are using. This section provides an overview of the different types of signal.

A.1.1 Types of Signal Sources

When making signal connections, you must first determine whether the signal sources are floating or ground-referenced.

A.1.1.1 Floating Signal Sources

A floating signal source is not connected in any way to the building ground system but, rather, has an isolated ground-reference point. Some examples of floating signal sources are outputs of transformers, thermocouples, battery-powered devices, optical isolator outputs, and isolation amplifiers. An instrument or device that has an isolated output is a floating signal source.

A.1.1.2 Ground-Referenced Signal Sources

A ground-referenced signal source is connected in some way to the building system ground and is, therefore, already connected to a common ground point with respect to the data acquisition card, assuming that the computer is plugged into the same power system. Non-isolated outputs of instruments and devices that plug into the building power system fall into this category.

The difference in ground potential between two instruments connected to the same building power system is typically between 1 and 100 mV, but it can be much higher if power distribution circuits are improperly connected. If a grounded signal source is improperly measured, this difference may appear as a measurement error. The connection instructions for grounded signal sources are designed to eliminate this ground potential difference from the measured signal.

A.1.2 Connecting Analog Input Signals

The following discussion describes the use of single-ended and differential measurements and makes recommendations for measuring both floating and ground-referenced signal sources.

Fig A.1 summarizes the recommended input configuration for both types of signal sources.

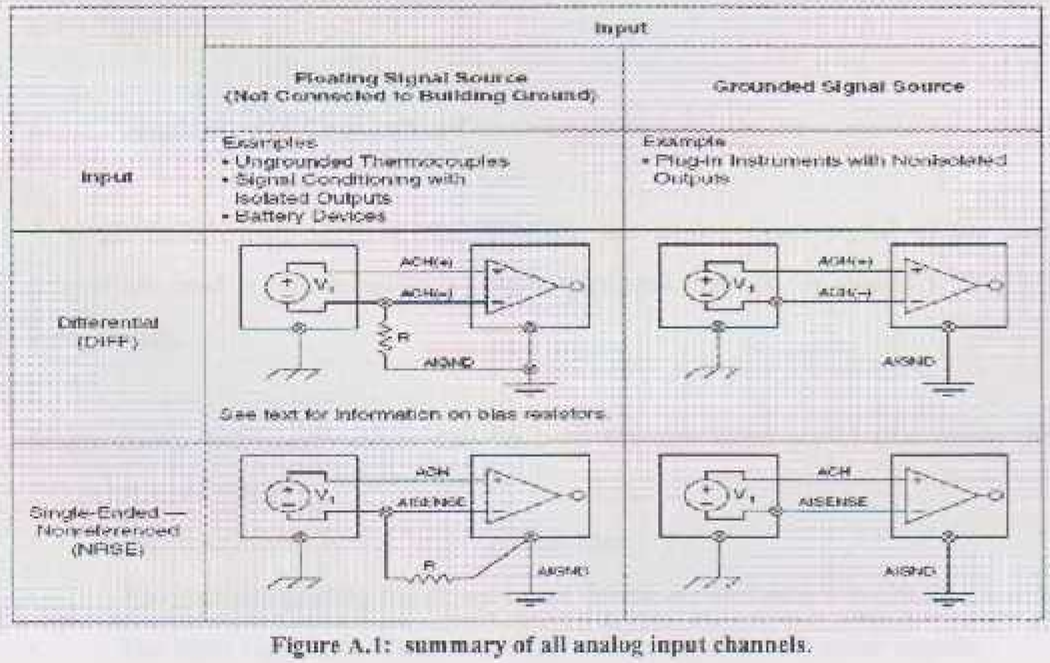


Figure A.1: summary of all analog input channels.

A.1.2.1 Differential Connection Considerations

A differential connection is one in which the analog input signal has its own reference signal or signal return path. These connections are available when the selected channel is configured in DIFF input mode.

In DIFF input mode, each signal uses two multiplexer inputs—one for the signal and one for its reference signal.

DIFF input connections should be used for any channel that meets any of the following conditions:

- The input signal is low level (less than 1 V).
- The leads connecting the signal to the device are greater than 3 m (10 ft).
- The input signal requires a separate ground-reference point or return signal.
- The signal leads travel through noisy environments.

Differential signal connections reduce noise pick up and increase common-mode noise rejection.

A.1.2.2 Single-Ended Connection Considerations

A single-ended connection is one in which the analog input signal of the data acquisition card is referenced to a common ground that can be shared with other input signals.

Single-ended input connections can be used for any input signal that meets the following conditions:

- The input signal is high level (greater than 1 V).
- The leads connecting the signal to the device are less than 3 m (10 ft).
- The input signal can share a common reference point with other signals.

DIFF input connections are recommended for greater signal integrity for any input signal that does not meet the preceding conditions.

In single-ended configurations, more electrostatic and magnetic noise couples into the signal connections than in differential configurations. The coupling is the result of differences in the signal path. Magnetic coupling is proportional to the area between the two signal conductors. Electrical coupling is a function of how much the electric field differs between the two conductors.

A.2 Connecting Digital I/O Signals

The following figure shows DIO<0..3> configured for digital input and DIO<4..7> configured for digital output. Digital input applications include receiving TTL signals and sensing external device states, such as the switch state shown in the Figure 4-9. Digital output applications include sending TTL signals and driving external devices, such as the LED shown in Fig A.2.

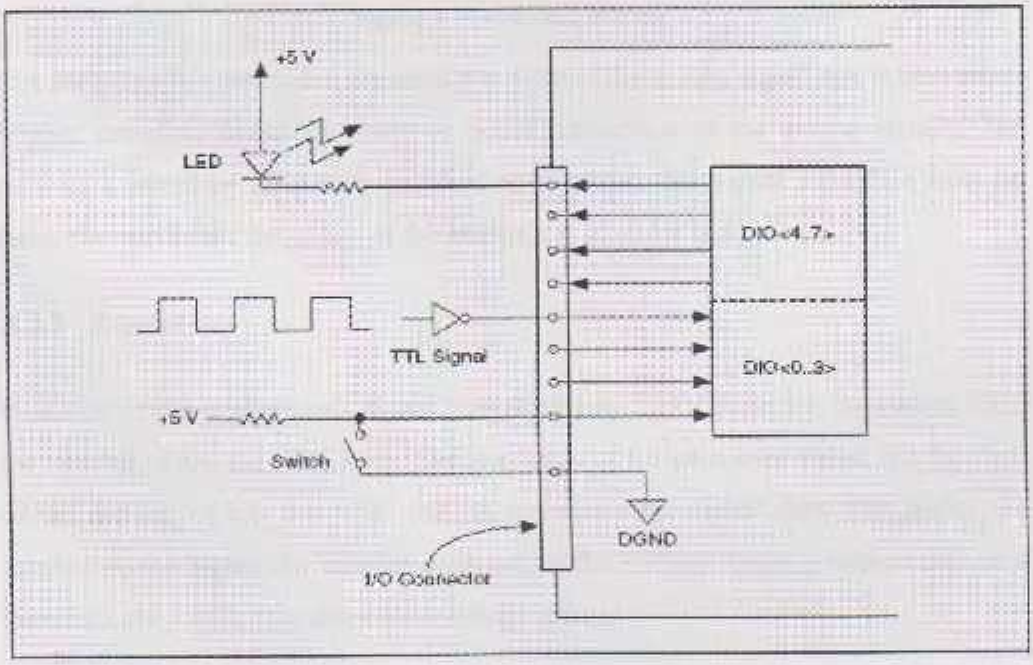


Figure A.2: Digital I/O connection.

A.3 AD and DA Conventions

A.3.1 Sampling

The data is acquired by an ADC using a process called sampling. Sampling an analog signal involves taking a sample of the signal at discrete times. This rate at which the signal is sampled is known as sampling frequency. The process of sampling generates values of signal at time interval as shown in fig 2.8.

Figure A.3: sampling process

The sampling frequency determines the quality of the analog signal that is converted. Higher sampling frequency achieves better conversion of the analog signals. The minimum sampling frequency required to represent the signal should at least be twice the maximum frequency of the analog signal under test.

A.3.2 Resolution

Precision of the analog input signal converted into digital format is dependent upon the number of bits the ADC uses. The resolution of the converted signal is a function of the number of bits the ADC uses to represents the digital data. The higher the resolution, the higher the number of divisions the voltage range is broken into, and therefore, the smaller the detectable voltage change

A.3.3 Settling time

On a typical board, the analog signal is first selected by a multiplexer, and then amplified before it is converted by the ADC. The amplifier used between multiplexer and ADC must be able to track the output of the multiplexer, otherwise the ADC will convert the signal that is still in transition from the previous channel value to the current channel value. Poor settling time is a major problem because it changes with sampling rate and the gain of the DAQ board

A.3.4 Analog to Digital Converter (ADC)

Once the signal has been sampled, one needs to convert the analog samples into a digital code. This process is called analog to digital conversion. This is shown in Fig2.9

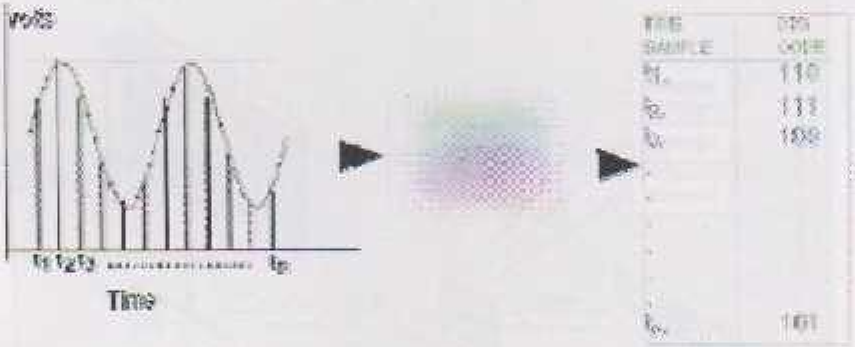


Figure A.4: Analog to Digital Conversion for a 3-bit ADC

A.3.5 Digital to Analog Converter (DAC)

The multifunction boards also have on-board digital to analog converters (DAC). A DAC can generate an analog output from a digital input. This allows the board to generate analog signals, both dc and ac voltages. Like the ADC, the DAC's performance is limited by the number of samples it can process and the number of bits that is used in converting the digital code into an analog signal.

Using high performance DAQ cards and fast computers, and data processing software like LabVIEW, one can achieve performance similar to expensive bench top instruments. The virtual instruments (VIs) can therefore control an output, process the input signals and log the data.

A.3.6 Data Transfers to the computer

Typically, DAQ boards are installed in a PC with high speed data bus like PCI. Depending on the speed of the motherboard of the PC, the maximum data transfers can occur between microprocessor and memory at 20 MHz to 40 MHz. To improve the data transfers, bus mastering (allowing DAQ board to transfer data directly) is implemented as shown below in fig (2.10 and 2.11).

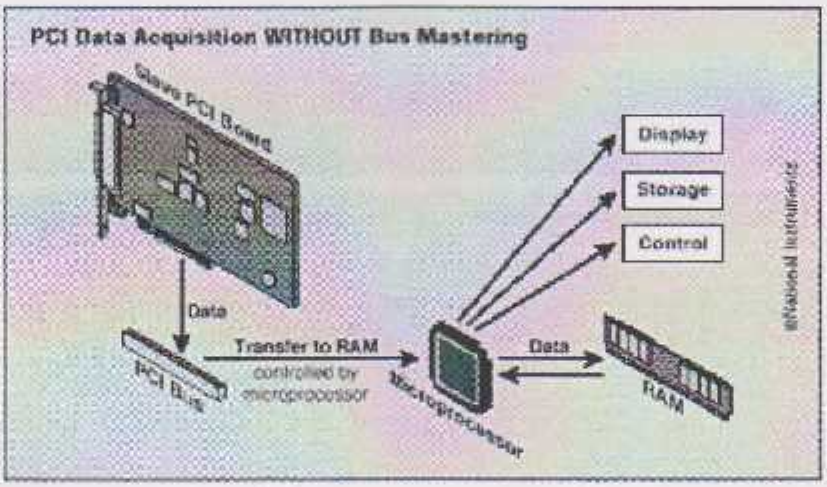


Figure A.5: Data transfer without bus mastering (conventional)

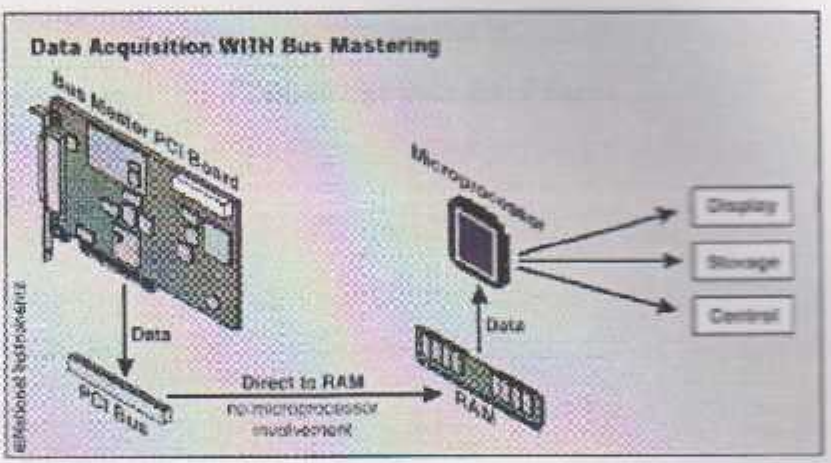


Figure A.6: Data transfer with bus mastering (used in expensive DAQ boards)

As you may now conclude, that sampling frequency and resolution are very important factors in determining the performance of a DAQ card. But, in addition to the sampling speed, there are other factors that can affect the functionality of a DAQ system.

Appendix B

Pressure sensor data sheet

Pressure sensors

For pressures up to 1800 bar (180 Mpa)

- Ratiometric signal evaluation (referred to supply voltage).
- Self-monitoring of offset and sensitivity.
- Protection against polarity reversal, overvoltage, and short circuit of output to supply voltage or ground.
- High level of compatibility with media since this only comes into contact with stainless steel.
- Resistant to brake fluids, mineral oils, water, and air.

Application
Pressure sensors of this type are used to measure the pressures in automotive braking systems, or in the fuel-distributor rail of a gasoline direct-injection engine, or in a diesel engine with Common Rail injection.

Design and function
Pressure measurement results from the bending of a steel diaphragm on which are located polysilicon strain-gauge elements. These are connected in the form of a Wheatstone bridge. This permits high signal utilisation and good temperature compensation.
The measurement signal is amplified in an evaluation IC and corrected with respect to offset and sensitivity. At this point, temperature compensation again takes place so that the calibrated unit comprising measuring cell and ASIC only has a very low temperature-dependence level.
Part of the evaluation IC is applied for a diagnostic function which can detect the following potential defects:
- Fracture of a bonding wire to the measuring cell.
- Fracture anywhere on any of the signal lines.
- Fracture of the bridge supply and ground.

Only for 0 265 005 303
This sensor differs from conventional sensors due to the following diagnostic functions:
- Offset errors
- Amplification errors

can be detected by comparing two signal paths in the sensor.

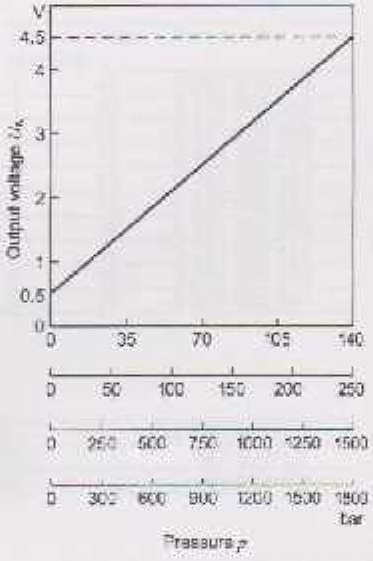
Storage conditions

Temperature range	–30...+60 °C
Relative air humidity	0...80 %
Maximum storage period	5 years

Through compliance with the above storage conditions, it is ensured that the sensor functions remain unchanged.
If the maximum storage conditions are exceeded, the sensors should no longer be used.

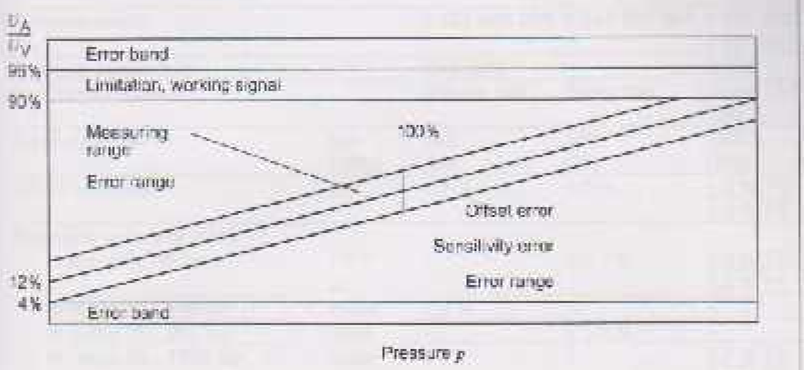
Explanation of symbols
U_A Output voltage
U_V Supply voltage
bar Pressure

Characteristic curve.
$U_A = (0.8 \cdot p / p_{Nenn} + 0.1) U_V$

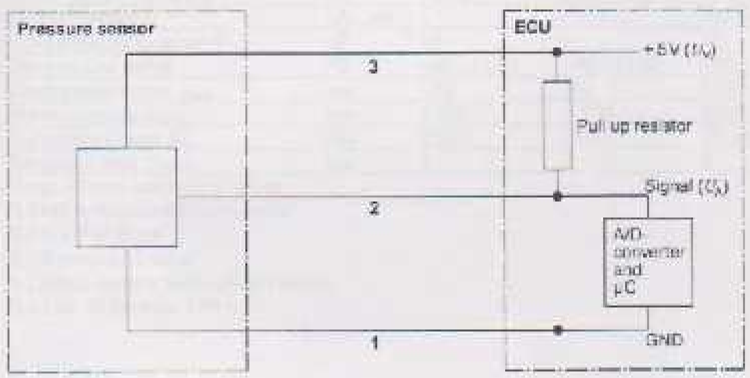


Pressure sensors (contd.)
For pressures up to 1800 bar (180 MPa)

Self-monitoring. Offset and sensitivity. Only for 0 265 005 303.



Measuring circuit.



Diagnostic function during self-test (following switch-on). Only for 0 265 005 303.
- Correctness of the calibration values
- Function of the sensor signal path from the sensor to the A/D convertor of the evaluation unit
- Check of the supply lines.

Diagram:
Characteristic of the output voltage following switch-on
- Function of the signal and alarm paths
- Detection of offset errors
- Detection of short circuits in wiring harness
- Detection of overvoltage and under-voltage
- If an error is detected during the sensor's self-test, the signal output is switched to the voltage range >96% U_V.

Diagnostic function during normal operation.
Only for 0 265 005 303.
- Detection of offset errors
- Detection of sensitivity errors (with pressure applied)
- Wiring harness function, detection of wiring harness short circuits
- Detection of overvoltage and under-voltage
- If an error is detected during the sensor's self-test, the signal output is switched to the voltage range >96% U_V.

Range

Pressure range bar (MPa)	Sensor Type	Thread	Connector	Pin	Dimens. drawing	Page	Part number
140 (14)	KV2 BDE	M 10x1	Compact 1.1	Gold-plated	1	47	**0 261 545 006**
250 (25)	–	M 10x1	PSA	–	2	46	**0 265 005 303**
1500 (150)	RDS2	M 12x1.5	Working circuit	Silber-plated	3	46	**0 281 002 238**
		M 12x1.5	Compact 1.1	Gold-plated	4	48	**0 281 002 405**
	RDS3	M 12x1.5	Working circuit	Silber-plated	5	48	**0 281 002 498**
		M 12x1.5	Compact 1.1	Gold-plated	6	49	**0 281 002 522**
1800 (180)	RDS2	M 12x1.5	Compact 1.1	Gold-plated	4	48	**0 281 002 398**
		M 18x1.5	Compact 1.1	Gold-plated	7	49	**0 281 002 472**
	RDS3	M 18x1.5	Compact 1.1	Gold-plated	8	49	**0 281 002 534**
		M 18x1.5	Working circuit	Silber-plated	9	49	**0 281 002 504**

Accessories

For 0 265 005 303				
Plug housing	–	Quantity required: 1	AMP No.	**2-967 642-1** [1]
Contact pins	for 0.75 mm²	Quantity required: 3	AMP No.	**965 907-1** [1]
Gaskets	for 1.4...1.9 mm²	Quantity required: 3	AMP No.	**967 067-1** [1]

[1] To be obtained from AMP Deutschland GmbH, Amperestr. 7–11, D-63225 Langen,
Tel. 0 61 03/7 09-0, Fax 0 61 03/7 09 12 23, E-Mail: AMP.Kontakt@tycoelectronics.com

Technical data

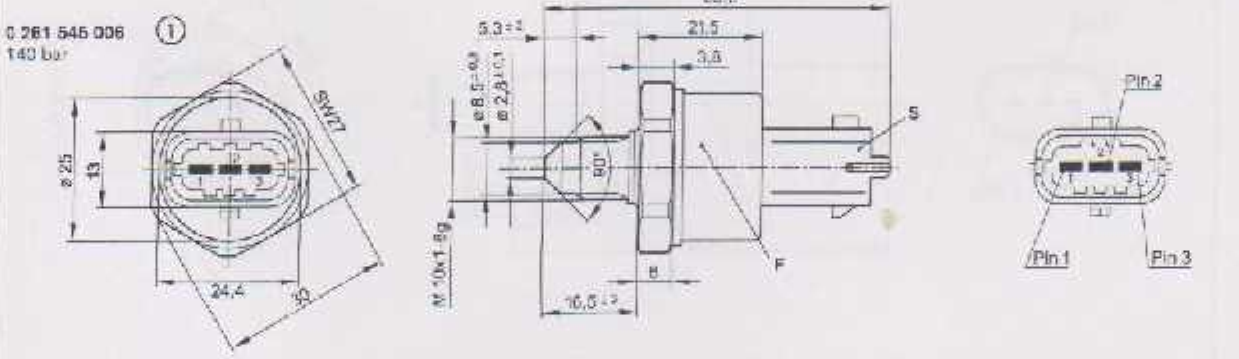
Pressure sensor		0 261 545 006	0 265 005 303	0 281 002 236 0 281 002 405	0 281 002 496 0 281 002 522	0 281 002 396 0 281 002 472	0 281 002 534 0 281 002 504
Pressure-sensor type		KV2 BDE	–	RDS2	RDS3	RDS2	RDS3
Application/Medium		Unlead. fuel	Brake fluid	Diesel fuel or RME [1])	Diesel fuel or RME [1])	Diesel fuel or RME [1])	Diesel fuel or RME [1])
Pressure range	bar (MPa)	140 (14)	250 (25)	1500 (150)	1500 (150)	1800 (180)	1800 (180)
Offset accuracy	U_V	0.7 % FS	2.0 %	1.0 % FS 1.5 % FS	0.7 % FS	1.0 % FS	0.7 % FS
Sensitivity accuracy at 5 V In range 0...35 bar	FS [2]) of meas-ured value	–	≤ 0.7 %	1.0 % FS 1.5 % FS	0.7 % FS	1.0 % FS	0.7 % FS
In range 35...140 bar		1.5 %	–	–	–	–	–
In range 35...250 bar		–	≤ 5.0 % [3])	–	–	–	–
In range 35...1500 bar		–	–	2.0 % FS 2.5 % FS	1.5 % FS	–	–
In range 35...1800 bar		–	–	–	–	2.3 % FS	1.5 % FS
Input voltage, max. U_E	V	16	–	16	16	16	16
Power-supply voltage U_V	V	5 ±0.25	5 ±0.25	5 ±0.25	5 ±0.25	5 ±0.25	5 ±0.25
Power-supply current I_V	mA	9...15	≤ 20	9...15	9...15	9...15	9...15
Output current I_A	µA...mA	–	–100...3	2.5 mA [4])	–	2.5 mA [4])	–
Load capacity to ground	nF	13	–	10	13	10	13
Temperature range	°C	–40...+130	–40...+120	–40...+120 [5])	–40...+130	–40...+120 [5])	–40...+130
Overpressure max. p_{max}	bar	180	350	1800	2200	2100	2200
Burst pressure p_{burst}	bar	> 300	> 500	3000	4000	3500	4000
Tightening torque M_A	Nm	22 ±2	20 ±2	35 +5	35 +5	70 +2	70 +2
Response time $T_{10/90}$	ms	2	–	5	2	5	2

Note: All data are typical values.
1) RME = Rapeseed methyl ester
2) FS = Full Scale
3) Of measured value
4) Output current with pull-up resistor
5) +140 °C for max. 250 h

Dimension drawings
Space required by plug, approx. 25 mm
Space required when plugging/unplugging, approx. 50 mm
SW = A/F size

Connector-pin assignment
Pin 1 Ground
Pin 2 Output voltage U_A
Pin 3 Supply voltage U_V

0 261 545 006 ①
140 bar



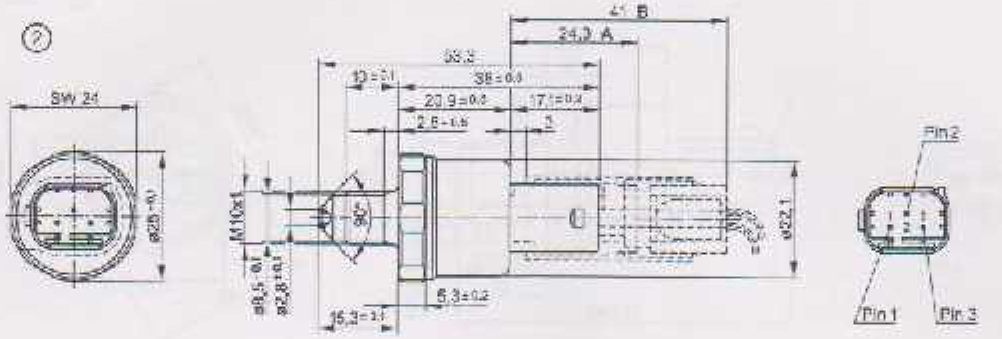
Pressure sensors (contd.)
For pressures up to 1800 bar (180 MPa)

Dimension drawings
Space required by plug, approx. 25 mm
Space required when plugging/unplugging, approx. 50 mm
SW = A/F size

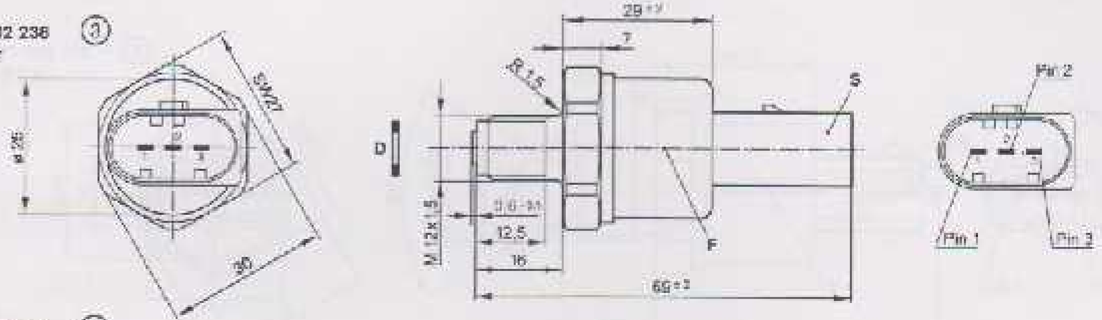
D Gasket
F Date of manufacture
S 3-pin plug

Connector-pin assignment
Pin 1 Ground
Pin 2 Output voltage U_A
Pin 3 Supply voltage U_V

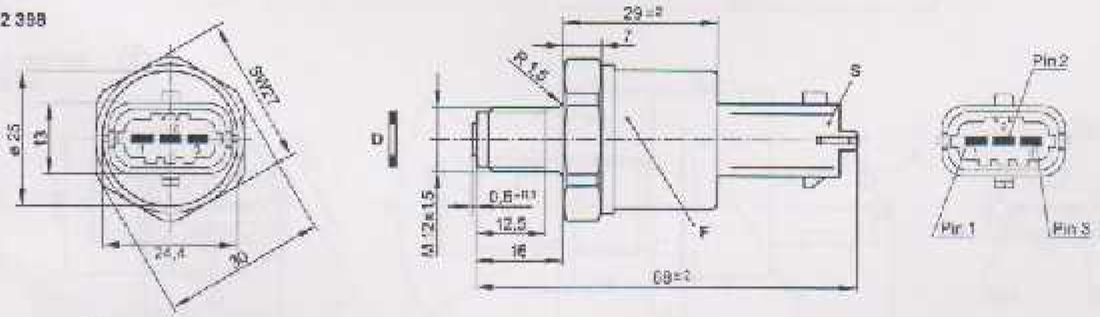
0 265 005 303 ②
250 bar



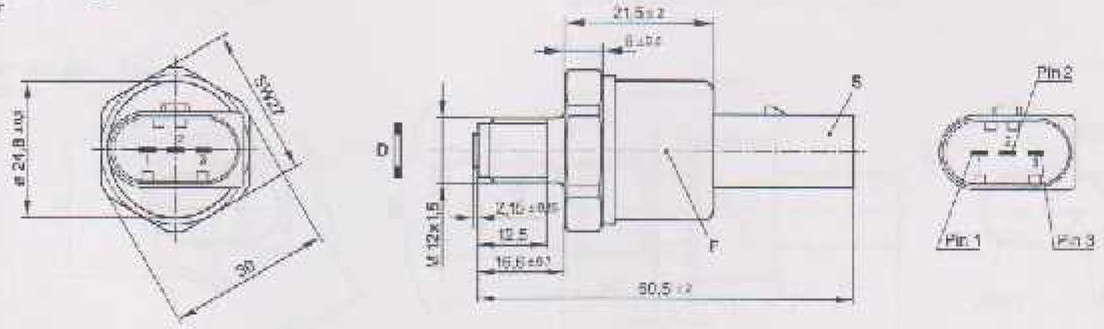
0 281 002 236 ③
1500 bar



0 281 002 405 ④
1600 bar
0 281 002 398
1800 bar



0 281 002 498 ⑤
1600 bar

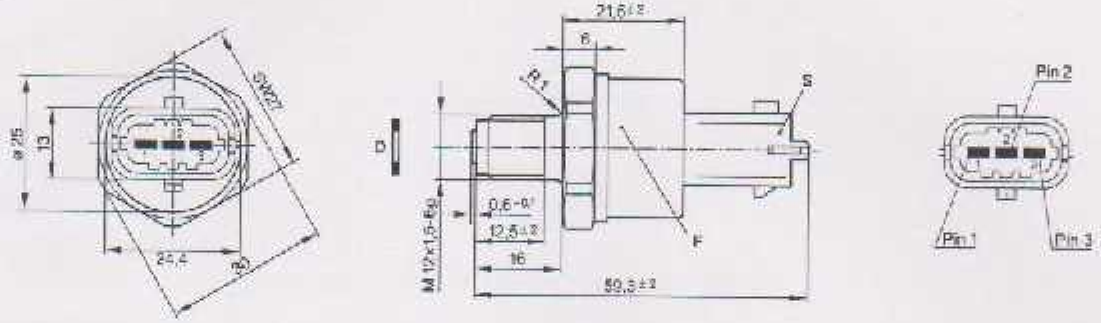


Dimension drawings
Space required by plug, approx. 26 mm
Space required when plugging/unplugging, approx. 60 mm
SW = A/F size

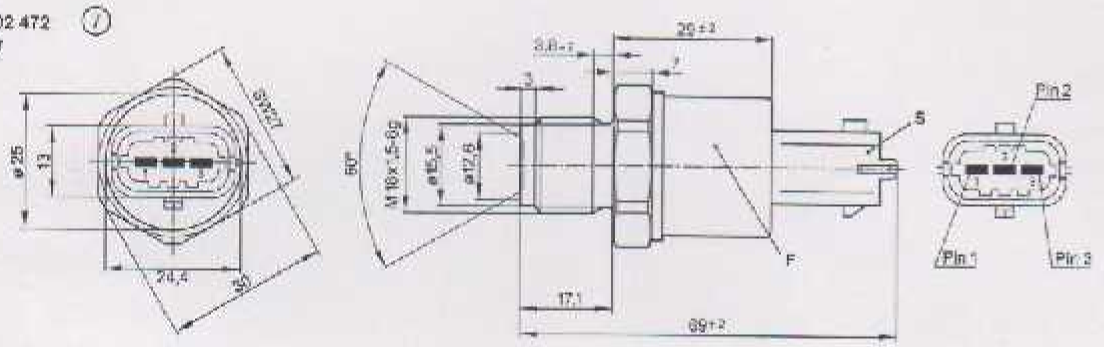
D Gasket
F Date of manufacture
S 3-pin plug

Connector-pin assignment
Pin 1 Ground
Pin 2 Output voltage U_A
Pin 3 Supply voltage U_V

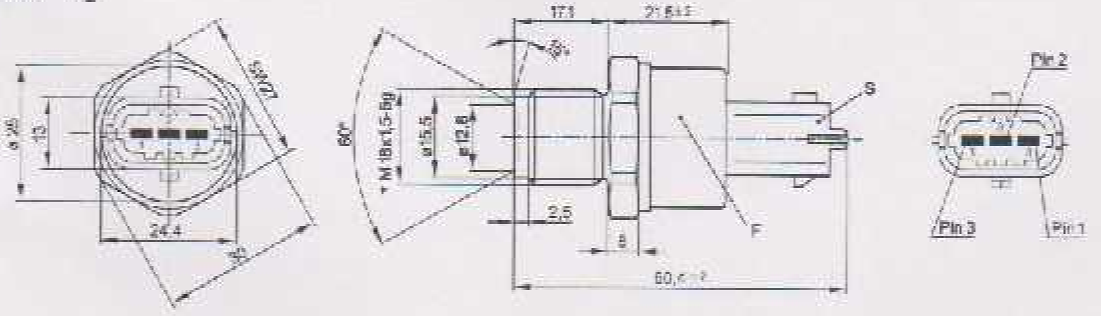
0 281 002 522 ⑥
1500 bar



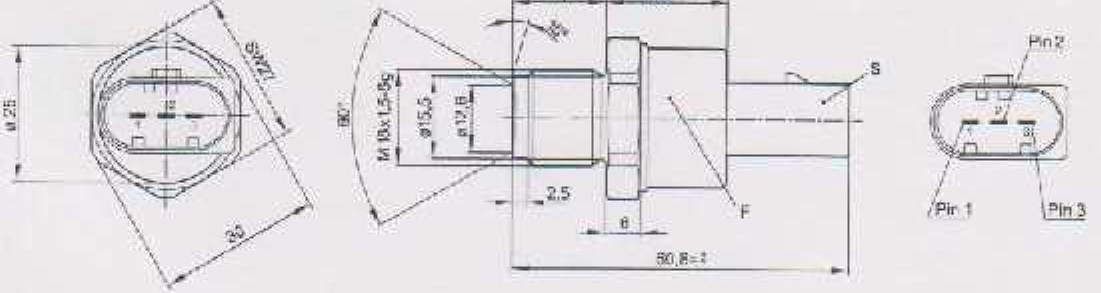
0 281 002 472 ⑦
1800 bar



0 281 002 534 ⑧
1600 bar



0 281 002 504 ⑨
1800 bar



Appendix C

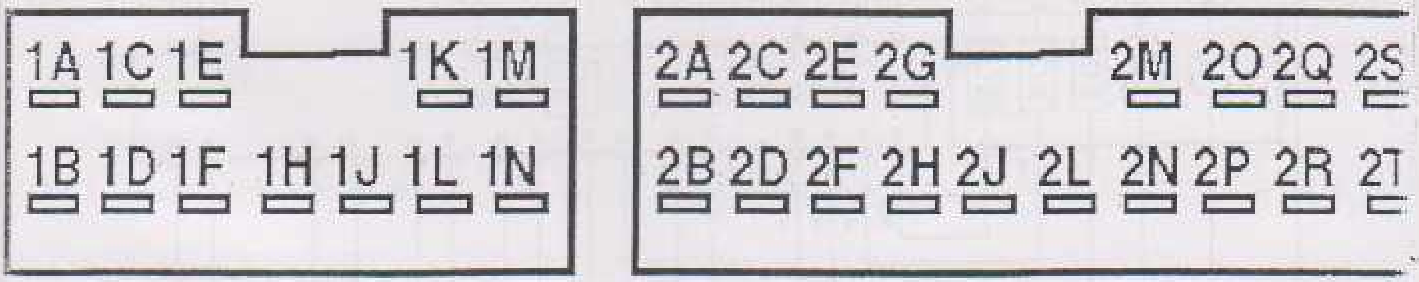
ABS System Wiring Diagram

Telephone:
Fax:
VAT Registration No.:

* رموز النظام ومعانيها .

H29	ABS warning lamp
S13	Brake pedal position (BPP) switch
X1	Data link connector (DLC)
A16	Electronic control unit (ECU)
F	Fuse
Y22	Hydraulic modulator
A5	Instrument panel
M61	Pump motor
K100	Pump motor relay
A171	Relay module
K38	System relay
B19	Wheel speed sensor, left front
B21	Wheel speed sensor, left rear
B20	Wheel speed sensor, right front
B22	Wheel speed sensor, right rear

* فيش وحدة التحكم الالكترونية الخاصة بنظام ال ABS

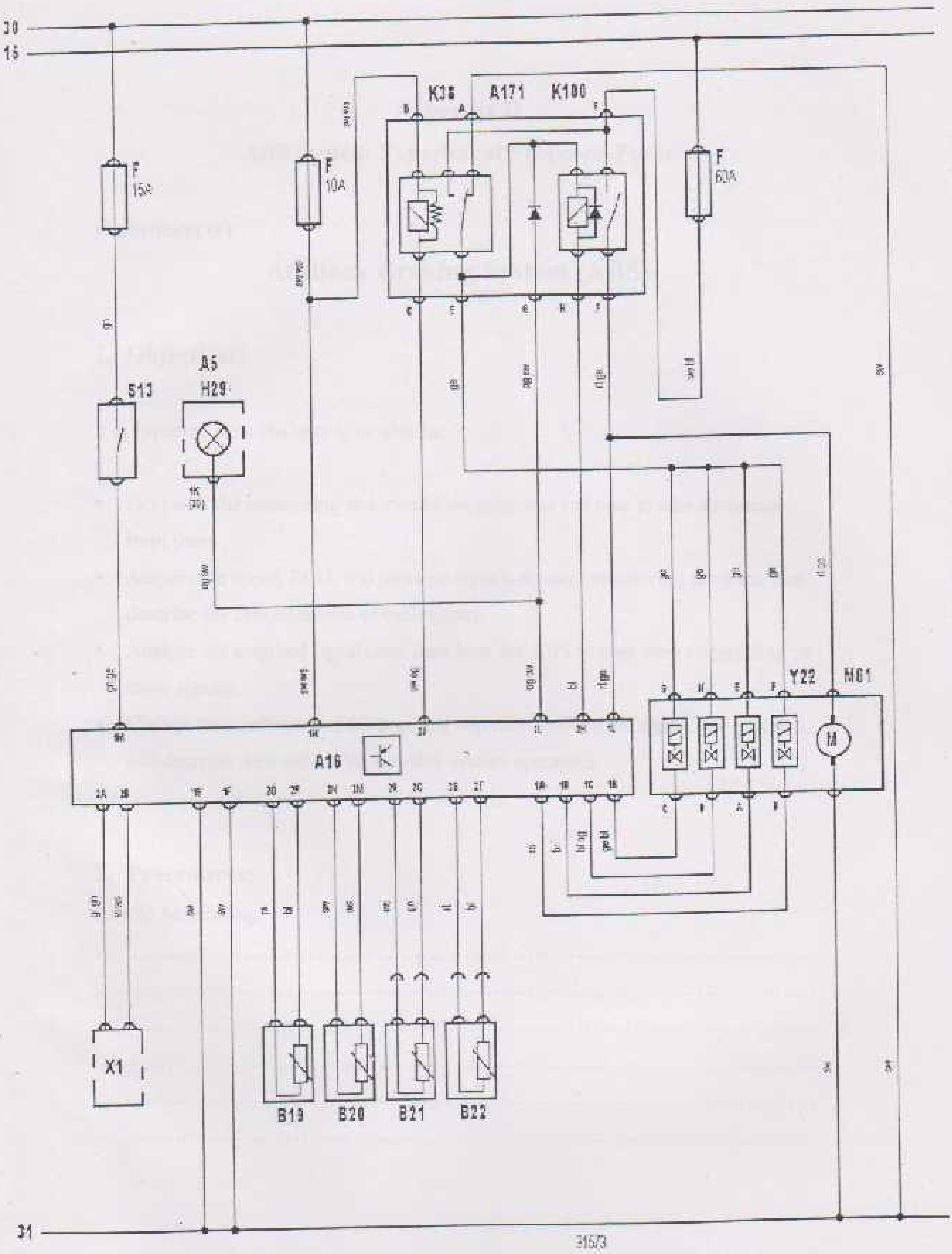


AD46 * الوان اسلاك النظام .

bl = blue	br = brown	el = cream	ge = yellow
gn = green	gr = grey	nf = neutral	og = orange
rs = pink	rt = red	sw = black	vi = violet
ws = white	hbl = light blue	hgn = light green	rbr = maroon
x = braided cable	y = high tension	z = non-cable connection	

NOTE: In certain diagrams (Citroen, Peugeot & Renault), colour codes are replaced by numbers which are used to identify a particular cable and not the colour. In this instance, the cables will be numbered at each end close to the harness connector.

… الخاصة بنظام ال ABS وطريقة توصيلها.



Appendix D

ABS System Experiment Proposed Form

Experiment (#)

Antilock Braking System (ABS)

1. Objectives:

It is expected from students to be able to:

- Deal with the monitoring and simulation program, and how to take advantage from them.
- Acquire the speed, ECU, and pressure signals through monitoring program, and describe the characteristics of each signal.
- Analyze the acquired signals and state how the ABS system works depending on these signals.
- Change the coefficient of friction, and slip ratio through the simulation program, and describe their effects on the ABS system operation.

2. Procedures:

Part A: Monitoring

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Part B: Simulation

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3. Dissection & Interpretation:

3.1. From the monitoring program:

- Plot the speed signal obtained from the monitoring program, then answer the following questions.

1. What is the maximum amplitude and frequency of this signal?

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2. Indicate the ABS operation on the graph explaining the phases that the speed has passed.

Hint: increase, decrease, and hold.

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- Plot the ECU signal and indicate the phases of the ABS system on the graph, then explain your results.

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- Plot the pressure signal and indicate the phases of the ABS system operation on the graph. Discuss your results.

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- Compare the three signals (speed, ECU, and pressure) on an interval, and show how your previous results and conclusions match with the three signals together.

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3.2. From the simulation program:

- Simulate the ABS system on two different surfaces (or more), and compare the effects on the stopping time and distance, also on the wheel speed behavior.

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- Choose one surface then try to notice the effects of changing the slip ratio on the various simulated signals, showing the ABS phases of operation.

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- During the simulation try to change the surface and the slip ratio, and explain the results on the various signals.

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تجربة #

نظام الكوابح المانعة للإقفال(ABS)

أهداف التجربة:

يتوقع من الطالب بعد إنهاء التجربة أن يكون قادرا على:

- التعامل مع برنامجي المراقبة والمحاكاة بسهولة ويسر، والاستفادة منهما قدر الامكان.
- التقاط إشارات السرعة، الضغط و إشارة وحدة التحكم المركزية (ECU) عن طريق برنامج المراقبة، بالإضافة إلى وصف خصائص هذه الإشارات.
- تحليل الإشارات التي تم الحصول عليها من نظام المراقبة من حيث مبدأ عمل نظام ال(ABS).
- تغيير بعض العوامل المتعلقة بمبدأ عمل نظام ال(ABS)، مثل معامل الاحتكاك ومعامل الانزلاق، وذلك من خلال برنامج المحاكاة، بالإضافة إلى وصف تأثير هذه الإشارات على عمل نظام ال(ABS).

خطوات العمل:

القسم (أ): برنامج المراقبة:

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القسم (ب): برنامج المحاكاة:

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المناقشة والتحليل:

القسم الأول: برنامج المراقبة:

- قم برسم إشارة السرعة الملتقطة على فترة محددة ثم اجب عن الأسئلة التالية:

ا- ما هي اقصى قيمة وصل إليها ارتفاع الإشارة وما هو أقصى تردد لهذه الإشارة؟

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2- على الشكل، حدد المراحل التي مر بها النظام أثناء التوقف، موضحا هذه المراحل من حيث (الزيادة، الثبات، التناقص) في قيم السرعة؟

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- قم برسم إشارة وحدة التحكم(ECU)على نفس الفترة السابقة التي تم رسم السرعة عليها، موضحا من خلالها ماذا تعني هذه الإشارة من حيث المستويات المختلفة لها؟

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- قم برسم إشارة الضغط على نفس الفترة السابقة، موضحا مراحل عمل نظام ال(ABS)؟

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- بالاستفادة من المنحنيات السابقة، قم بتوضيح مبدأ عمل نظام ال(ABS) بشكل متكامل موضحا ذلك من خلال المراحل التي يمر بها النظام وتسلسلها؟

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القسم الثاني: برنامج المحاكاة:

- قم باختبار اثر تغيير معامل الاحتكاك على مسافة وزمن التوقف، بالإضافة إلى تأثيره على سرعة العجلات وتصرفها مع ثبات معامل الانزلاق؟

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- قم بتثبيت معامل الاحتكاك ثم قم بتغيير معامل الانزلاق موضحا اثر ذلك على مختلف الإشارات من حيث مبدأ عمل نظام ال(ABS)؟

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- أثناء التشغيل حاول تغيير معامل الاحتكاك ومعامل الانزلاق موضحا اثر ذلك على تصرف السيارة بشكل عام وعلى مختلف الإشارات من حيث مبدأ عمل نظام ال(ABS)؟

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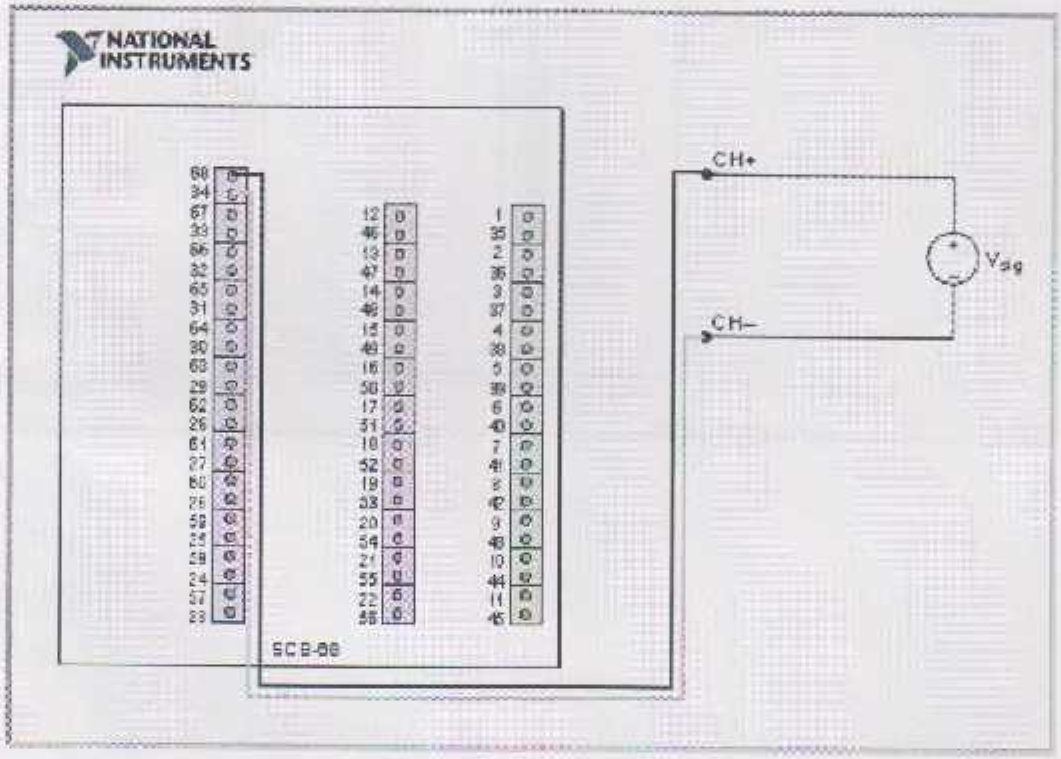
Appendix E
Connection Diagram Report

Task Name: differantial

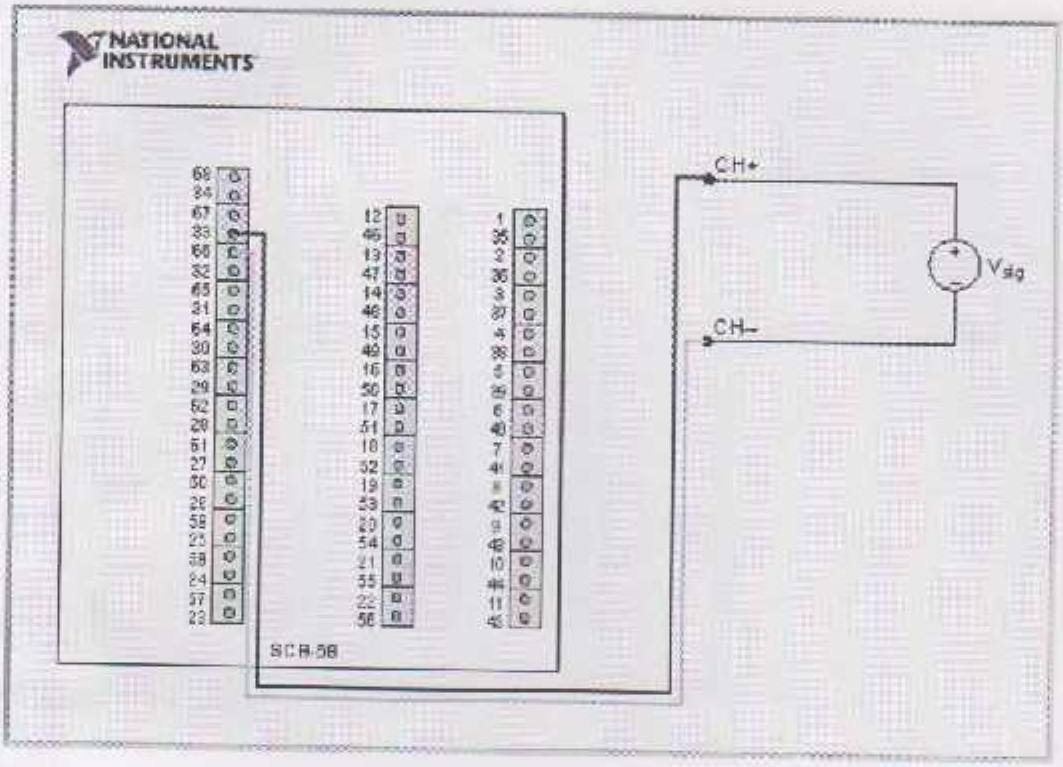
Channel Name	Physical Channel	Device Type	Measurement Type
Speed Signal	Dev1/ai0	PCI-6034E	Voltage
Pressure Signal	Dev1/ai1	PCI-6034E	Voltage
ECU Signal	Dev1/ai2	PCI-6034E	Voltage

Speed Signal	
Point 1	**Point 2**
Voltage/CH+	SCB-68/68
Voltage/CH-	SCB-68/34



Pressure Signal

Point 1	Point 2
Voltage/CH+	SCB-68/33
Voltage/CH-	SCB-68/66



ECU Signal

Point 1	Point 2
Voltage/CH+	SCB-68/65
Voltage/CH-	SCB-68/31