İSTANBUL TECHNICAL UNIVERSITY ★ INSTITUTE OF SCIENCE AND TECHNOLOGY

AUTOMOTIC CONTROL IN AUTOMOTIVE SYSTEMS

M.Sc Thesis by

Meltem ÖKSÜZOĞLU, Mech.Eng.

503970212011

Date of submission : 7 July 2000

Date of defence examination: 26 June 2000

Supervisor (Chairman): Prof. Dr. N.Aydın HIZAL

Members of the Examining Committee Prof.Dr. Ahmet GÜNEY (İ.T.Ü.)

Assoc.Prof.Dr. Kenan KUTLU (İ.T.Ü.)

JUNE 2000

İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

OTOMOTİV SİSTEMLERİNDE OTOMATİK KONTROL

YÜKSEK LİSANS TEZİ

Mak.Müh. Meltem ÖKSÜZOĞLU
503970212011

Tezin Enstitüye Verildiği Tarih : 7 Temmuz 2000
Tezin Savunulduğu Tarih : 26 Haziran 2000

Tez Danışmanı : **Prof.Dr. N.Aydın Hızal**

Diğer Jüri Üyeleri **Prof.Dr. Ahmet GÜNEY (İ.T.Ü.)**

Doç.Dr. Kenan KUTLU (İ.T.Ü.)

HAZİRAN 2000

ACKNOWLEDGEMENT

The preparation of the present thesis has made a big improvement in my career with the help and guidance of my supervisor, colleagues, friends and my family.

I am grateful with the guidance provided by Prof.Dr.N.Aydın Hızal during all phases of the study. Without his help and wisdom, I wouldn't able to be successful at this tough study. His critical evaluation of the thesis has been a valuable assistance as well.

I thank my brother Ersin Öksüzoğlu and my colleague Murat Eygi for their great helps all throughout this process and without their encouragement this work would not have been realized.

My special thanks go to my Manager Burak Gökçelik for his support and understanding during this tough study.

And last my very special gratitudes belongs to my parents who always believed in me .

Page Number

LIST OF ACRONYMS USED IN THIS DOCUMENT

ABS	- Anti-lock Braking System
ACC	- Adaptive Cruise Control
AD	- Analog to digital
ASM	- Auto Shift Manual Transmission
ATC	- Adaptive Transmission Control
BTCS	- Brake traction control system
CAN	- Controller Area Network
CARIN	- Car information and navigation system
CCD	- Charged couple device
CD-ROM	- Compact Disc- Read Only Memory
CSMA/CD	- Carrier sense multiple access with collision detect
CVT	- Continuously Variable Transmission
DI	- Direct Injection
DISI	- Direct Injection Spark Ignition
DSP	- Digital Signal Processing
DSRC	- Dedicated Short Range Communication
ECU	- Eledronic Control Unit
ETCS	- Engine traction control system
FM	- Frequency Modulation
F/S	- Fuel spark
FW	- Front wheel
GPS	- Global Positioning System
GSM	- Group special mode

HCU	- Hydraulic Control Unit
HID	- High Intensity Discharge (Lamps)
HMI	- Human-machine interface
HUD	- Heads-Up Display
IDC	- Infinite Door Check
IVD	- Interactive Vehicle Dynamics
IVHS	- Intelligent Vehicle Highway System
LCD	- Liquid Crystal Displays
LED	- Light Emitting Diode
LSD	- Limited slip differentials
NRZ	- No return to zero
PATS	- Passive Anti-Theft System
PFI	- Port Fuel Injection
PIN	- Personal Identification Number
RDS	- Radio data system
RESCU	- Remote Emergency Satellite Cellular Unit
RKE	- Remote Keyless Entry
RW	-Rear wheel
SHO	- Super High Output
SOCRATES	- System of cellular radio for traffic efficiency and safety
SPI	- Split Port Induction
SSM	- Select Shift Manual Transmission
TMC	-Traffic message channel
T/S	- Throttle spark
VAPS	- Variable Assist Power Steering
VEMS	- Vehicle Emergency Messaging System
WSS	- Wheel speed sensor
4WD	- Four wheel drive

LIST OF FIGURES

LIST OF SYMBOLS

ΔT	axle torque difference
Δn	wheel speed difference
M_{LSD}	moment in the yaw direction
ψ	yaw rate
F_L	longitudinal force
F_S	side force
α	fixed slip angle
S^t	aimed slip ratio of sub-throttle control
S^b	aimed slip ratio of brake control
ΔV_H	the difference in the rotation speed between the front and rear wheel
V_{WF}	front-wheel rotating
V_{WR}	rear-wheel rotating
T_V	torque distribution signal to the front wheels
T_{as}	sub-throttle target angle
V_{ts}	driven wheels target speed
V_t	driven wheels speed
S	target slip ratio
V_b	vehicle velocity
KA, KB	feedback control gain
C_I	initial value of T_{as}
R_w	wheel radius of free-rolling tire (m)
B_v	road surface/tire adhesion coefficient

μ_p	peak μ value for μ-λ curve in the acceleration region
μ_v	peak μ value for μ-λ curve in the braking region
B_r	tire rolling resistance friction coefficient
J_w	moment of inertia of rotating parts referred at the wheel ($kg.m^2$)
ω_w	wheel angular speed (rad/s)
ω_v	angular speed of free-spinning wheel (rad/s)
V	vehicle linear speed (m/s)
M_v	vehicle mass (kg)
B_v	aerodynamic drag coefficient ($=0.5\rho.C_D A_f$) ($N/m^2/s^2$)
N_v	normal force at tire-surface contact (N)
λ	wheel slip
λ_p	wheel slip corresponding to μ_p on the μ-λ curve
λ_n	wheel slip corresponding to μ_v on the μ-λ curve
T_e	engine torque at the wheel (N.m)
T_b	brake torque at the wheel (N.m)
F_t	tire tractive (friction) force (N)
F_w	wheel friction function (N.m) ($=R_w B_r N_v$)
F_v	vehicle friction function (N) ($=B_v V^2 + B_r N_v$)
$S(t)$	time varying surface
$\tilde{x}$	tracking error
Φ	boundary layer thickness

ÖZET

Otomotiv sektöründeki elektronik alanda son 30 yıl içinde çok hızlı bir gelişme olmuştur. Günümüze kadar otomobiller özellikle performans, emniyet ve araç ile çevre arasındaki etkileşimler açısından oldukça az gelişme göstermiştir. Yollardaki araç sayısının artması ile birlikte, trafik yoğunluğunda ve çevresel kirlilikte büyük bir artış gözlemlenmektedir. Bunun sonucu olarak verimsiz, emniyetsiz ve çevreye zarar veren taşıma sistemleri ortaya çıkmıştır. Verimli taşıma sistemi, kullanıcının ihtiyaçlarını karşılayan sistem olarak kabul edilmektedir. Araç kullanıcısı, kazaları minimum hasarlar ile atlatabileceği emniyetli taşıma sistemlerinin beklentisi içindedir.

Mevcut teknolojik ilerleme ortaya çıkan problemleri çözerek, akıllı araçların gelişimini sağlamıştır. Araçların ilerlemesini sağlayan bu devrim enformasyon teknolojisindeki gelişmeleri, telekominikasyonu, araç ve trafik sistemlerindeki elektronik aksamı kapsamaktadır. Bu da performansın ve yol güvenliğinin artmasını ve çevresel zararların azalmasını sağlamıştır.

Birinci bölüm akıllı araç sistemleri ile bu sistemlerin kontrolünün otomasyonu için gerekli olan teknolojilere ışık tutmaktadır. Bu bölümde akıllı araçlar için ihtiyaç duyulan altyapı sistemlerine yönelik olarak teknolojiler tanıtılmış, bu teknolojilerin temel içerikleri ve kullanılan kontrol metodları sunulmuştur.

İkinci bölümde günümüzde kullanılan ve henüz araştırma aşamasında bulunan otomotiv teknolojilerinin bir derlemesi yapılmıştır. Her sistemin tanımlaması yapılmış, sistemlerin çalışma şekline ve kullanıcıya sağlayacağı kazançlara değinilmiştir. Sistemlerin çalışma şeklinde araçtan araca değişiklikler olabileceği gözönüne alınarak çalışma sistemleri genel olarak ele alınmıştır.

Üçüncü bölümde ilk olarak araç çekiş kontrol teknolojisindeki gelişmelerden bahsedilmiştir. Daha sonra aracın ivmelenmesi sırasında tekerlek-yol temasında yetersiz sürtünmeden kaynaklanan kaymayı asgari seviyelere indirgemeyi sağlayan ASR teknolojisi ile ilgili bilgi verilmiştir. İlk olarak ASR sisteminde kullanılan elektronik aksam incelenmiştir.Bunun arkasından, ASR sisteminde uygulanan çeşitli

kontrol yöntemlerine değinilmiştir. Son olarak günümüz otomotiv sektöründe kullanılan ASR teknolojileri ile ilgili örnekler sunulmuştur.

Dördüncü bölümde, kayma olmaksızın ivmelenme için basitleştirilmiş çeyrek araç modeli tanımlaması yapılmıştır. Oluşturulan bu model sadece bir tekerlek için dönme dinamiğini, doğrusal araç dinamiğini ve ikisi arasındaki etkileşimleri kapsamaktadır. Aktivatörler, süspansiyon vb. konulara değinilmemiştir. Bu model temel alınarak, uygulanması planlanan değişken durumlu kontrol yöntemi için limit koşulları oluşturulmuş ve gerekli denklemler elde edilmiştir.

İvmelenme sırasında lastik tarafından sağlanan çekiş kuvveti; tekerlek kaymasına, yol yüzeyine, araç hızına ve tekerleğe gelen normal kuvvet gibi parametrelere bağlıdır. Normal yük ve çekiş kuvveti arasındaki oran olan μ; çekiş kayma katsayısı, lastik kayması, yol yüzeyi ve araç hızının bir fonksiyonu olarak ele alınmıştır.

Elde edilen limit koşullarından ve denklemlerden faydalanılarak MATLAB'de bir simülasyon programı hazırlanmıştır. Bu program vasıtasıyla, çekiş kuvveti üzerinde rol oynayan değişkenler ve parametrelerin etkileri incelenmiştir.

ABSTRACT

Automotive electronics has grown rapidly during the past 30 years. Up to now, the road vehicle for personal and mass mobility was still considered as under-developed, especially in terms of performance, safety and the interaction between the vehicle and environment.

As a result of the increase in the number of the vehicles, the road infrastructure has become overcrowded, resulting in inefficient and environmentaly damaging transport systems. An efficient transportation system is regarded by the user as a necessity. Also the user expects a transportation system to be safe, secure and with minimal environmental impact.

The recent technological developments to solve these problems provide for the continuing development of advanced vehicle systems. This revolution includes the development in information technology, telecomunication and electronics in road vehicles and traffic systems. This provided the performance, increase road safety and reduce environmental pollution.

The recent technological advancement to solving these problems provide for continuing development of advanced vehicle and infrastructure systems.

First chapter will highlight the essential technologies and automation for intelligent vehicle system and control.

Second chapter is a collection of descriptions of recently introduced and potential automotive technologies. Each section includes a description of the technology, how it works and the customer benefit. The "how it works" section is general and implementation may vary on a specific vehicle.

Third shapter deals, first, with the current history of the development of traction control technology. Afterwards, the ASR technology, which minimizes the spinning of the wheel as a result of insufficient friction between tire-road surface while acceleration was discussed. Some information is given about the control systems. And some applications of ASR technology was introduced.

In chapter four a simplified longitudinal one-wheel vehicle model is described for anti-spin acceleration. This model contains one-wheel rotational dynamics, linear vehicle dynamics and the interactions between these two. Dynamics, such as actuators, suspension, etc., are not considered. Based on this vehicle model, limiting conditions for applying sliding-mode control to vehicle traction are obtained.

The tractive force developped by a tire during acceleration, depends on wheel slip, road surface, vehicle speed tire normal load, etc. The tractive adhesion coefficient, μ, which is the ratio between tractive force and normal load, can be plotted as a function of wheel slip for a given tire, road surface and vehicle speed.

Using these sufficient conditions and equations a simulation program is prepared in MATLAB. With the help of this program, the effects of parameters and variables on traction control are studied.

1. INTRODUCTION

1.1 VEHICLE ELECTRONICS AND CONTROL

Electronics and control technology is dramatically speeding up the automation and evolution of the road vehicle as the personal and mass mobility system. The electronics and control technology used in vehicles are influenced by in-vehicle devices and subsystems, such as, sensors and actuators, electronic control unit (ECU), software, vehicle electrical systems and multiplexing subsystems. Figure 1.1 shows an example of the application of electronics in the road vehicle. The cost associated with the three essential electronics functional blocks used in automated control systems have remarkably reduced over the last 10 years. For example, the price performance ratio of the electronic actuators used commonly in automated vehicle systems has improved by a factor of approximately 10:1. This has made it possible for the faster introduction of motorized seats, mirror adjustment and automatic doors as seen in most Japanese taxies. The development of the micro controllers, signal transmitters and programmable miniature computers have been used for wide range of vehicle electronic applications. For example, the keyless access system incorporates a receiver which checks an incoming signal against a unique code in a memory, and then release the locking system if the code is correct.

Other possible applications are based on the reverse procedure, whereby a coded signal from a vehicle is transmitted to a roadside toll booth or more commonly to a security gate. On a worldwide scale, the increasing developments in the enabling technologies and the decreasing cost of the electronic devices are providing engineers with opportunities to design advanced and intelligent transportation systems. Meanwhile, the user of the road vehicle is presently experiencing some of the outcomes of the new information technological inclusion in today's vehicles. This ranges from the modest improvement in vehicle performance, improved driver and occupant safety, emission control, convenience, comfort and vehicle traffic management systems not thought possible even 12 years ago. So the primary reasons for the development of electronics and control systems for automation of the road vehicle is to provide these improvements. One can therefore

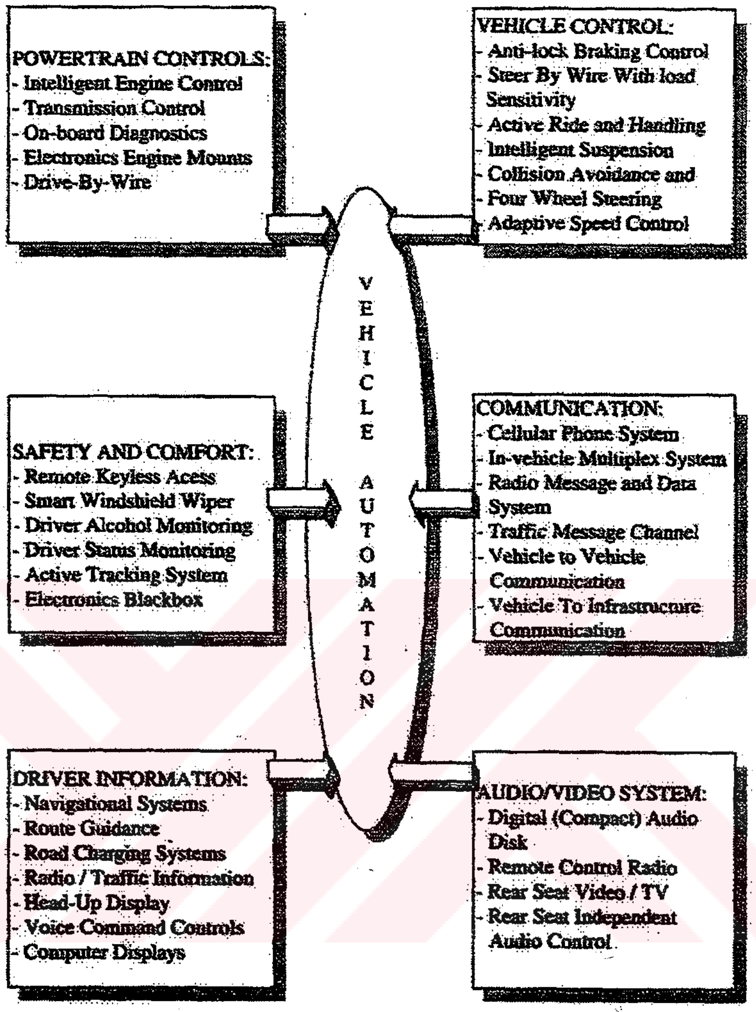


Figure 1.1 Electronics inclusions in road vehicle

forecast that, by the year 2005, the electronic content in an advanced vehicle will account for more than 20% of the cost of the vehicle, with the cost of electronic management control alone at about £3.2 billion in Europe at that time. These electronic systems will be integrated, with shared data obtained via communication links (data highway network) rather than the current "add on" and "stand alone" compromises.

1.2 Vehicle Sensors

In the automation of vehicles, we are concerned with the necessary control of the dynamic system, such as the control and management of the ignition systems or the adaptive control of the advanced suspension system. The control of the behaviour of the dynamic system can be simplified to three functional blocks required in the directional control of a vehicle (Figure 1.2). The sensor is part of the vehicle electronics with the functional responsibility of detecting, acquiring and transmitting information from the given stimulus, in the case of vehicle steering, the condition of the road. This information is passed to the computer (processor), which determines the appropriate action to be taken, and finally the actuator is instructed to bring about the changes required to maintain the necessary vehicle dynamics control for the actual position on the road.

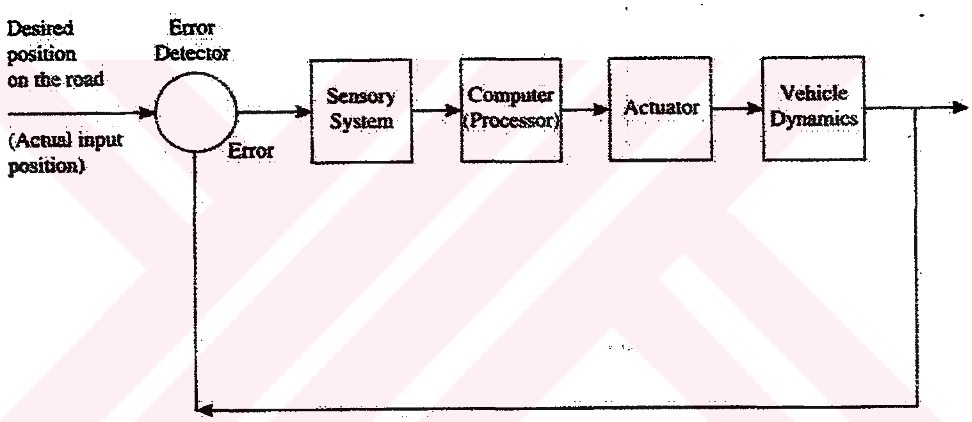


Figure 1.2. Three functional blocks of the control of vehicle steering

Vehicle sensors are essential components of advanced vehicle and infrastructure systems. A variety of sensors exist for automation of an advanced vehicle. Most of the present advanced vehicles contain more than 30 sensors on average. For an in vehicle system, the majority of the sensors are used for the monitoring, managing and control of the power train, vehicle ride and handling, driver behaviour, safety systems, distance sensing, navigational systems and driver/occupant comfort. Normally, each sensor is connected to its own local signal condition circuit and has its own wiring. The size and cost of the wiring used in the vehicles is rapidly becoming larger. This problem will indeed be increasing in the future, especially as it has been predicted that the number of in-vehicle sensors will exceed 100 by the end of century. This problem will be alleviated by the use of intelligent sensors. Vehicle to infra structural systems interaction requires sensors such as roadside sensors which are able to detect changing aspects of the road traffic environment. This will include the volume of vehicle traffic on the road, the prevailing weather conditions, exhaust pollution emission levels, integrated road payment system and law enforcement systems.

The future lies in the use of intelligent or smart sensors for advanced vehicles. In vehicle electronics and automation, there has always been a discussion about the suitability or otherwise of using the term "intelligent" or "smart" for sensors. None the less, the technical meaning of this now well established term has become quite celar during the course of time, and therefore may be defined within various texts. This is developing sensor technology which is based on the concept of integrated sensory systems; instead of being a éstand-alone sensor" providing a voltage output to an electronic unit, the sensor itself becomes an integral part of the instrumentation system, with different systems requiring access to one and the same sensor signal. In the event of sensor failure of malfunction, a diagnostic, self-correcting or fault tolerance function is invoked. Intelligent sensors may be identified by means of the features shown in Figure 1.3 and typical operational factors shown in Figure 1.4.

The basic intelligent sensor can be described by using a conceptual silicon micromachined pressure sensor model shown in Figure 1.5. The first stage of the model is the initial functional element, which may be a silicon diaphragm. This modifies the raw input, i.e. the applied pressure, to a more acceptable state, which is the mechanical deflection. The second stage of the model is the primary transduction element which is the piezoresistive bridge.

This provides the change in the energy state from mechanical deflection to an electronic analogue signal. The next stage of the model is the signal conditioning element which may be provided to generate a suitable signal (e.g. an amplified temperature compensated voltage signal). The subsequent stage is the analogue to digital (AD) conversion element, with the AD converter which must, however, fully satisfy the corresponding measurement signal requirements regarding the converter speed, resolution and accuracy. The next stage in the model is the correction unit, which can be a micro controller or a dedicated processor for the specific digital signal correction algorithm. The digital correction unit is interfaced with the programmable memory unit for model parameter variation. The final stage in the model is the sensor interface designed to accept the corrected digital signal for active or passive function within the intelligent vehicle.

STANDARDIZED INTERFACE:
- Bidirectional
- Adaptable
- Communication with Digital/Analogue Systems (Bus Capability)

CHARACTERISTICS:
- Inherent Monitoring
- Multivariable Data Acquisition
- Self-recalibration Ability
- Additional Output of Influencing Variables
- Performance Diagnostics and Prognostics

LIMITATION OF THE TOLERANCE USING ELECTRONICS:
- Acquisition and Consideration of Disruptive and influencing Variables on the Spot (Static Correction)
- Improvement of the Dynamic Behaviour (Dynamic Correlation)
- Consideration of Specimen-specific Characteristics (Self-calibration)

Figure 1.3. Features of intelligent sensors

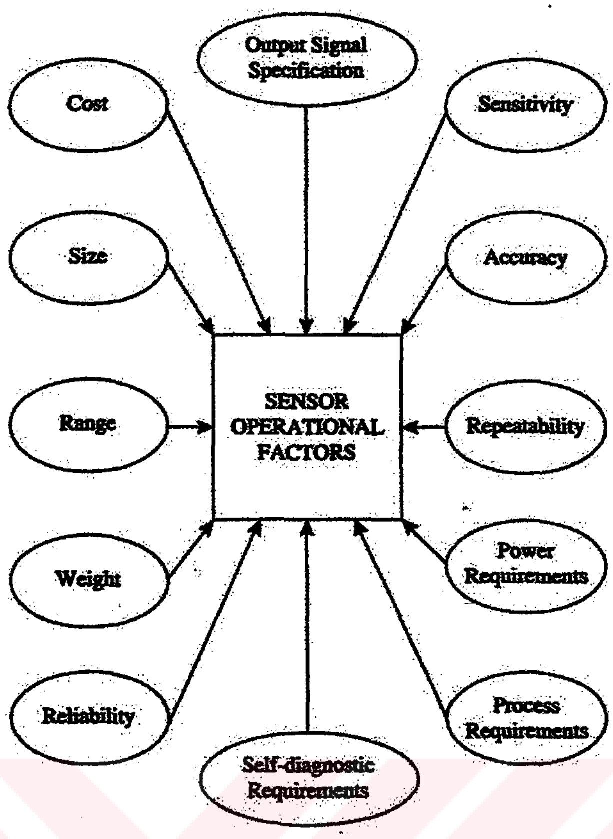


Figure 1.4 Typical intelligent sensor operational factors

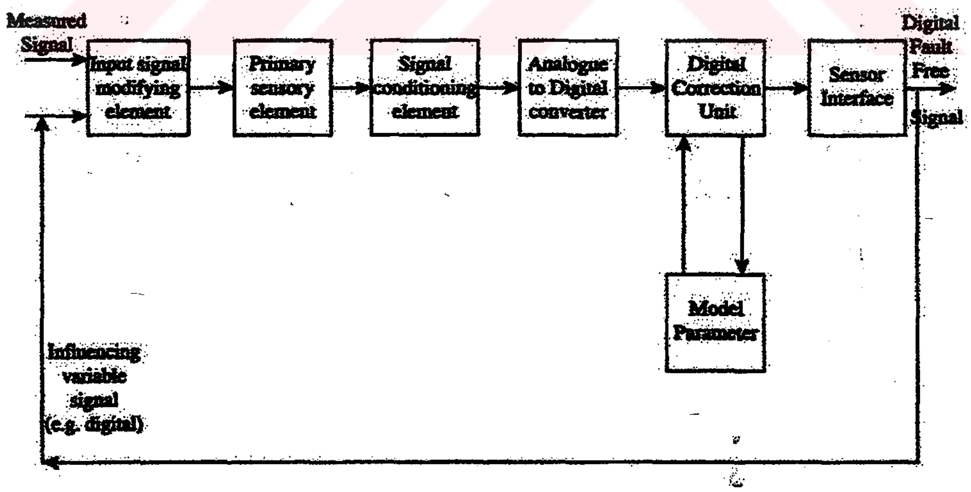


Figure 1.5 Functional intelligent sensor configurations

The model in Figure 1.5 is one version of an intelligent sensor. There are other types of intelligent sensors for specialist application and of simpler configuration.

1.3 Sensors And Components Interconnections

As the number of sensors and electronic devices in the vehicle grows, so does the need for a standard network to ensure that the various devices, sensors and modules will not only communicate with each other, but also will be capable of sharing power resources, software and central computation power. A great deal of systems development is currently been done in this area involving the use of multiplex wiring system.

A multiplex wiring system architecture will be adopted in some vehicles with modular intelligent sensors and devices. The preferred objective is to get the individual, independent, separately develciped vehicle electronic modules and sensors to be interconnected in a network protocol. The International Standard Organization (ISO) approved several network protocols which can be used for vehicle networking and automation. Of the three ISO accepted protocols (SAE-J1850, VAN, CAN), Controller Area Network (CAN) is the popular choice within the European automotive industry, it is also gaining acceptance with the American automotive industry. Figure 1.6 illustrates how the independent components can be linked to one another and to a master controller by a signal carrying a CAN linear bus network with different transmission speeds. This type of bus system is known to have a high data transmission rate (1 Mbit/s) and it is flexible with special facilities ensuring an interference suppressed operation.

CAN was developed by Bosch for automotive applications to reduce the complex wiring systems in road vehicles with multiple micro controller-based control systems (e.g. engine management, suspension control, ABS, etc.). CAN is a multi-master bus topology that has a layered structure specific to Systems designers, as shown in Figure 1.7. For data transmission, it uses carrier sense multiple access with collision detect (CSMA/CD), with non-destructive bit-wise arbitration for bus contention. To provide a faster transmission of real-time information, CAN utilizes broadcast-type functional addressing with a non-return to zero (NRZ) data format with bit stuffing at data rates in the range of 15 Kbit/s and 1 Mbit/s.

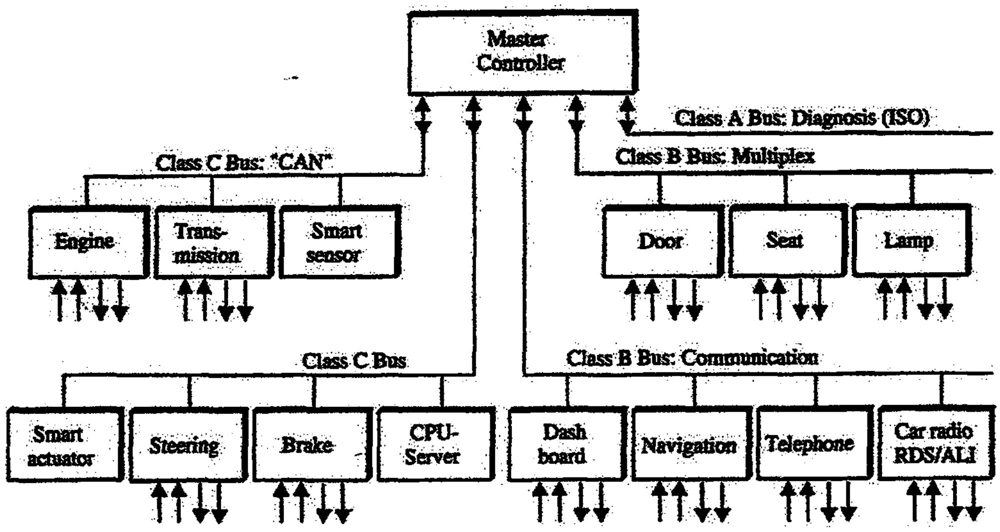


Figure 1.6 Decentralized sensors and electronics systems interconnection

There are presently various microchip manufacturers that have entered into the CAN controller market, such as, Philips, Motorola, Siemens, NEC, Intel and National Semiconductor. It is expected that with time, more automotive manufacturers that are presently reluctant to take up standard network structure will adopt the CAN system.

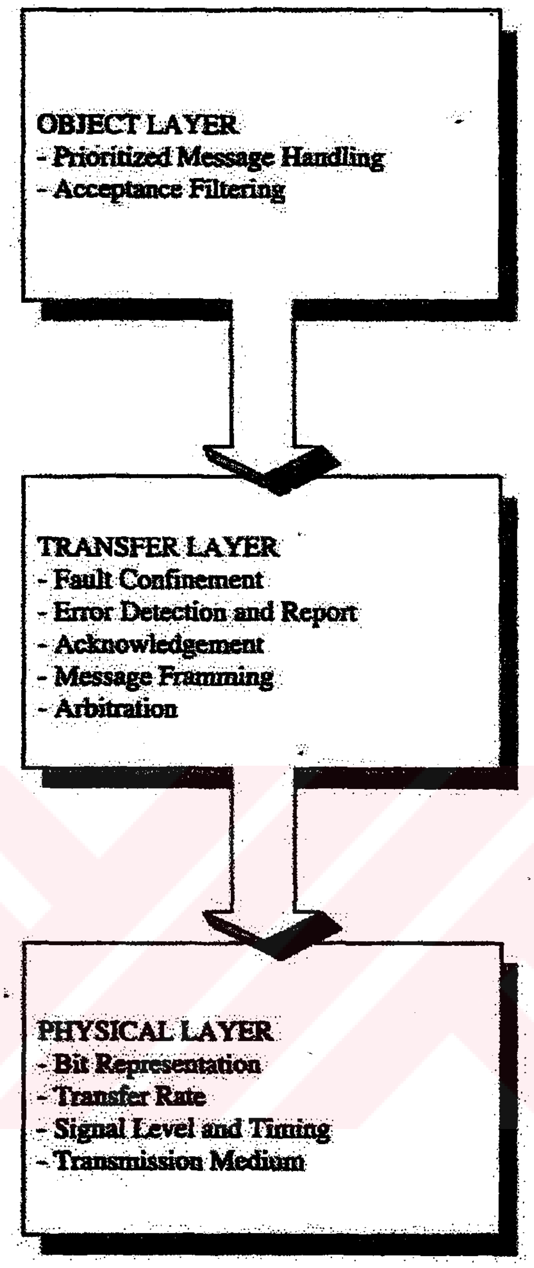


Figure 1.7 CAN layered architecture

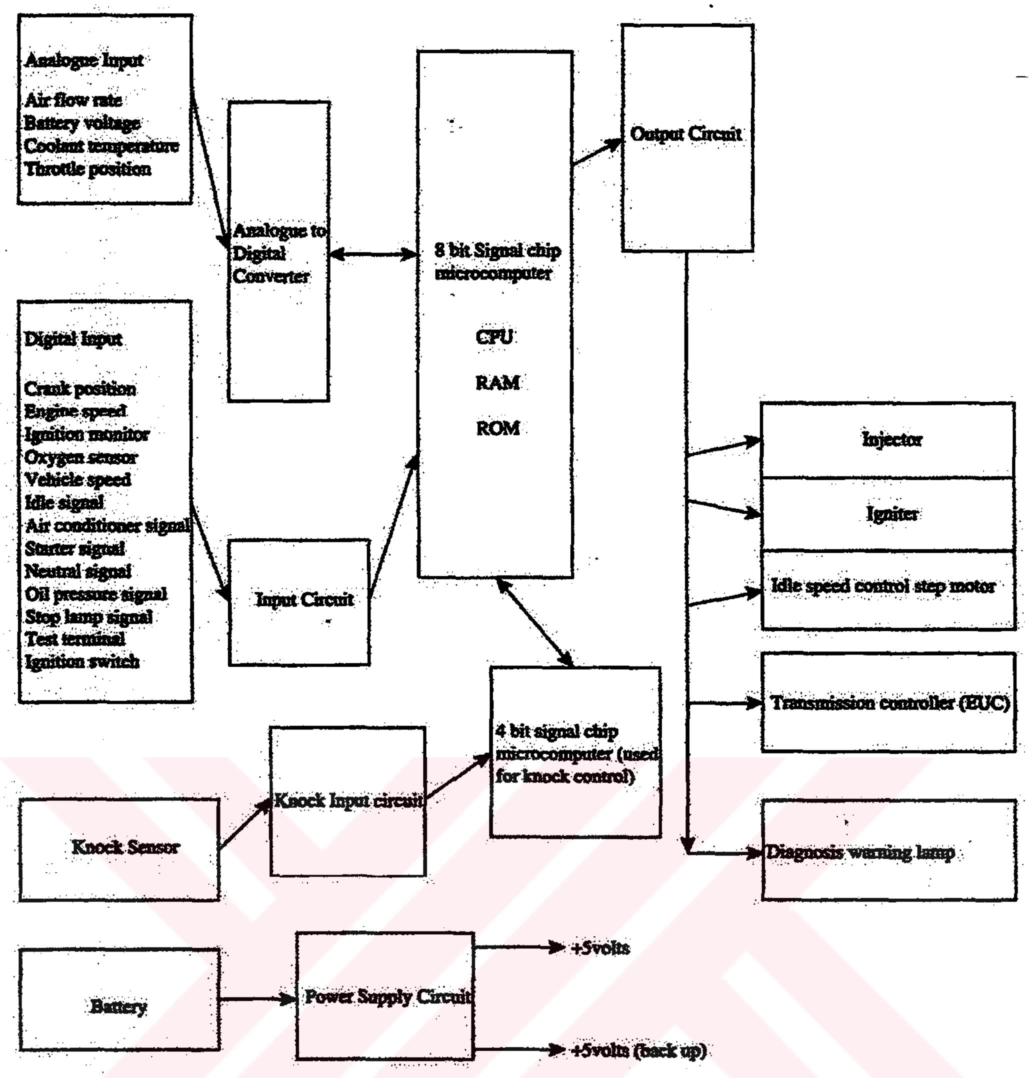


Figure 1.8. Basic systems of the electronic control unit

1.4 Electronic Control Unit

The ECU is the centre for the in-vehicle electronics systems management, and it interfaces with the most essential devices used for the monitoring and control of many vehice functions. As shown in Figure 1.8 the ECU can receive a varying range of analogue or digital signals from sensors. The microprocessor uses these values to calculate the required control values based on preprogrammed settings. As a result of the calculation, signals are sent to drive actuators, motors, solenoids and other devices to adjust the required activities within the vehicle.

The ability of an ECU to perform a range of control function within the vehicle depends on the size of the ECU which is dependent on the number of signal inputs and outputs it has. The early ECUs only had five to eight inputs and outputs, some of the recent designs can have up to 70 inputs and outputs. Some examples of this type of systems are shown in Figure 1.9 typifying sensor usage in advanced vehicles. However, as the systems and devices required to automate advanced vehicles grows the number of inputs and outputs in an ECU will also grow, but above all, the complexity of the unit will also grow.

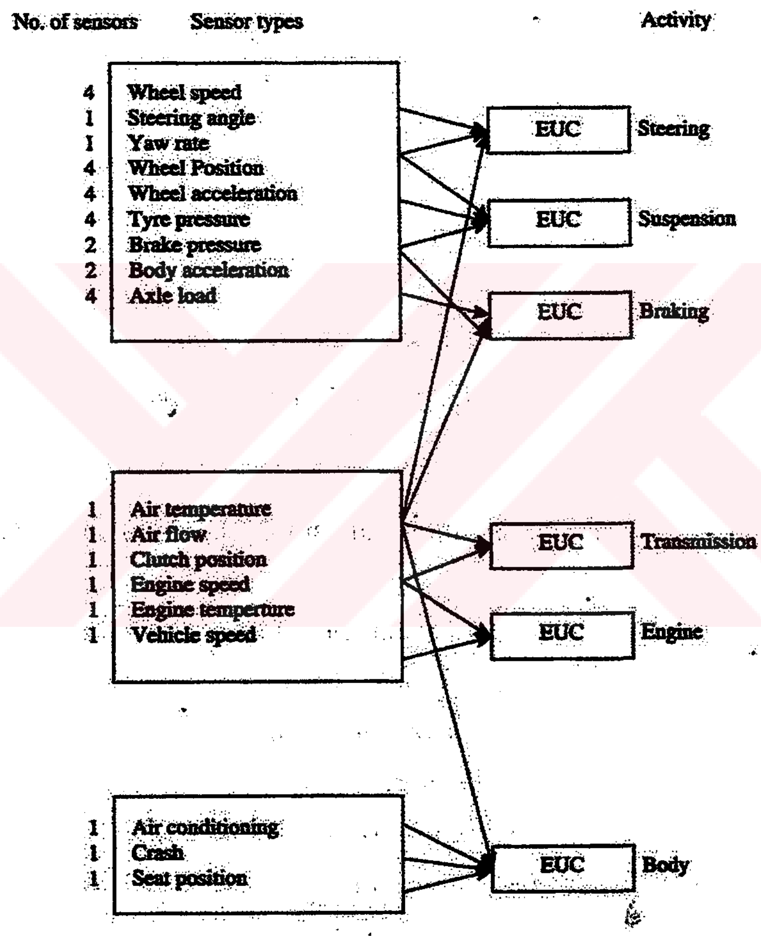


Figure 1.9. Example of sensor interconnection in an ECUs

1.4 Vehicle Following

In designing collision avoidance system for an intelligent vehicle control system, one of the vehicle's performance requirements will involve the understanding of the vehicle's interaction with other vehicles on the road. This will require the understanding of various vehicle following concepts and models. For example, under normal traffic conditions, vehicle following by a driver who has to drive the vehicle as part of a string of vehicles on a highway can indeed be a complicated control process. The driver may take account of the fact that the vehicle in front will require some time and distance to stop or accelerate. Therefore if the driver can brake or accelerate as quickly as the driver in the front or rear, collision can be avoided provided that the distance separating the vehicles is sufficient to compensate for the reaction time required by the second driver to apply the brake or accelerate after the first driver has done so. This example does not take into account the fact that obstacles can suddenly appear on the roadway and that different drivers can react differently to a given set of traffic circumstances. It also assumes that the vehicles travel in a single lane, and no overtaking occurs. If we take this somewhat simplified example it becomes possible to provide a one-dimensional quantitative model that can describe the driver's behaviour in a manner which may have significance in the understanding of a collision avoidance system.

As shown in Figure 1.10, the driver as part of the vehicle following scheme can be treated as a control system, where the input will be the position, speed and acceleration of the car which he/she is following and the output will be the behaviour of their own vehicle. This is in line with various vehicle following models, where the behaviour of a vehicle, to some extent, is dependent on the behaviour of the vehicle in front and the modelling task is to find the relationship between each pair of vehicles.

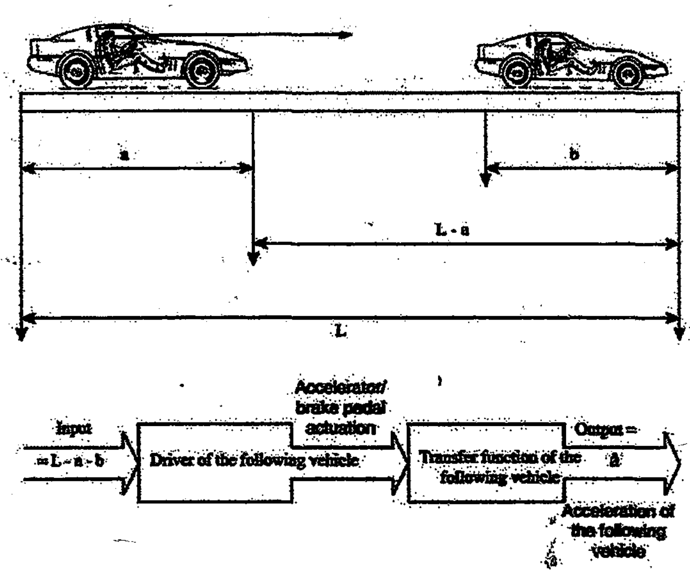


Figure 1.10 Vehicle following control

1.5 Collision Avoidance Systems

It has already established the basic concept of vehicle collision using the basic vehicle following model. The model so reviewed is based on vehicle to vehicle interaction, but collision can arise from other situations such as visual blind spots, other road users emerging from junctions, driver falling asleep, driver not paying attention or distracted, incidental objects on the road, etc. These situations cannot be easily predicted and are very difficult to model, but one way of taking account of these variables is to use the collision avoidance system.

The collision avoidance system is an active driver support and vehicle safety system aimed at preventing or mitigating accidents by enabling obstacles and developing critical situations to be detected in a sufficiently safe time for the driver or the system to take appropriate avoidance action. The fundamental methodology of obstacle avoidance is based on perceiving the vehicle outside environment and traffic situations using appropriate sensory systems and subsequently providing the most important driver assistance under the hazardous conditions.

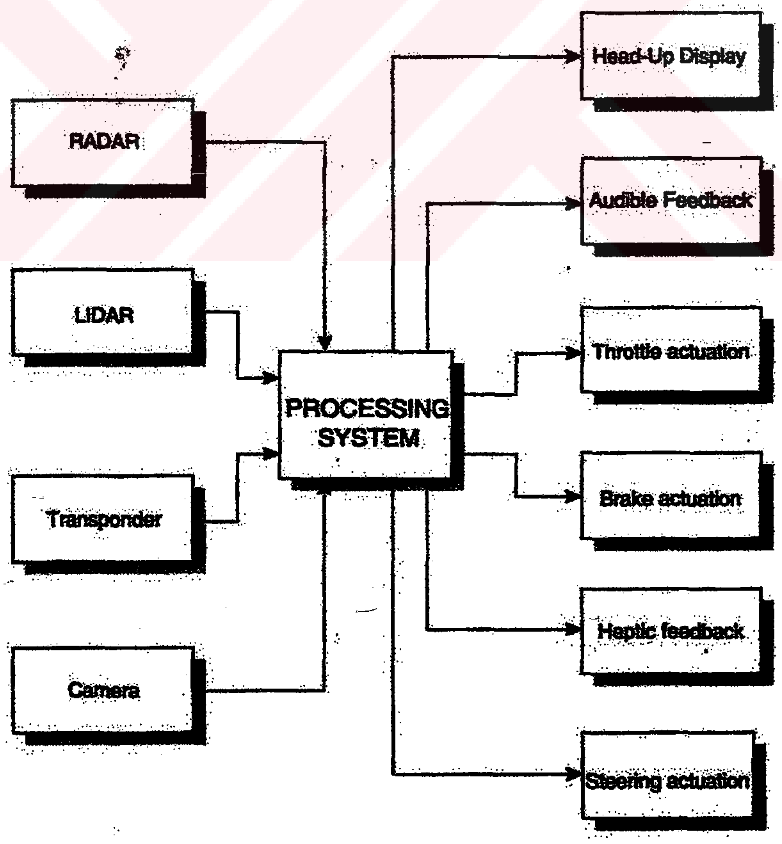


Figure 1.11. Potential subsystems representation of an obstacle avoidance system

The driver assistance can be through driver information system or through active and just-in-time intervention-based vehicle control. As shown in Figure 1.11 there are three essential subsystems of a collision avoidance system: the multisensory subsystem acquires the environmental information on the world around the vehicle; the processing subsystem interprets and evaluates the environmental or traffic situation, and subsequently assesses and prioritizes the threat potential of the obstacle; the output subsystem provides prioritized data to the driver through the driver interface system and also issues fast and just-in-time intervention data to the actuators for vehicle longitudinal or lateral control in a situation where there is no chance for the driver to react in time.

There are several sensor technologies available for use in an obstacle avoidance system, some of these are shown in Figure 1.11 but the most common of the sensors used are the RADAR (microwave device), laser type (LIDAR) and camera (imaging systems), with the RADAR presently most commonly used for intelligent vehicle application, especially when considering environmental conditions. The RADAR antenna mounted on a vehicle can provide obstacle detection in excess of 100 m from the vehicle. The frequencies greater than 100 GHz can be used with acceptable antenna size, in Europe and the USA the specific range of 76, 77, 94 and 144 GHz band are used. A typical system uses 38.5 GHz VCO (voltage-controlled oscillator) with frequency doubling to obtain about 40 mW of power at 77 GHz. A frequency modulated continuous wave or pulse-modulated system can be used. The system uses Gaks devices to meet the frequency and power requirements.

To utilize the full potential of an obstacle avoidance system, an integrated system that is capable of having some basic intelligence which allows it to sense possible threat on the road and continuously transmits a signal which is acquired by the central processor (onboard computer system). In the event of any obstacle, the processor then calculates the distance of the threat from the time taken for the RADAR signal to return from the obstacle. The obstacle size may also be deduced from the change in the signal frequency. When the signal is fully processed, the resultant data warns the driver and the support vehicle manoeuvres through the actuation of the brake, throttle, steering, haptic feedback or any of the relevant vehicle dynamics and control systems.

1.6 Cruise Control System

To alleviate driver stress, avoid accidents and uneconomical driving, a road vehicle speed control system can be arranged as a simple throttle latching device to a sophisticated computer control system that constantly maintains a set vehicle speed under varying driving conditions. The main function of a basic cruise control system shown in Figure 1.12 is to control and maintain a certain level of engine speed such that the vehicle travel can be maintained at a certain speed without the driver needing to depress the accelerator pedal once the speed is set.

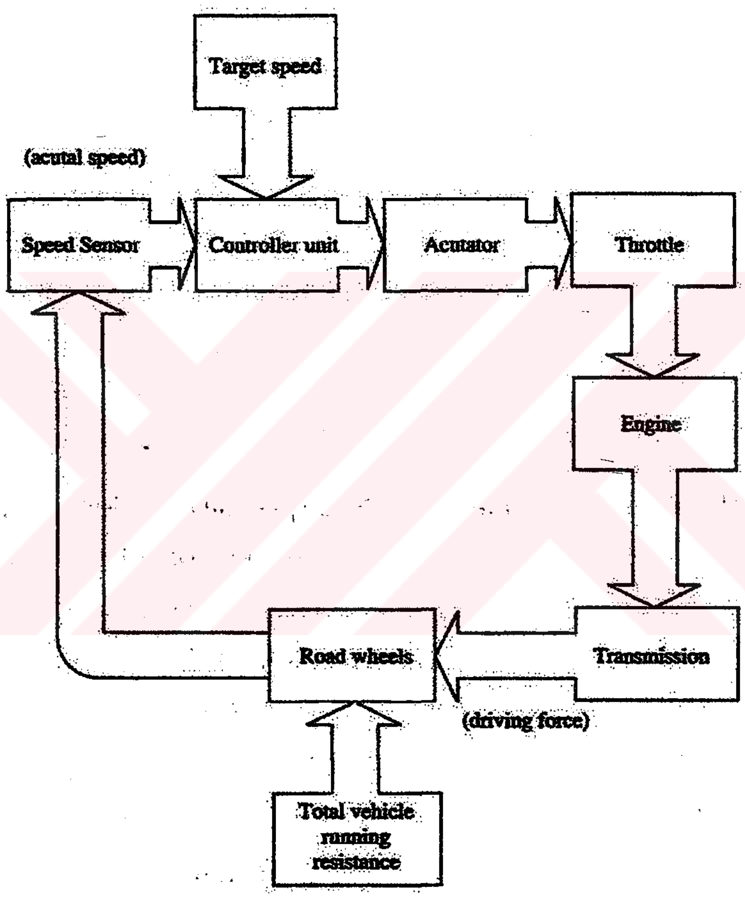


Figure 1.12 Block diagram for a simple cruise control system

The cruise control system is a closed-loop control system (Figure 1.12) and it consists of an actuator that opens and closes the engine throttle valve in lieu of the driver's depression of the accelerator pedal. The actuator is linked to the controller that controls the actuator motion. The input signals to the controller are the driver's speed set-point, the vehicle's actual speed and the signal transmitted to the controller to enable the relinquishment of the cruise control. The output signals are the ones that activate the throttle servo control actuator, the cruise ON indicator, data for diagnostics plus information to the engine and transmission system.

When the cruise control is switched on, the control unit, initiates control by means of the set signal, memorizes the speed at the set signal input time as the set speed, and controls actuator so that the actual speed will coincide with the set speed. In addition to this basic functional requirement, cruise control system has other functions, such as:

1. Acceleration and coasting function which allows the setting of the travel speed to be changed during cruising.

2. Resuming function where the cruise travel is released when the brake is applied due to difficulty in maintaining the necessary distance from the car ahead or when the clutch is used to change gears.

3. Overdrive release function allows the cruise control to operate with a vehicle equipped with automatic transmission, such that fuel consumption and improvement in transmission quietness can be obtained, especially during repeated kickdown and overdrive return.

1.7 Intelligent Cruise Control System

An intelligent cruise control system, which may be regarded as autonomous or adaptive intelligent cruise control, performs the standard function of a cruise control and additionally acts as a driver assistance system for intelligent control of the relative speed and distance between two adjacent vehicles in the same lane. By adapting vehicle speed automatically to the demands of traffic flow, driving at a safe distance, increasing road capacity as a result of speed harmonization, enabling smoother driving, reducing fuel consumption and subsequently exhaust emission, adaptive cruise control will become part of intelligent vehicle systems.

The use of appropriate sensors capable of measuring up to a few hundred metres away from the vehicle with a tight focal point in all weather conditions is fundamental to the use and development of an intelligent cruise control system. Intelligent cruise control operates in a similar fashion as the collision avoidance system, but with the ability to track the vehicle in front. Several types of sensors have been used by different European automotive manufacturers. Similar to a standard cruise control systems, actuators for longitudinal and lateral control of the vehicle is an important unit of the intelligent system. Software for applying cruise control strategies and driver information is used. The cruise control software uses any of the control laws described in the early part of this chapter. A communication system which allows roadside to vehicle interaction for traffic regulation may be used.

The performance of the systems is supported by a configuration of several subsystems shown as block diagram in Figure 1.13 The six blocks of the subsystem's units are functionally affected by the output information from the data processor with exchange of information through a communication network.

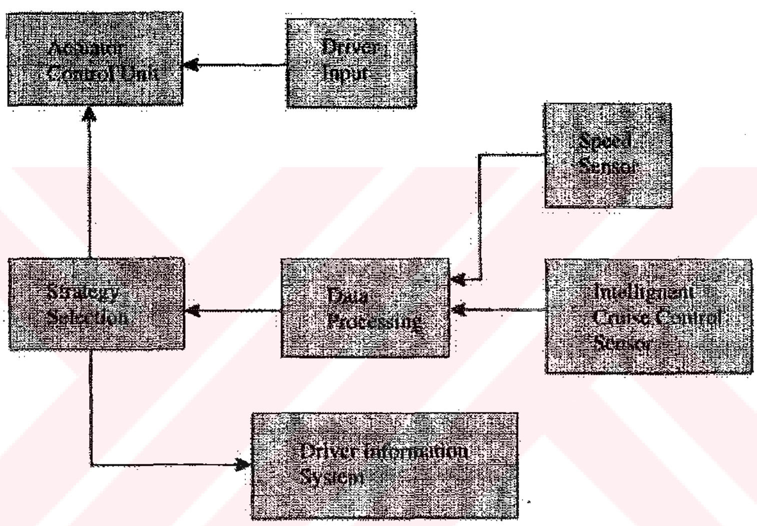


Fig 1.13. Configuration of an intelligent cruise control system

Pulse encoders are installed at the wheels, this function as the wheel speed sensors. They detect the number of wheel revolutions and the information is fed into the data processor (main computer) and used to compute wheel speed. The intelligent cruise control sensor detects the presence and the positional coordinates of the vehicle in front, the information is fed to the data processor, and this is combined with the speed sensor signal. Based on this information, the strategy selection subsystem decides whether the cruise control should be effected through the actuator control unit or the driver informed of the safety distance to the preceding vehicle, whereby the system switches to distance control and the alarm is activated in case of a large speed difference with the preceding vehicle. The intelligent cruise control system can be activated or deactivated by the driver when the environment and the driving conditions are adequate. The system can also be overridden at any moment by the action on the accelerator or brake pedal.

With the data processor receiving input from the appropriate sensors, the intelligence of the system is developed mainly through the control software. For example, the response time and gain of the cruise control system can be adaptively adjusted to match individual drivers. In this case, some class of drivers may prefer to allow the vehicle to slow down slightly when climbing a gradient and then respond quickly to maintain a set speed. Some other drivers may prefer a constant speed at all times, while other drivers may prefer very slow responding cruise conditions to minimize fuel usage and pollution. At a human-machine interface level, the cruise system can be adapted by either driver selection switch or by prior analysis of the classes of driver's acceleration/deceleration habits during non-cruise conditions. At later stages of the development of the intelligent cruise control system, the adaptive software can be improved by using a self-learning neural network technique for classifying the different types of drivers that will use the system.

1.8 Navigation And Route Guidance Systems

One of the fundamental requirements of an intelligent road vehicle is to assist the driver in finding their anticipated destination in the most economical, reliable and safe way. There are several questions usually resident in a driver's mind, for example, "Where am I ?", "What route do I take to reach my destination?", "How can I best react on different traffic situations?" and "Where can I get particular services?". As part of road vehicle automation, these questions can be answered by using an in vehicle system capable of providing relevant driver assistance that includes accurately identifying the actual location of the desired destination, determining the optimum and high-quality route and assisting the driver to follow the route in order to avoid traffic congestion. Generally, vehicle navigation and route guidance systems provide the necessary assistance required to answer all of these questions.

1.8.1 Vehicle Navigation Systems

Navigation is the process of directing the movements of a user from one point to another. Successful navigation is dependent on establishing where the user is, where the user wants to be and how to get there. Therefore, a vehicle navigation system allow the driver to specify his/her current location and desired destination and it provides some variety of computer-based support to assist the driver in getting to that destination. The type and level of support given to the driver depends on the type of system used. From the early years of vehicle navigation technology (e.g. the south-pointing chariot - China, c.a. 1000 Bc) to when mechanical vehicle navigation systems were introduced in the USA at about 1910, the system has always incorporated the information of the route maps in various forms, which include sequential instructions printed on turntable, punched on a rotating disk, and printed on a moving tape, all driven by odometer shaft in synchronization with the distance travelled along the route. Some elements of this fundamental technology have formed the basis on which the first and second generation of vehicle navigation system is developed.

Several systems with a variety of functions can be grouped as "navigation system". These can be broken down into the following general categories:

1.The system that only display map of road network. This only serve as a substitute for paper map and it is a passive system.

2.Those systems which only display current position of the vehicle or local area in which the vehicle navigates, these include:

(i) systems which display names of the place and coordinate number;

(ii) systems which display the names and patterns of intersection along the route;

(iii) systems which display the vehicle's current position on a map with the direction and route travelled.

3.Those systems which give the guidance to the driver's destination:

(i) these are the systems which display the vehicle's direction and the distance from the commencement of the journey to the end destination;

(ii) systems which display a map showing the optimum route from the start point to the destination with added information on the current location of the vehicle;

(iii) systems which display intersections and indicate right or left turns along the optimum route selected manually or automatically.

4. Those systems which use road infrastructures as an added information source and subsequently provide comprehensive information for navigation.

(i) systems which display maps indicating traffic congestion and provide traffic control information advisories;

(ii) systems with computerized means of receiving and processing traffic congestion and general conditions information, and use that information to optimize the vehicle route.

There are in general various types of navigation systems which fall into the categories described, for example:

1. Pre-trip information Systems. These are quasi- and static-based navigational aids (e.g. Auto-route PC-based route planner.

2. Traffic information systems. These are systems which give event-based information on the traffic conditions in the road network. Development using the radio data system which is a digital sideband information channel (RDS), and Traffic Message Channel (TMC) for driver information is central to this type of navigational system. TrafficMaster is another type of a traffic information system in this class.

3. Autonomous navigation systems. In these systems, information is presented to the driver to help guide the driver to a predetermined destination either by showing an appropriate segment of a map or by providing a turn by turn icon and voice information to the driver

4. Dynamic route guidance systems. Navigational systems of this type provide route guidance for an optimum route after taking account of prevailing traffic conditions. This may be achieved by an in-vehicle communication with an infrastructure of beacons providing a centrally calculated route (e.g. Siemens EUROSCOUT) or by integrating traffic information from, e.g. RDS-TMC or the System of Cellular Radio for Traffic Efficiency and Safety (SOCRATES), into the route calculation of an autonomous navigation system.

The most important requirement of a vehicle navigation system is its ability to position the vehicle and the driver at the required location using the necessary technologies. Most of the navigation systems use dead reckoning, map matching and global positioning systems (GPS) as their main posin omng technologies. For the system to function within the vehicle, a means of sensing the yehicle speed and the orientation along its principal direction is required. This is usually achieved by using an electronic equivalent to the odometer, such as, speed encoders/optical sensors on the vehicle wheels to sense the speed and heading sensors such as geomagnetic sensors, gas-rate gyro sensors or fibre-optic gyroscope.

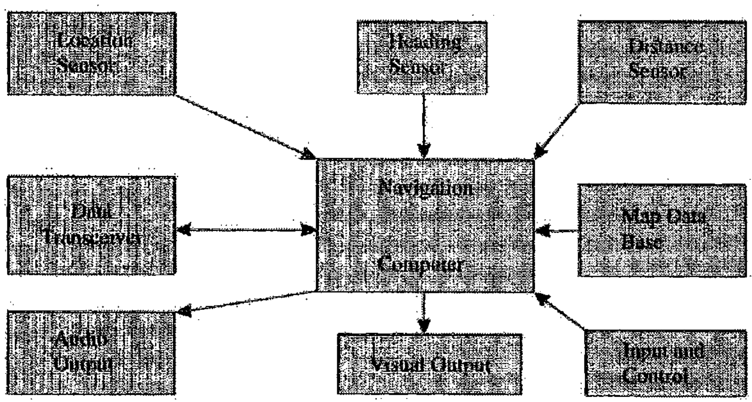


Figure 1.14 System's block diagram of a vehicle navigation system

1.8.2 Digital road map matching

For the navigation system to make sense of the vehicle's environment, it needs to be aware of the road map from which the driver's destination can be identified. The navigable road map can be a digitized map in a database centrally located in control centre as a traffic infrastructure system, but the most common is the digitized road map resident in-vehicle within the navigation system's computer. The database provides a complete and accurate detailed-level information about the roadway infrastructure in a manner that facilitates computer processing. Within urban areas, the map should include precise geometry, full characteristics, names, address ranges for all navigable roads at all levels, travel speed variation within road segments, directionality, traffic signals, etc. In normal cases some of the roads can be easily more identified by the landmarks within a recognizable vicinity (e.g. shopping centres, government/major office buildings, air/rail/bus terminals, etc.). These landmarks must therefore be included. The database should also contain towns and cities within the surrounding urban areas.

These road maps are digitized for computer processing using matrix encoding and vector encoding. A matrix-encoded map is a digitized image of the map in which each pixel on the computer screen with its X-Y coordinates represents profile shades and colour of the road. Matrix-encoded maps require large computer memory storage and are ill-suited for fast analytical treatment required for dynamic map matching and route guidance. The vector-encoded map uses mathematical modelling to represent the geometrical features of the road, boundaries and surroundings with minimum data abstraction. Most of the navigation systems use the vector encoding method where each road is represented as a series of straight lines and each intersection of the road as a node.

The digitized image is stored in the memory of the computer, such as CD Rom, but for the vehicle to navigate through the road network, map matching of the road network on which the vehicle is driven to the digitized road map stored in the memory is essential. Map matching is therefore a knowledge-based process which may be said to use artificial intelligence to recognize the present vehicle location by matching the patterns of vehicle path, as approximated by the dead reckoning and/or any external roadside beacons, with the digitized road map stored in the computer. There are various methods of software-based map matching, but they can be classified into two types on the basis of the matching concept used. The two types which have been named in the past are called "semideterministic" and "probabilistic".

The semideterministic approach is to search for the most likely road that the vehicle is travelling by comparing driving directions and angles at each intersection assuming that the vehicle is essentially confined to a predefined route or road network. In this approach all roads that the vehicle is likely tp travel are normally stored in a computer memory or computer disk. Taking into consideration the alternative route in the network, the chosen route is represented by vectors and a map matching routine is used to ascertain the optimum vehicle path.

A simplified map matching algorithm for the semideterministic technique is shown as a flow chart in Figure 1.15 At the starting point after initialization, when 90° and L = 0 the algorithm repeatedly asks, "Is the vehicle still on the route?" and "What is the present location along the route?" The vehicle is then confirmed as being on route if certain tests are satisfied. The location along the route is estimated by the wheel sensors, any error in the estimate is automatically deleted at each node where it is ascertained that an expected change in the vehicle heading actually occurs.

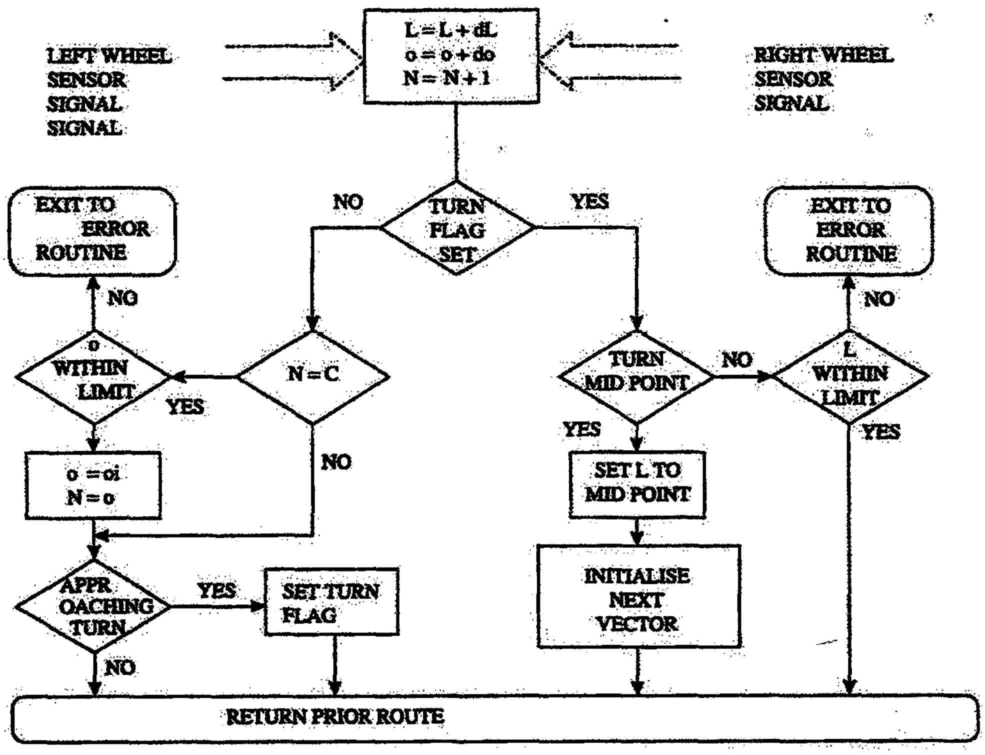


Figure 1.15 Example of a simple map matching algorithm

The wheel sensors normally installed at the left and right wheels to sense the vehicle speed transmit the signal interrupt which drives the algorithm. The distance L from the beginning of a route segment is updated by adding an increment AL for each left wheel sensor signal interrupt, also the vehicle heading Φ towards its principal coordinate axis, is updated by adding an increment $\Delta\Phi$ derived from the difference in travel of the left and right wheels since the count N was last set to zero.

The N counter controls the monitoring for the unexpected changes in the vehicle heading over a relatively short distance. The turn flag can be set to denote that the vehicle is approaching a distance L, where the vehicle heading change should occur, otherwise, count N is checked after each sensor signal interrupt to determine if it has reached a limit C corresponding to an arbitrary amount of travel on the order of say 75 m. When the count limit C is reached, a test is made to determine if Φ is within a limit of say $\pm 5°$. If that is the case then Φ is reset to Φ_0 in the direction of the vector, and N is set to zero to recommence another cycle of monitoring for the unexpected changes in the vehicle heading. If any of the preceding tests are outside the limits, the vehicle is presumed to have turned off the route in the encoded map, hence other vehicle path recovery or safety routines can be invoked.

Within the road network, when the vehicle approaches within a given distance of say 70 m of a node where a change in vehicle heading should occur, the turn flag is set and a route guidance instruction is issued. This will give the direction of the vehicle turn and possibly a pointer to the subsequent road to be approached. At this juncture, the algorithm monitors for the changes in to confirm that the mid-point of the expected turn is reached within a given limit of say 10 m of the value of L specified for that node, and subsequently, should confirm that the turn is successfully completed.

The probabilistic approach is used for vehicle navigation not constrained to a predefined road network. In this case, when the vehicle commences a journey from a known route within a road network, the vehicle's present correct location is deduced by collating a travelling locus with the pattern of the road shape without assuming that the vehicle is always travelling on a road. This means that the vehicle's current location can be determined even when the vehicle is travelling on a road not encoded in the digitized map (e.g. parking space or departure as a result of a dead reckoning error).

When the vehicle travels from the left side of the road network with the navigational aim of road (B), but instead turns right, possibly due to a dead reckoning error, along an unrecognized route (E), the probabilistic technique will compare the road situation and the vehicle dead reckoned coordinates with the existing roads (A, B, C) in the neighbourhood and repositions the course to road (B) with the highest probability. A navigational system using this technique depends on the input from the dead reckoning sensors, such as, geomagnetic sensors to detect the vehicle directional angles, differential wheel speed to detect the vehicle speed and GPS to detect the global coordinates of the vehicle. Unlike while the vehicle is on a define road network, map matching adjustments do not prevent accumulation of the dead reckoning error. Therefore, depending on the distance travelled off the road network and the accuracy of the dead reckoning sensors, there may be considerable uncertainty in the vehicle coordinates, which could produce misleading conclusions when tested against the surrounding and possible routes in the road network. This problem can normally be reduced by the use of accurate sensors, reinitialization of vehicle position using roadside beacons and the use of map matching algorithms of high precision.

The main task of an algorithm of this type is to repeatedly ask the navigational system, "Where is the vehicle?", with no prior presumption that the vehicle is on an acceptable road. At the commencement of the algorithm, several alternative roads near the current vehicle location are selected from the road network by searching as the vehicle travels on the current route.

Generally, probabilistic map matching algorithms seek to minimize the potential of off-road errors by maintaining a running estimate of uncertainty in the dead reckoned location. The estimate of location uncertainty is minimized each time in the search when it is ascertained that the vehicle location is on an acceptable road.

1.8.3 Dynamic Route Guidance Systems

Dynamic route guidance systems are vehicle navigation systems with an added in-vehicle facility which allows it to self-determine the optimal route using the technologies already described in this chapter with the road map stored as a database in a CD-ROM device. This type of system may also have dual mode route guidance capacity which allows it to communicate with the hardware provided by the traffic infrastructure such as roadside beacons (e.g. ALI-SCOUT systems such as Siemens EUROSCOUT(Infrastructure base route guidance system-part of ite Siemens Plessey "Universal Vehicle Information system" and Autoguide) for dedicated short-range communications via infrared sensors inside a receiver mounted in the vehicle or by incorporating traffic information and management systems from, for example, RDS-TMC (Radio Data System- Traffic Message Channel) or SOCRATES (System of Cellular Radio for Traffic Efficiency Safety) The switchable modes provide a system's capability which allows itto perceive, ahead of the vehicle, the dynamics of traffic conditions such as road link times, traffic incident reports and traffic flow, and use the results of that perception to guide the vehicle dynamically through the optimal route. To enhance the communications of several vehicles with the traffic infrastructure without information capacity restraints, specific communication channels from the digital mobile phone network which allows a multiple-access protocol, such as the pan-European GSM (Group Special Mode-Digital Pan European Cellular Radio System) system, is necessary.

The driver/vehicle interface is normally provided by a human-machine Interface (HMI) control station. In addition to other facilities provided by the HMI, a display unit which shows the driver a simplified picture of the road and a direction arrow is provided. Normally, the navigation function superimposes vehicle location on the map display screen, highlights on the map then suggests the optimal route, and route guidance instructions are issued. Voice and LED can be used to provide the driver with a route guidance which may include direction information before junctions and other route characteristics. This system is similar to the TravTek system which was used in 100 General Motors vehicles, where prototype multifunctional architecture provided navigation, route selection and guidance, real-time traffic information, local yellow pages and a cellular phone service.

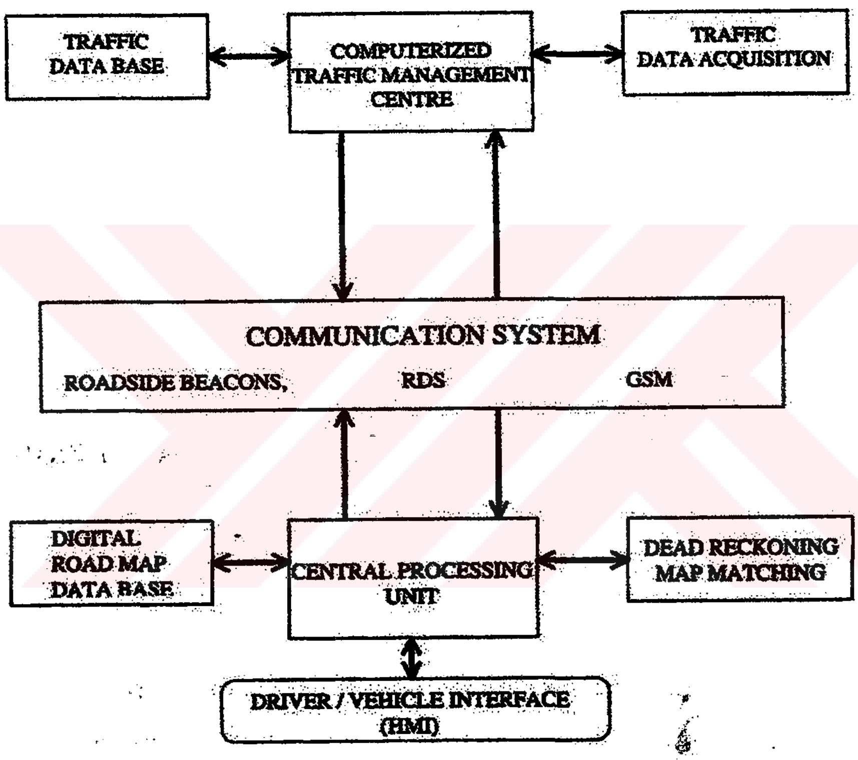


Figure 1.16 Dual mode route guidance system

An example of a system which uses some of the technology described is the Carin system (CAR Information and Navigation system). The CARIN system is based on CD-i (interactive) and digital map technology, and it consists of basic components, such as, magnetic compass, connection to ABS, GPS systems, HMI, CD-i mapping and RDS-TMC that allows digital traffic information to be received.

1.9 Communication Systems

The information age has altered completely the whole nature of time, space and distance relating to personal mobility. The telecommunication revolution encapsulated in the "information superhighway" is progressing at a galloping pace, and it will underpin the most profound development and changes in the social and work pattern over the next 10-20 years. The effect of this on personal mobility is as yet not fully known. What can be said is that the role of vehicles are shifting from a pure "personal mobility" oriented system to what can be safely termed a "personal-infomobility"-oriented system. We now live in a wired society, where internet, E-mail, satellite communication, mobile phone, voice recognition and digital network is part of the communication system. In addition to the traditional requirements of vehicles, it is apparent that vehicles of today are becoming an extension of a living space and a means of conducting business which would have otherwise been carried out in a normal office, it is also part of an integral traffic system.

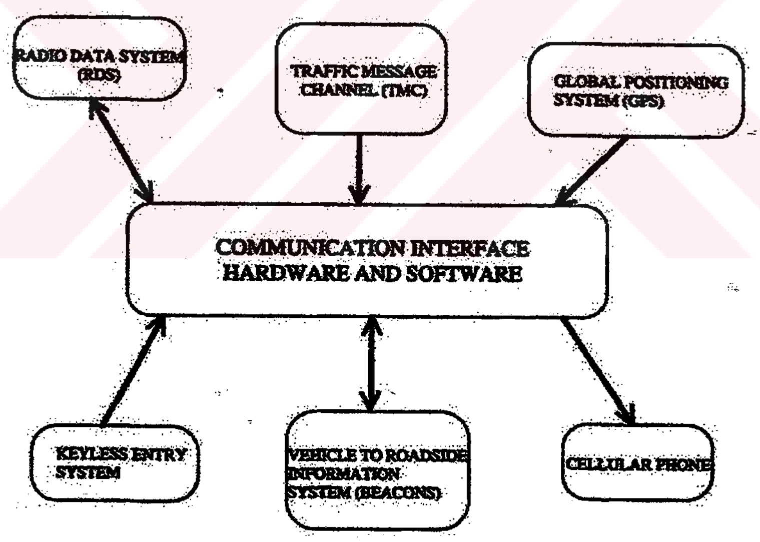


Figure 1.17 Vehicle radio frequency communication systems

The communication system which is deemed at present very important and popular is that which allows the vehicle, driver and the vehicle passive occupants to communicate with the outside world while the vehicle is still in motion or stationary, as the case may be. There are several sources of communicable information which can be interfaced with an intelligent vehicle, but the basic practical sources are shown in Figure 1.17. These are essentially, radio frequency (RF) communication systems capable of operating within a short and wide-area range through high, medium and low data rate communication channels.

The overall systems requirement is therefore to provide the driver of an advanced vehicle with a communication system-based framework which converts him/her to become an "informed driver" driving a safe and secured vehicle, capable of communicating with other vehicles, traffic infrastructural systems and business/social units. The "informed driver" is the driver that has the in-vehicle communication and information system that enhances the driver's capability to be linked into the wired society, possibly through the information superhighway. The communication systems within the advanced vehicle should provide the "informed driver" with the communication channel linked within the global concept of the "informed traveller", where an automatic intermodal travel interface is provided so that he/she is able to use an alternative transport system (e.g. airline, train, bus/coach, etc.) when required. The "informed traveller" concept is in the recent Technology Foresight report published by the UK Office of Science and Technology.

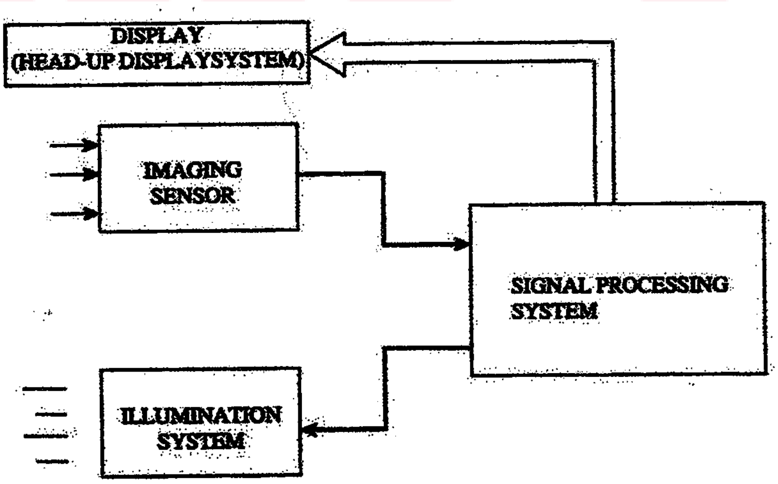
As increasing demand is made of radio frequency communication, it is a normal practice to allocate a different frequency range to different users for intelligent vehicles.

1.10 Driver Vision Enhancement

A high percentage of accidents occur because the driver's visibility is poor or the driver finds the visual conditions of the traffic in front of the vehicle very poor. The ability of the driver to visualize objects and traffic in front of the vehicle is dependent on several factors. These include, among other factors, the driver's age, weather conditions, the time of the day and the health of the driver. So any system capable of providing enhanced visual capability of the driver should form part of an intelligent vehicle.

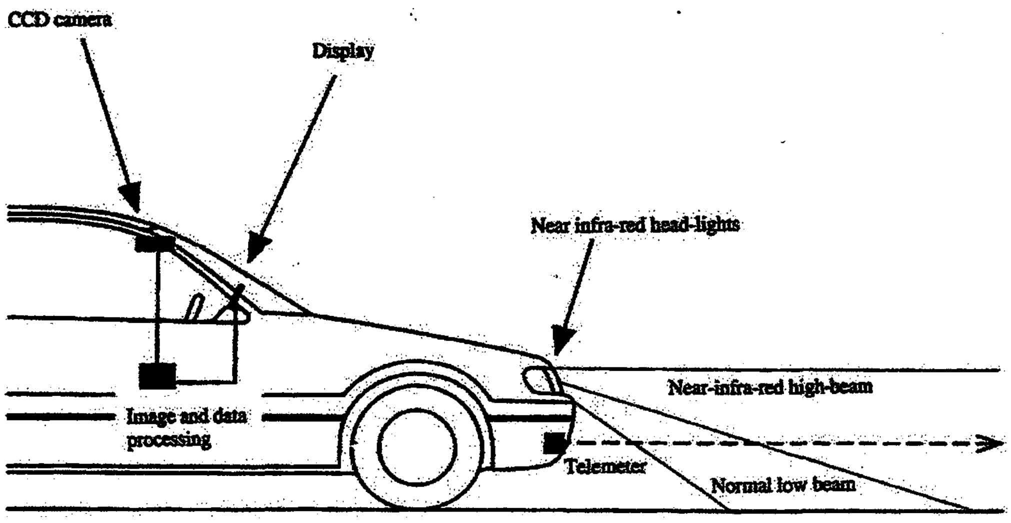
Driver vision enhancement is a vehicle safety system which provides an enhanced driver vision under varying weather and time of day conditions. This is achieved by perceiving the traffic environment through sensory systems that monitors the road scenery condition and subsequently processes the visual data in order to ascertain the traffic and road conditions in front of the vehicle and provide relevant visual information to the driver. The basic systems identifying the main subsystems are shown in Figure 1.18 and 1.18(a) shows the block diagram and the relationship between the individual subsystem, while in Figure 1.18(b) a type of in-vehicle system with the near infra-red illumination and camera is shown.

The type of sensors used in a driver vision enhancement are typically imaging sensors such as a charged couple device (CCD) camera, thermal imaging system with far infra-red camera and gated intensified camera with pulsed illumination. For these cameras to work, appropriate illumination of the road scene, which may be a dark or fog road scene, is required. Examples of the illumination systems used include ultraviolet illuminators and near infra-red illuminators. The illumination systems are normally mounted in the headlamps or adjacent to it (Figure 1.18(b)). In order to make sense of the road scenery, image data acquired from the sensor is processed by an image and data processing unit. Irrespective of the type of camera used, the main task of the processing system is in fact to enhance the image by using different types of image enhancement routines in the data processing system. Once the image is processed, the resultant information is relayed to the driver. This can be done by displaying the information on a head-up display system shown in Figure 1.19.



(a)

Figure 1.18.a System's block diagram



(b)

Figure 1.18.b In-vehicle Systems layout System's diagram of driver vision enhancement

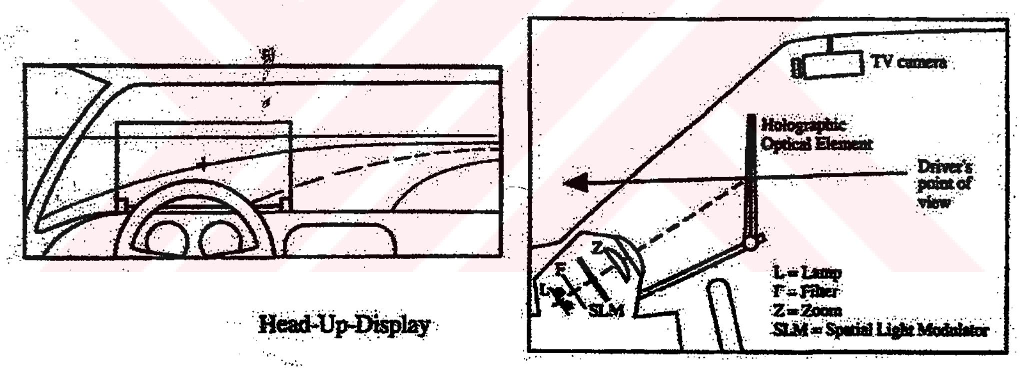


Figure 1.19. Head-Up display for vision enhancement system

The head-up display system allows the overlapping of the scene the driver sees with the image acquired by the camera sensor. With the type of head-up display shown in Figure 1.19 the road images acquired by the camera are projected on to the holographic optical element (combiner) through a spatial light modulator and the zoom lens .

2. Terminology in Automotive Technology

This Automotive Technology Glossary is a collection of descriptions of recently introduced and potential automotive technologies. Each section includes a description of the technology, how it works and the customer benefit. The "how it works" section is general, and implementation may vary on a specific vehicle.

2.1 Active Suspension System

What it is: Active suspension systems move each wheel up and down to control body motion in response to road abnormalities. The system responds to inputs from the road and the driver. With an active suspension, a vehicle can simultaneously provide the smooth ride of a soft suspension along with the superior handling associated with a firm suspension .

How it works: Most active suspension systems use a high-pressure pump with hydraulic cylinders at each wheel to position the wheels with respect to the vehicle.Up and down motion of the wheels is actuated by electronically controlled valves. Other alternatives to power active suspension systems include electric motors or electromagnets. In any system, sensors at each wheel determine vertical wheel position and the force of the road acting on the wheel. Some systems use "road preview" sensors (radar or laser) to provide information about road abnormalities before the front wheels reach them. Accelerometers tell the computer when the vehicle is accelerating, braking or cornering. The computer uses complex algorithms to continuously process information and decide the position of each wheel.Coil springs can be used at aech wheel to avoid "bottoming out" of the suspension in case of system failure; they also can reduce the power required to support the sprung weight of the vehicle.

Customer Benefit: Outstanding ride and handling, even on rough roads.

2.2 Active Tilt Control

What it is: Active tilt control winds up the stabilizer bars in the front and rear suspension to resist body lean while cornering. Because active control is used only as needed, vehicle spring rates and stabilizer bar stiffness can be reduced, improving normal ride characteristics.In addition, this system has potential to increase low-speed, off-road traction on 4WD vehicles.

How it works: The control module receives a lateral acceleration signal from a body-mounted accelerometer.The module directs pressure from a pump to hydraulic cylinders that replace stabilizer bar links. During cornering, the cylinders wind up the stabilizer bars, which increases resistance to body lean. The system is deactivated at slow speeds to increase driver comfort. Off-road traction is improved due to lower resistance from the stabilizer bars, allowing the front and rear wheels to better follow the surface of rough roads.

Customer benefit: Reduced vehicle lean when cornering and improved ride.

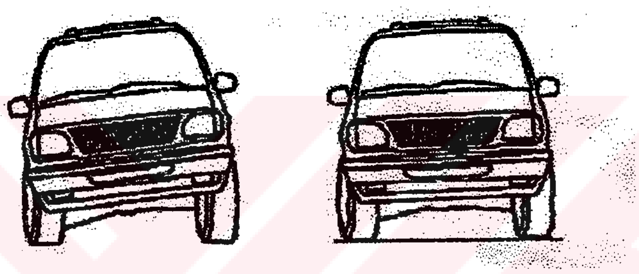


Figure 2.1 Active tilt control

2.3 Adaptive Cruise Control (Intelligent Cruise Control)

What it is: Adaptive cruise control (ACC) improves on traditional cruise control by allowing a vehicle to automatically follow another vehicle at a set distance. With ACC, the driver sets the system when his or her vehicle is at the desired interval from the lead vehicle. ACC maintains that spacing up to a maximum vehicle speed, also set by the driver. The driver must remain alert to override the system the system if necessary. When the distance to the lead vehicle and/or relative speed indicates a need for braking, some ACC concepts merely disengage the throttle (and enable a downshift) and give a warning to apply the brakes. Other concepts actually tap thebrakes to warn the driver. When the lead vehicle changes lanes or exits and the road is clear, the ACC will accelerate to the set speed.

How it works: When actuated by the driver, a microwave radar unit or laser transceiver on the front of the vehicle determies the distance to the vehicle ahead and relative speed. The computer continually adjusts the throttle (and braketap system if so equipped). Braking can override the system at any time.

Customer benefit: Increased driver convenience and improved traffic flow on busy highways.

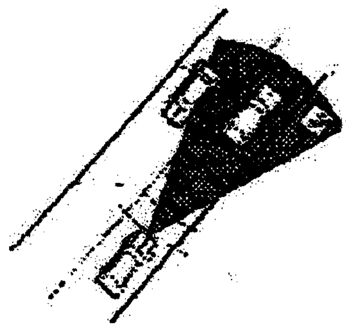


Figure 2.2 Adaptive cruise control

2.4 Adaptive Transmission Control (ATC)

What it is: The adaptive transmission control system recognizes individual styles of driving (e.g., aggressive vs.relaxed) and adapts transmission shift parameters accordingly. Two types of ATC are adaptive shift-scheduling and adaptive shift-quality control. Adaptive shift scheduling uses information to assess driving style and decides when to upshift or downshift. It also can identify uphill or downhill gradients and recognize hard cornering. This helps inhibit shifts that might be annoying to the driver or affect vehicle stability. Adaptive shift-quality control uses information about the vehicle or environment, such as changes in the transmission due to wear, to improve the quality of shifts. This system can also adjust shift smoothness to suit driving style (e.g., crisper shifts for aggressive driving or smoother shifts for normal driving).

How it works: Adaptive shift scheduling uses a microprocessor to read signals from various sensors. It uses a complex algorithm and ongoing memory to decide when to shift. For wxample, high lateral acceleration during cornering may prevent shifting even if the accelerator is suddenly depressed or released. This helps avoid potential loss of tire grip due to load reversal. Shift points can be based on calibration curves in memory. Adaptive shift-quality control adjusts parameters that effect the speed and smoothness of the shift by interpreting data, including driveline feddback, from various sensors.

Customer benefit: Transmission shifting that is better suited to specific driver styles or operating conditions.

2.5 Anti-Lock Braking System (ABS)

What it is : ABS keeps the wheels from fully locking up while braking to allow the driver to maintain steering control. Without ABS, too much force applied to the brake pedal can cause one or more wheels to stop turning (lockup) and begin skidding, greatly reducing the capability of the driver to steer. With ABS, maximum force on the brake pedal slows each wheel to the point of maximum braking – without skidding. Since all wheels are still rolling, the driver maintains steering control within the limits of traction. Many light trucks use rear-wheel ABS to prevent rear wheel lockup.

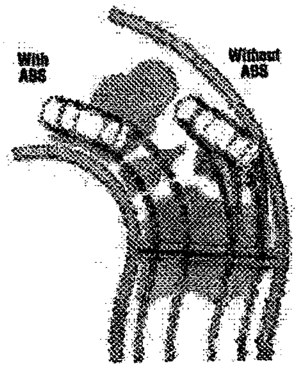


Figure 2.3 Anti-Lock Braking System (ABS)

How it works: ABS consists of an electronic control unit (ECU) with microprocessor, hydraulic control unit (HCU) with pump and motor (to modulate brake line pressure), and wheel speed sensors for each wheel. If a wheel begins to lock up during braking, the computer senses a speed difference compared to the other wheels. The HCU reduces pressure to that brake until it begins to roll again. This occurs many times per second during braking, making pumping of the brakes unnecessary. When the brake is applied firmly, each wheel is kept at maximum braking without locking up to help the driver make the best use of available traction.

Customer benefit: ABS provides the average driver with greater vehicle stability and control during severe braking, allowing the driver to steer away from a potential accident.

2.6 Automatic Ride Control

What it is: Automatic Ride Control adjusts vehicle shock absorber resistance (damping) in response to driver inputs such as steering and braking and for changes in road surface. During maneuvers such as hard braking or quick lane changes, the system increases suspension damping to improve dynamic stability. Damping is automatically decreased during steady driving, so that bumps and potholes are absorbed rather than being transmitted to the occupants. Some systems also allow the driver to select suspension settings: soft, normal and firm(sport).

How it works: Most systems use switchable-rateshock absorbers (dampers). Different sensors may be used depending on the complexity of the system.

- A basic system measures steering wheel position and braking. He computer adjusts the damping of all shock absorbers equally.

- A road-calibrated suspesion system, also known as semiactive suspension, measures the position of individual road wheels as well as driver inputs. This type of system (used on Continental and Taurus SHO) adjusts shock absorber damping independently for each wheel for the best combination of performance and ride. In vehicles equipped with a suspension-firmness switch, selecting a firm setting would cause the computer to choose heavy damping for most driving conditions, while the soft setting would result in light damping more often.

Customer benefit: Improved ride and handling, tailored to driver preferences.

2.7 Auto Shift Manual Transmission and Select Shift Manual Transmission

What it is: Select Shift Manual (SSM) and Auto Shift Manual (ASM) use a combination of Auto-Clutch and Shift-By-Wire electronic control system technology to provide the customer a fun-to-shift experience along with significant fuel economy improvements over a base manual transmission. The Select Shift Manual mode allows a customer to command gear changes according to his/her personal preference like a conventional manual transmission. The Auto Shift Manual mode provides the customer automatic gear shifting much like an automatic transmission.

How they work: Both the Auto-Clutch subsystem and Shift-By-Wire subsystem use an electro-mchanical actuation system controlled by a stand-alone transmission control module.

A customer requests a gear shift by using the appropriate driver interface mechanism (shift lever, push buttons,etc.).In place of the usual cable/linkage (which is eliminated), a sensor informs the controller of the requested gear shift. The controller processes the requested gear shift. The controller processes the request and commands the actuators to open/close the clutch and disangage/engage the gear squence with very fast response times. Engine torque is controlled during the shift either by controlling the throttle directly (Drive-By-Wire) or enabling ignition/fuel injection control to provide smooth shifts.

Customer benefit: Fuel economy improvement with fun-to-shift convinience and shift mode flexibility.

2.8 Continuously Variable Transmission

What it is: A continuously variable transmission is an automatic that can select any desired drive ratio within its operating range.Unlike a traditional three-, four-, or five- speed automatic transmission the CVT is an "infinite speed" transmission, the CVT continually selects an optimum overall drive ratio between engine and drive wheels for all operating conditions, whether accelerating or cruising. Unlike conventional automatics, there are no perceptible shifts. During maximum acceleration, the drive ratio is adjusted to maintain peak engine horsepower. At a constant vehicle speed, the ratio is set to maintain an engine rpm which will support the required power. A CVT provides smooth, fast acceleration and high cruising efficiency with the convinience of an automatic transmission.

How it works: The most common CVT design uses a segmented metal V-belt running between two pulleys of variable diameter. Each pulley consists of a pair of cones that can be moved close together of further apart to adjust the diameter at which the belt operates. The pulley ratios are electronically controlled to select the best overall drive ratio based on throttle position, vehicle speed and engine speed.

Customer Benefit: Performance, fuel economy improvement and smoother operation.

2.9 Direct Injection Engine

What it is: Direct Injection (DI) refers to fuel injected directly into the combustion chamber above the piston. Direct Injection has long been used on large diesel engines. Smaller diesels are increasingly adopting direct injection (vs. indirect injection into a pre-chamber). Direct injection also can be used in spark ignition (generally gasoline) engines instead of port fuel injection – for cleaner emissions, increased full throttle power and potentially for lean-burn operation.

Ref- Port Fuel Injection (PFI): By comparison, Port Fuel Injection (used spark-ignition engines) have injectors in the intake port near the valve. During the intake stroke, fuel sprayed into the port enters the combustion chamber along with the air charge.

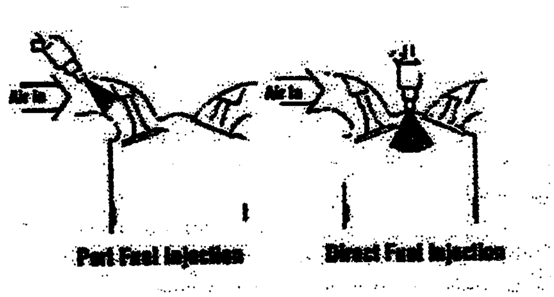


Figure 2.4 Direct injection engine

Direct Injection: With Direct Injection Spark Ignition (DISI) engines, fuel is injected in one of two ways depending on operating conditions. Lean burn operation (at part throttle), injects fuel after the air has entered, causing higher fuel concentration near the injector and spark plug for easy ignition. This is known as stratified charge. The overall air/fuel ratio is lean for better fuel consumption. At full power, fuel is injected at the same time as air (same as for conventional) to promote good mixing. Fuel evaporating in the combustion chamber cools the air slightly for higher volumetric efficiency and power. Snce all fuel being injected goes directly into the cylinder, it can be metered more precisely, promoting cleaner emissions.

Customer benefit: Better fuel efficiency and more power.

2.10 Double Locking

What it is: The double locking feature makes it virtually impossible for an intruder to open a locked vehicle door without key or remote transmitter (key fob), whether from outside or inside. Even after breaking a window, a thief could not unlock the doors and would have to enter through the window to attempt to steal the vehicle.

How it works: Double locking is activated by turning the key in a specific sequence (toward locked position twice within 3 seconds). With remote keyless entry (RKE), double locking is activated by pressing the "lock" button twice. Double locking is deactivated by unlocking the door, either with remote transmitter or the vehicle key. To reduce the possibility of locking people in the vehicle, the double lock can be activated only when the ignition is off and the key removed.

Customer benefit: Increased security for parked vehicles.

2.11 Driver Alertness Monitoring

What it is: Driver alertness monitoring is designed to detect when the driver's ability has become impaired, whether from inattention, drowsiness or intoxication. A simple system may merely sound an alarm. More complex systems could include warnings of impending collisions or that the vehicle is staying from the roadway.

How it works:Two methods are proposed to monitor driver alertness. One uses infrared cameras that detect eye motions and compute trends that track driver vigilance. Another monitors driver performance in maintaining the vehicle in its lane, using cameras which detect lane markers.

Customer benefit: Warns driver when not adequately alert.

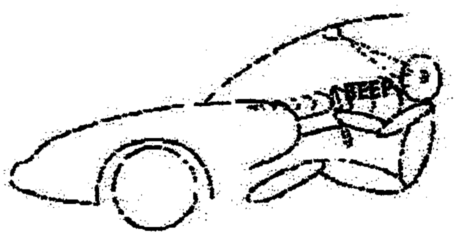


Figure 2.5 Driver alertness monitoring

2.12 Electronic Air Suspension

What it is: Electronic Air Suspension provides the comfort of riding on air with adjustable spring rates and capability to change ride height and load-carrying ability. Under normal driving conditions, an electronic air suspension vehicle rides at the same height as a traditionally sprung vehicle. With a heavy load, ride height is increased automatically. On current vehicles, the suspension lowers the ride height by 20 mm at highway speeds for improved aerodynamics, with about 2 percent better fuel economy. Lower ride height also can improve on-center feel of steering due to the change in suspension geometry and increased caster angle. On Expedition, the driver can lower the vehicle several inches for easier entry and exit (access mode).

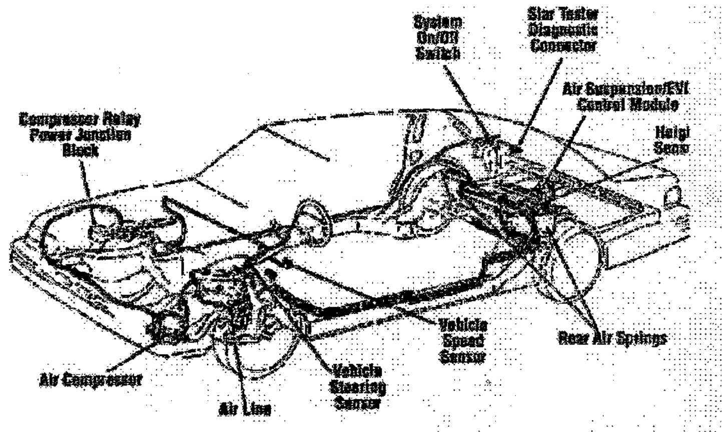


Figure 2.6- Electronic Air Suspension

How it works: Instead of coil or leaf spring, each cornes of the vehicle is supported by an air spring (bladder). Shock absorbers are still required. With a constant quantity of air, each air bladder acts similarly to a normal spring. To increase vehicle ride height, more air is pumped into the bags by a pump. Air is released from the bags to decrease the height.

Customer benefit: Improved ride, handling and fuel economy with ease in entering and leaving tall vehicles.

2.13 Electronic Message Center

What it is: The Electronic Message Center displays text containing vehicle information and system warnings. The computer keeps track of fuel consumption, oil life, engine temperature, exterior lightning, charging systems and various fluid levels. If trouble arises in any of these areas, a message alerting the driver is displayed. In addition, a check can be performed by the driver on the other vehicle systems such as automatic ride control.

How it works: A fluorescent or LCD text display is mounted in the center or overhead console or instrument cluster. A computer reads input from various systems; some systems are monitored continuously, others only during a systems check. If a problem occurs in any continuously monitored system, an appropriate warning (e.g, check taillamps) is displayed. Other vehicle system problems are identified when a systems check is performed.

Customer benefit: Customer convenience and early problem identification.

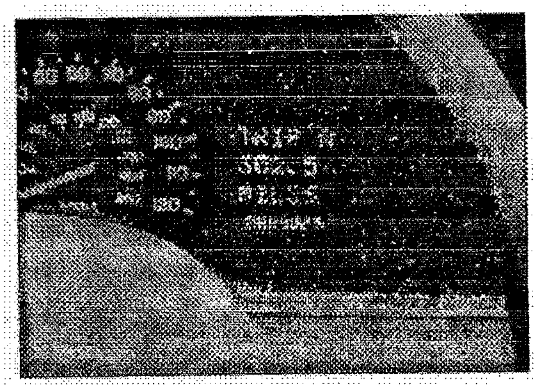


Figure 2.7 Electronic Message Center

2.14 Electronic Messaging

What it is: Electronic Messaging provides traffic information and other warnings to the driver through an interface in the vehicle. Encoded traffic information is continually transmitted to the vehicle's FM radio. A dynamic warning information system being piloted in some regions could include warnings such as a train crossing, icy bridge, high wind, deer crossing or falling rocks. Its advantage is that current information (vs. blanket warnings) about specific hazardous conditions can be transmitted. Convenience information also could be displayed (e.g.,parking, food, gas, lodging, intersections and other items of interest).

How it works: The Electronic Messaging system operates on various roadside-to-vehicle communication systems. Two-way communication is possible over short distances between the vehicle and antennas along the roadway and at parking areas. A Dedicated Short Range Communication system proposed as a standard for electronic toll collection also could be used for dynamic warnings. Other alternatives such as cellular telephone and FM radio band are being proposed for longer-distance communications.

Customer benefit: Improved convenience and safety with situation-specific information targeted to drivers.

2.15 Electronic Toll Collection

What it is: Roadway and bidge tolls can be paid automatically without slowing down. This eliminates lost time and relieves congestion at tollbooths.

How it works: A transponder mounted in the vehicle communicates by radio signals to antennas buried in the pavement or mounted at roadside. The appropriate fare is deducted by the transponder from aprepaid account. A typical unit on top of the dash or in the instrument panel is about the size of a deck of cards, with a display, keypad and an audio signal for instant account balance. As part of a vehicle to roadside communications system, the transporder also could send and receive other information. Standards such as Dedicated Short Range Communications (DSRC) are being developed for roadside readers and in-vehicle tags.

Customer benefit: Time savings and convenience when paying tolls.

2.16 Frontal Collision Warning

What it is: A Frontal Collision Warning system warns the driver when it detects objects in the path of the vehicle; e.g., a vehicle slowing ahead. Som systems also apply braking to help avoid a collision. The collosion warning system has several advantages over human performance in helping to avoid collosions. These include constant attention (e.g, to the vehicle ahead), and reacting more quickly to situations.

How it works: The vehicle is fitted with a forward-looking sensor (such as radar or laser), similar to one used for additional input. The combined information provides a reliable picture of the road ahead, and may be used to support other functions such as vision enhancement.

Customer benefit: Reduced risk of a frontal collision due to inattention or conditions with poor visibility.

2.17 Infinite Door Check

What it is: The Infinite Door Check (IDC) is a mechanical-hydraulic device designed to hold the door open at any position along its swing path. Traditionally, vehicles equipped with mechanical door checks (or detents) hold the door only at half open or fully open positions; the door will not stay in place at other positions. Infinite Door Check, by holding the door open at any position, enables customers to protect their own vehicle and avoid denting or chipping the paint of adjacent vehicles in tight parking places. It also allows the occupant position the door at any convenient position when entering or exiting, even when the vehicle is parked on an incline.

How it works: The IDC makes use of a phenomenon called stiction.Stiction is defined as the ratio of static to dynamic friction.The IDC mechanism utilizes patented valving technology to amplify the dynamic force to overcome static friction, which makes the door easy to move once it is in motion.

Customer benefit: Easier entry and egress from the vehicle, and reduced likelihood of damage to the door edge or to adjacent vehicles.

2.18 Interactive Vehicle Dynamics (IVD)

What it is: Interactive Vehicle Dynamics is designed to minimize loss of vehicle control due to loss of traction. The IVD system could be activated when a vehicle is taking a turn too quickly or when encountering an icy patch.

How it works: The system compares the driver's intended direction (from the steering wheel angle) to the actual vehicle path, which is inferred from accelerometers and wheel-speed sensors. If the actual path is different from that intended (e.g., when the vehicle is understeering or oversteering or on slippery roads), the IVD controller applies braking at selected wheel(s) and reduces engine torque if required to correct the situation. The system is designed to make the best use of available traction to keep the vehicle on the intended path and minimize loss of control.

Customer benefit: Increased driver control, handling, performance and safety.

2.19 Intelligent Vehicle Highway System (IVHS)

What it is: The Intelligent Vehicle Highway System (IVHS) provides a variety of infonnation to the vehicle and driver through cooperation of automotive electronics, communications, controls and systems engineering technologies. IVHS has two areas of interest to car and truck makers: (1) telematics and (2) active safety warning and control systems. Several features have been identified:

Telematics:

- Navigation systems
- Traffic messaging
- Emergency messaging and security tracking (e.g. RESCU – Remote Emergency Satellite Cellular Unit)
- Short range communicationsi automatic toll collection
- Active Safety Warning and Control Systems
- Collision warning/avoidance
    - Backup and parking aids
    - Side vision aid
    - Vision enhancement (all weather/night vision)
    - Adaptive cruise control
    - Lane departure control

Many features could share technologies or components. Some are described separately in this guide.

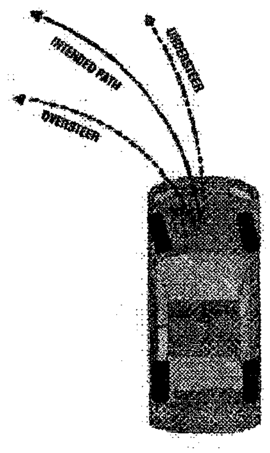


Figure 2.8- Intelligent vehicle highway system

Customer benefit: Increased comfort and safety through exchange of real-time information on highway conditions and vehicle operating environment

2.20 Lean Burn Engine

What it is: A lean bum engine is designed to operate with a very lean air-fuel ratio during light load conditions. Most modern gasoline engines are controlled to run at a chemically correct (stoichiometric) air fuel ratio (about 14.7:1) to make the threeway catalyst operate at high efficiency, reducing tailpipe emissions. Lean bum engines mix more air with the fuel when full power is not needed, resulting in better fuel economy. Air/fuel ratio in lean bum engines can be as high as 20:1. When full power is needed, such as during acceleration or hill climbing, a lean bum engine reverts to a stoichiometric (14.7:1) ratio or richer.

How it works: A very lean mixture of air and gasoline will not ignite as easily as a stoichiometric mixture when a spark is introduced. Several methods can be employed to achieve lean bum, including high temperature, high turbulence and stratification (high concentration of fuel vapor near the spark plug). Lean bum engines are often designed with high intake swirl to increase turbulence. Direct injection is one way to provide stratification. Since more air is taken in, the throttle plate can be opened wider for a given power, and losses associated with pumping are reduced. Lean operation also results in higher combustion efficiency and lower heat losses for better fuel economy.

Note: *Current three-way catalysts are designed to optimize* NOx *reduction at close* to stoichiometric ratio. Lean burn engines generally cannot meet strict NOx emissions standards using a three-way catalyst; additional NOx controls are necessary.

Customer benefit: Better fuel efficiency without sacrifidng engine power.

2.21 Low Tire Pressure Warning

What It is: A low tire pressure warning system alerts the driver W the air pressure in a tire becomes too low. Typically, a light on the instrument panel will be illuminated to warn of the low-pressure condition.

How it works: Two common implementations exist for this warning. The first uses pressure sensors in each wheel to periodically transmit pressure data to a receiver in the vehicle. If the tire pressure falls below a set level, a warning light is illuminated. *In some applications, the pressure in each tire can be read inside the* vehicle. The pressure sensing system is particularly useful for vehicles with run flat tires that do not go flat when losing pressure.

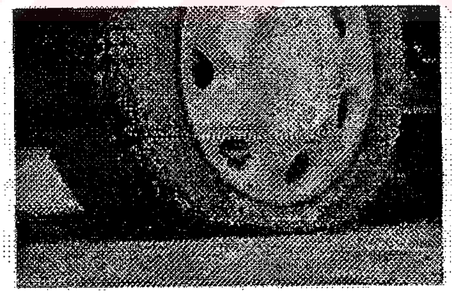


Figure 2.9 Low Tire Pressure Warning

Another implementation uses four-wheel anti-lock brake hardware, including wheel-speed sensors and a computer that processes the signals. If a tire has low *pressure, it will turn faster than the other wheels. Wheel speed differences are used* to detect low pressure, and a warning light will alert the driver in approximately three miles. Customer benefit:Automatically alerts drivers to low tire pressure.

2.22 Memory Profile System

What it is: The Memory Profile System offers different drivers the ability to set into memory their preferred positions for several comfort and convenience features. A driver is identified by a unique key fob or entry code. And the vehicle systems automatically adjust to his or her settings. Depending on the vehicle, some of the following features can be included in the memory profile:

• Seat position

• Steering wheel position (tilt/telescope)

• Mirror positions

• Safety belt-ring height

• Pedal positions

• Radio stations

• Power steering assist level

• Ride firmness

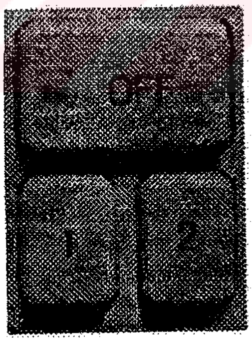


Figure 2.10 Memory profile system

Additionally, the profile can include features desired to be inactive or active, such as automatic door locking.

How it works: A driver records a personal profile by first adjusting everything in the vehicle the way he or she likes it Pressing and holding a numbered memory button on the door records the profile onto a computer chip. Additional drivers can set their own preferences. Later, the driver can restore the vehicle to personal preferences by touching the numbered button or with a specific key fob or keyless entry code. Various actuators are required to adjust the settings on the vehicle systems.

Customer benefit: Improved comfort and convenience.

2.23 Multiplex Communication

What it is: Multiplex Communication permits electronically controlled components such as sensors, actuators and modules to share information by transferring digitally encoded data on a wire or optical buL Multiplexing could eliminate a great deal of vehicle wiring and may eliminate redundant sensors and actuators.

How it works: The multiplexing system consists of a network of computer-based modules and their local sensors and actuators. when components need to communicate, a digital signal is transmitted on the multiplex bus as digitally encoded information. An example may be found in the power door-lock/window system. On conventional systems, control switches on the driver's door are wired diredly to actuators in other locations, resulting in numerous wires running through the driver's door. In a Multiplex system, a door module transmits required information and/or commands on the bus media (wire or optical fiber) to operate the appropriate actuator. For example, when the power window switch on the driver's side is pressed to open the passenger-side window, a digitally encoded signal is transmitted to the passenger window motor modulator as opposed to directly closing the window motor circuit as with a conventional system.

Customer benefit: Greater reliability due to less wiring along with reduced cost and weight Multiplexing also provides a central point diagnostic vehicle connection via a single connector. This provides a rapid and uniform means for the diagnostic technician, potentially allowing for better vehicle diagnostics and reduced warranty costs.

2.24 Navigation System

What it is: In-vehicle navigation provides directions to a destination. Instructions can be delivered by voice, graphic icons such as arrows, a scrolling video map or a combination. To begin, the driver inputs a desired destination. The computer accesses a database and plans the route. Instructions are fed to the driver as the vehicle approaches pertinent intersections. If the driver deviates from the intended route, the computer selects an alternate route and delivers new instructions.

How it works: For a navigation system to deliver timely instructions, the computer must know the location of the vehicle. Usually, a Global Positioning System (GPS) receiver in the vehicle is used for this. In some systems, dead reckoning is used, either on its own or in conjunction with GPS. Dead reckoning uses wheel speed sensors and/or accelerometers to infer vehicle movement and track the location of the vehicle. Dead reckoning, when used with GPS, improves accuracy and provides more predse route instructions than GPS alone. Once the current, or starting, point and destination are known, the computer accesses a street-map database to plan the route. The data can be stored on-board the vehicle in a CD-ROM or off-board in a remote computer. A potential advanced feature option is when up-to three minute traffic information is accessed from a central location to plan the best route.

Customer benefit: Convenience and security.

2.25 Passive Anti-Theft System

What it is: Passive anti-theft systems (PATh), like Ford's patented SecuriLock-Systems protect against theft by requiring a specially coded ignition key. The vehicle starts and operates only with the key that matches the sensor in the vehicle, thwarting attempts to hot wire the ignition. An indicator lamp shows the system is working.

How it works: A miniature transponder with integrated circuit and antenna is embedded in the ignition key. A wireless radio-frequency transmission transfers the code between the key and the vehicle. If the codes match, the module sends a signal through the wiring system to the engine electronic control, allowing the engine to start There are 72 million-billion possible codes, so every Ford sold worldwide for the next 10 billion years could have a unique code. New keys for replacements or spares can be encoded by dealerships.

Customer benefit:Increased protection against vehicle theft.

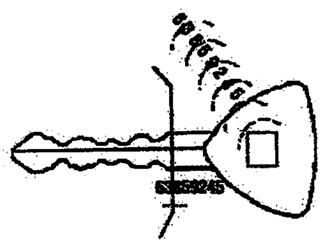


Figure 2.11 Passive anti-theft system

2.26 Photovoltaic Panel

What it is: photovoltaic panels contain cells that convert sunlight into electricity. while solar-powered vehicles are not currently feasible for production, solar panels could be used to power vehicle components, such as a fan to exhaust hot interior air when the vehicle is parked in the sun or to recharge the vehicle battery. Photovoltaic panels can be integrated into the hood, root sunroof, deck lid or spoiler.

How it works: Photovoltaic cells use energy from incoming photons to excite electrons. These electrons produce a very small amount of electrical energy in the cell. Power produced depends on the total cell area; many cells are required to run a small electric motor or to trickle charge the battery. Modem solar cells are able to convert about 40 percent of the energy of sunlight to electricity.

Customer benefit: Supplemental power source for additional customer features, resulting increased fuel economy.

2.27 Remote Control Convenience Features

What it is: This system allows vehicle owners to control certain functions of their automobiles by calling an automated service with a touch4one phone. Functions can include opening or closing windows or sunroof, unlocking doors, disabling the engine (in case of vehicle theft), or other functions. The service also could be used to flash lights or sound hom to find a parked vehicle, set the vehicle clock, or configure certain features.

Figure 2.12 Remote Control Convenience Features

How it works: The vehicle owner calls an automated voice response system with a touchphone phone, enters a personal identification number (PIN) and selects the desired function from the menu. A pager signal is sent to a receiver in the vehicle, and the vehicle sent from controller executes the requested function. Paging technology also allows text messages a telephone or computer to be displayed in the vehicle.

Customer benefit: Increased convenience and vehicle security, theft deterrent and vehicle recovery.

2.28 Remote Lighting System

What it is: The Remote Lighting System removes the sources of light from the lamp fixture. Instead, light for all fixtures is generated from a single light battery. Light is transmitted to the various fixtures and accessories via fiber optics or light pipes. The advantages of remote lighting include reduced power consumption, greater durability and more flexibility in packaging and styling lamp fixtures.

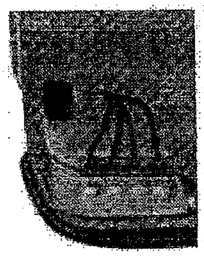


Figure 2.13 Remote lighting system

How it works: A halogen bulb or a high-efficiency light source (high-intensity discharge light) is located in a light collector assembly. There are several possible configurations or architectures. One is the multibeam setup pictured, in which the remotelighting system controls one function. Another concept is central lighting, in which light from a single remote source is distributed to perform multiple functions (headlamps, turn signals, etc.) and controlled by light valves.

Customer benefit: Increased lighting efficiency and reliability, styling flexibility.

2.29 Reverse Aid/Parking Aid

What it is: Reverse Aid/Parking Aid is a short-range collision-warning system to aid in reversing and parking maneuvers. As the vehicle approaches pedestrians or other vehicles or obstacles, beep warning sounds. The frequency of beeping increases as the obstacle is neared, until it becomes a solid tone when the vehicle is closer than a set distance (about 8 inches). Reverse Aid uses rear sensors only. Parking Aid uses front and rear sensors.

How it works: Low-cost, high-performance sensors such as ultrasonic range sensors are fitted to the vehicle. Generallv more than one sensor is used to form a detection zone as wide as the vehicle. A microprocessor monitors the sensors and emits a signal to help the driver reverse or park.

Customer benefit: Easier and safer reversing and parking maneuvers, especially for vehicles where drivers have limited view at the front, rear or corners of the vehicle.

2.30 Safety Belt Pretensioner

What it is: A Safety Belt Pretensioner tightens the belt in the first milliseconds of an accident to better keep the occupant in position. With a tightened belt, an occupant is less likely to strike interior surfaces such as the roof or steering wheel. It also may restrain the occupant from contacting the air bag before it is fully deployed, further reducing the risk of injury.

Figure 2.14 Safety belt pretensioner

How it works: A collision sensor, often the same sensor used to trigger the air bags, detects the beginning of a collision. A signal from the sensor activates a mechanical or pyrotechnic pretensioning device at a safety-belt anchoring point. The pretensioner takes up slack in the belt system until a predetermined force is reached. The belt remains tight around the occupant for the duration of the collision.

Customer benefit: Increased safety for belted occupants.

2.31 Side vision Aid (Blind Spot Detection System)

What it is: Side vision Aid alerts the driver if another vehicle is in the blind spot when changing lanes. Blind spots are the obscured areas immediately to the left and right sides of vehicles, behind the driver's peripheral view. When the driver activates the turn signal, an indicator, typically located on the side view mirror, signals whether a vehicle is in the blind spot The side vision aid supplements the driver's view to the side and rear from windows and mirrors, to permit safe lane changes.

How it works: Active infrared detectors are mounted on each side of the vehicle such as near tail-lights or side mirrors. These detectors ulooku into the next lane to see if a vehicle is there. When the driver activates the turn signal, an indicator (usually an LED) appears, indicating whether the lane is occupied or unoccupied or that the system has malfunctioned.

Customer benefit: Potential increase in safety and accident avoidance when changing lanes.

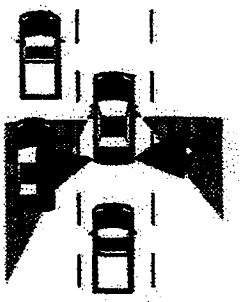


Figure 2.15- Side vision Aid (Blind Spot Detection System)

2.32 Smart Wipers

What they are: Smart Wipers are windshield wiper systems that can determine when and how the windshield wipers operate, based on moisture on the windshield. Smart wipers do not require the driver to continually adjust wiper speed or delay inten'al. This system is an enhancement to vehiclespeed-dependent interval wipers (which inaease the frequency of strokes with vehicle speed).

How they work: Smart Wipers sense moisture on the windshield. One alternative is an optical sensor with a light source that works as shown in the diagram. When moisture is detected on the windshield, the controller starts the wipers. continually selecting appropriate wiper settings depending on moisture measured.

Customer benefit: Increased safety and convenience through reduced driver adjustments.

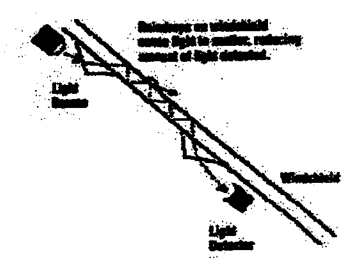


Figure 2.16 Smart wipers

2.33 Split-Port Indudion (SPE)

What it is: Split Port Induction uses two intake runners leading to a single port and intake valve for each cylinder. One of the runners is open at all engine speeds, while the other opens only at higher speeds. This allows increased mixing of the intake charge at lower engine speeds, with unrestricted engine breathing at high speeds. Peak power is increased while fuel economy emissions and cold startup are improved during normal operation.

Figure 2.17 Split-Port Indudion (SPE)

How it works: The lowspeed intake ports are located low in the head, creating a tangential flow path into the cylinder. The geometry produces a high degree of swirl, more effectively mixing the air and fuel for combustion. At higher engine speeds (above 2,50-3,000 rpm) butterfly valves open (see illustration) for airflow through both ports. The high-speed ports can be tuned for efficiency.

Customer benefit Increased power. better emissions and improved fuel economy.

2.34 Supercharger

What it is: A Supercharger is an air pump or compressor that forces pressurized air into the cylinders during the intake stroke of the engine. Increased density intake air, along with additional fuel, increases power. The term Supercharger is generally applied to engine-driven compressors, but also can include exhaust-gas-driven turbochargers. Mechanical Superchargers do not have the lag associated with turbochargers.

How it works: Mechanically driven Superchargers receive power from the crankshaft via a belt or chain-drive. The supercharger mechanism can be a positive displacement type (Roots or scroll compressor), or airfoil based (centrifugal compressor). Since the supercharger speed is proportional to engine speed, pressure builds instantly, giving power on demand. Operating a Supercharger continually can hurt fuel economy so some Superchargers have a clutch to disengage the compressor when high power is not demanded.

Customer benefit: Increased power on-demand for a given engine.

2.35 Theater Lighting / Illuminated Entry

What it is: Theater Lighting is an enhancement to the illuminated entry feature. Illuminated entry can turn on interior lights when; a door is opened, the remote key fob transmits an unlock signal, or the customer lifts a door handle. Theater lighting: 1) ramps up the lights when the door is opened, 2) keeps lights on for about 20 seconds after the door is closed and 3) dims the lights gradually over a period of about two seconds.

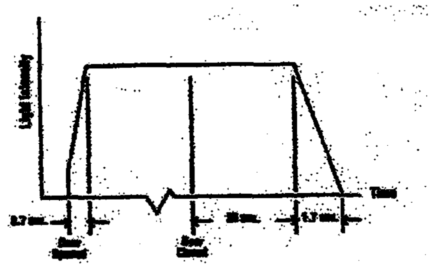


Figure 2.18- theater lightning

How it works: An electronic drcuit detects the various signals that turn on the interior lights.With Ford's implementation of Theater Lighting, the drcuit sends power to the lights according to the profile shown in the illustration below. Other illuminated entry features remain unchanged.

Customer benefit: A more pleasant and dramatic entry and exit experience.

2.36 Traction Control System

What it is: Traction Control is designed to prevent a vehicle's wheels from spinning on slippery surfaces. It shares many of the mechanical and electronic elements of anti-lock brakes. Each wheel Nsearchesw for optimum traction several times a second and adjustments are made accordingly. All-speed traction control is designed to prevent wheel spin by reducing engine output in conjunction with electronic brake application. Traction Control is intended as a driver aid which allows a vehicle to make better use of available traction on slippery surfaces.

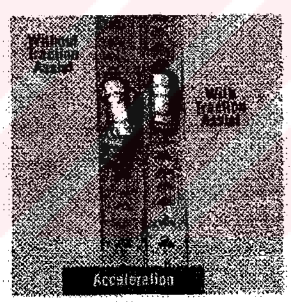


Figure 2.19 Traction control

Another system, traction assist, works below 25 mph. It is used primarily to avoid wheel spin while accelerating from a stop on slippery surfaces. This system does not reduce engine output, but relies on electronic brake application for spin control.

How it works: A computer detects wheel spin by reading relative wheel speed difference between driven and non-driven wheels. Wheel spin is controlled by one or a combination of the following:

- Brake application at one or more wheels Closing the throttle
- Retarding the spark
- Fuel cutout

• Leaner air/fuel ratio

These actions reduce the torque of any spinning wheel to improve traction.

Customer benefit: Better use of available traction on slippery surfaces.

2.37 Turbocharger

What it is: A Turbocharger is a type of Supercharger that is powered by engine exhaust gas. ft increases engine power by pressurizing intake air into the cylinders.

How it works: Turbochargers are centrifugal compressors powered by an exhaust gas-driven turbine. The turbine and compressor are on opposite ends of single rotating shaft fitted in the turbocharger housing. The shaft runs at speeds up to about 100,000 rpm. An advantage over the mechanically driven supercharger is better fuel effidency because it does not use direct crankshaft power. The disadvantage of the turbocharger is turbo-lag (slow speedup of the compressor from a closed throttle), resulting in longer time to boost compressor pressure and slow engine response. Some customers dislike this lag.

Customer benefit: Increased power.

2.38 Variable Assist Power Steering

What it is: Variable Assist Power Steering changes the power assist depending on vehicle speed. At low speeds, steering assist is greater, resulting in lower efforts for low-speed tums and parking. At freeway speeds, assist is reduced, resulting in relatively higher efforts for better road feel from the steering wheel. Some systems, such as that used on Continental, allow the driver to select among different steering-assist modes (levels).

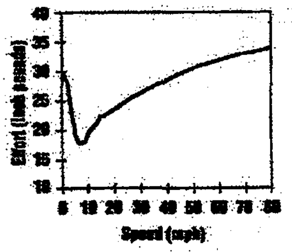


Figure 2.20 Variable assist power steering

How it works: Most production power steering Systems use a hydraulic pump driven by the engine. To reduce the power assist, the flow of power steering fluid to the steering gear is restricted. Some systems can switch between two flow levels for low or high assist Other systems have multiple levels to provide smoother transitions and better steering feel at intermediate speeds.

Customer benefit: Combination of reduced steering effort and good road feel.

2.39 Variable Valve Timing

What it is: Variable Valve Timing allows the point at which an engine's valves open and close to change with operating conditions - such as engine speed and throttle position. In addition to changing the valve timing with respect to the crankshaft, some systems also change the duration the valve is open and the extent to which it opens. Varying these parameters allows the engine to operate more efficiently at all engine speeds while maintaining driveability.

How it works: Traditionally, camshafts open and close intake and exhaust valves at fixed points in the engine cycle regardless of engine speed or throttle position. Variable Valve Timing can employ several mechanisms to change valve opening and closing. It can affect either the intake valves and/or the exhaust valves, depending on the design. Some methods include advancing or retarding the cams or valves or activating additional camshafts or rocker arms.

Customer benefit: Improved power, fuel economy and emissions (depending on the system).

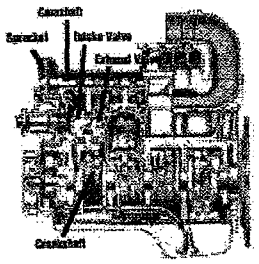


Figure 2.21 Variable valve timing

2.40 Vehicle Emergency-Messaging System (VEMS)

What it is: This system allowvs the driver to push a button in an emergency to contact a service center. Ford's system, first installed in the Continental, is called Remote Emergency Satellite Cellular Unit (RESCU). The system allows the occupants to talk to a service center representative via cellular phone and transmits the following information:

Type of alarm (roadside assistance or medical emergency)

• Vehicle identification number

• Vehicle location

• Last recorded speed and direction of the vehicle

• Time associated with the last recorded position

• Call-back number of the vehicle's cellular phone

Figure 2.22 Vehicle emergency-messaging system (VEMS)

The voice channel allows the center to:

- Maintain direct voice contact until emergency help arrives

- Notify pre-designated family contacts or friends in case of emergency

- Provide estimated time of arrival of roadside assistance

- Call back to confirm resolution of the problem

A possible enhancement to VEMS is automatic activation of the system when the vehicle's air bags are deployed.

How it works: The RESCU system includes a cellular telephone that dials the RESCU Response Center in Irving, Texas. Vehicle location is determined through a global positioning system (G PS) receiver in the vehicle. Vehicle position and speed are continuously fed to the RESCU computer, which determines the direction of the vehicle. RESCU can be manually activated through one of two buttons on the overhead console, one for roadside assistance, the other for police or medical emergency. Some systems include automatic activation when an air bag is deployed. Once the system is activated, a voice channel is opened while data are transmitted to the center and displayed on the computer of the person at the service center who talks to the driver. If the driver is unable to speak, the emergency is immediately relayed to 911. The driver can press a cancel button if the system is activated by mistake.

Customer benefit: Safety and security.

2.41 Vision Enhancement System (All-Weather/Night Vision)

What it is: All-weather/Night Vision provides the driver with information about objects in the path of the vehicle that could not normally be seen at night or in adverse conditions. It is especially helpful for identifying pedestrians and anim~ls crossing in front of the vehicle. Some systems also can display information about the roadway, such as the proximity of upcoming vehicles and changes in the road. The information is generally displayed in the driver's normal field of vision.

How it works: All-weather/Night Vision systems can use radar or infrared lights/receiver on the front of the vehicle. Data are fed into a computer which continually processes the information and creates an image displayed in front of the driver. Potential capability includes ability to distinguish between other vehicles or obstructions and non-threatening objects, redudng the possibility of false alarms.

Customer benefit: Safety and improved vision at night or during adverse conditions.

2.42 Voice Activation

What it is: Voice-activated control Systems allow the occupants to use voice commands to control a variety of vehicle systems and features. Voice activation works with such features as cellular telephone, audio system. navigation, climate control and other electronically controlled Systems. At present, primary controls and those crudal to safety are not candidates. Voice-activation systems can reduce acddents by minimizing the time the driver's hands are off the wheel and eyes are off the road.

How it works: Voice-activated control systems interface with other systems through multiplexing networks. Voice commands are processed by the computer and an appropriate signal sent to the commanded device. The system is designed to work with any spoken voice, without requiring training for each user. By comparison, current voice-activation systems for cellular phones are able to recognize only a small number of commands and must be trained to recognize the voice of the user.

Customer benefit: Potential safety advantage and improved convenience.

3. HISTORY OF TRACTION CONTROL SYSTEMS

If the accelerator pedal is used excessively when driving on slippery road surfaces, such as snowy roads, the driven wheels start to spin and the vehicle does not travel as intended by the driver, or the steering wheel jerks to one side and the vehicle becomes unstable, something that is often experienced by people driving in snowy areas. It was largely because of such road surfaces which provided only a small frictional force between the tyres and the road surface that four-wheel-drive (4WD) systems came to be used, in order to compensate for this insufficient traction force.

Incidentally, insufficient frictional force on snowy roads is an obstacle to driving safety more during braking than during normal driving. As four-wheel-brake systems are now implemented on virtually all vehicles, preventing the vehicles from locking in order to absorb efficiently the energy of movement of the vehicle when braking, while also maintaining handling performance, became an important implementation feature. To achieve this, first , anti-lock brake system (ABS) technology was taken from technology used in the aircraft industry and adapted, with actual application in vehicles beginning in the last half of the 1970s in Europe, and in Japan from the beginning of the 1980s. A short time after the introduction of ABS, traction control systems (TCS) that prevented the driven wheels from spinning were and publicized in the early part of the 1970s as a technology that was as important as ABS. However, this technology was finally implemented in a real way only after the application of the ABS electronic control technology in road vehicles, and was commercialized during the mid-1980s in Sweden, which was one of the major centres of research into vehicle safety.During this period, four-wheel-steering (4WS) technology independently developed in Japan to improve accident-avoidance capabilities, and electronically controlled 4WS was also being implemented. In addition, electronically controlled technology for vehicles that began with ABS has thrust itself into the age of fully fledged control technology using digital computerization during the latter part of 1980s.

TCS began with engine control, but has been expanded and developed over time to cover a variety of types of systems utilizing the drive transmission system and the brake system, and was implemented in Europe and Japan at almost exactly the same time. On the other hand, 4WS research was one of the triggers that revived research into vehicle dynamics. This did not only mean linear handling performance, but also covered research into driving performance and braking performance in order to investigate the full range of the vehicle performance in detail. The end of the 1980s saw the birth of TCS and electronically-controlled 4WDs that took into account handling performance using traction control technology, and also active suspension that controlled steering characteristics using four-wheel load control technology. Specifically, this was used as a means to fontrol faces acting on the tyres. Indeed, 1980s were dawn of the age of control of the vehicle dynamics by computer.

However, because controls in each field covering the whole range of vehicle dynamics performance were developed independently, almost no consideration was given to the framework of an overall system, and some important effects were overlooked. Also, as these control systems were expanded while this state of affairs still existed, the relationship between the driver and the vehicle became more and more complicated, resulting in the problem that vehicles with fewer advantages were created. Thus, it is evident that there is a need to investigate an overall control theory that considers comprehensive vehicle dynamics. This theory includes people and vehicle systems that are called total control or cooperative control.

At the beginning of nineties, two unique systems for traction control appeared from what seem to be opposite directions. On the hand, there was the "lateral acceleration regulation" type TCS that aimed for a brand new improvement in driving stability, and than there was the "driving pleasure" type automatic transmission that skillfully attempted to make the driver's task easier. There two systems hint at the future of traction control and an overall theory for vehicle dynamics.

In addition, in line with the pursuit of higher levels of vehicle performance, it has also became evident that TCS does not fully correspond to the pattern of the originally intended "foolproof" application control, which could take the steps to recover from mistakes made by the driver. An example of this is where the reduction in the load on the inside wheels during lateral acceleration turning is relatively quicker than the turning movement of the vehicle. In this case, the wheels soon start to spin and the transmission of drive power in order to come smoothly out of the turn would not be possible, or the TCS control operates too quickly and the vehicle movement characteristics desired by the driver could not be obtained. Furthermore, there are also cases of impetus being applied by transient movement with complex time lags over a non-linear range in suspension systems, an area which is always seeing continual improvement, and in the reductions in surplus camber angle due to the recent increased flatness of tyres. Moreover, if tyre performance under dry conditions is targeted, then performance under wet conditions or on snow-covered surfaces will be affected relatively easily. This has not been done for the reason that TCS will be effective only on snow-covered roads.

Thus, in line with improvements in vehicle performance, TCS could not provide complete control logic within the range of a single physical quantity such as wheel rotating speed. If this is termed "micro-control" then it has become necessary to estimate the "macro" driving view, i.e. vehicle movement, and apply this to the control logic. This can also be referred to as progression to a stage where control logic should be extended from a mechanism to prevent wheel slippage to a vehicle TCS. As a part of the man-vehicle-environment relationship and as one of the control systems implemented in vehicles, TCS can be said to be moving from the field of traction performance to provide assistance in the harmonization between the whole of this relationship.

3.1 Steering and Braking

The goal of the ABS systems is to maintain the steerability of the car even during excessive braking and under different road conditions. Also the stopping distance should be minimized.

If during a braking maneuver wheels are locked up, both deceleration and steerability are worsen.The reason for this is shown in Fig.3.1. ABS-systems are able to avoid locked wheels and so guarantee optimal stopping distance and directional stability. An ABS-System consists of a hydraulic modulator, an ECU and at least 3 WSS (wheel speed sensors).

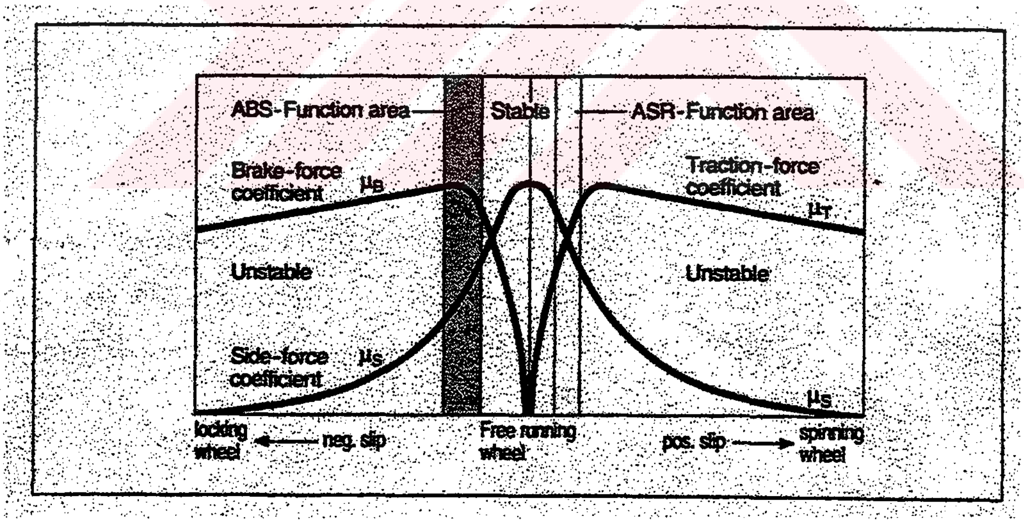


Fig 3.1 Brake-, traction- and side-force coefficient over wheel slip

3.2 Traction Control as a Basis for Vehicle Dynamic Control

Marrying chassis and powertrain controls promises to bring dramatic improvements to vehicle mobility and safety. Traction control serves as the first chassis control system that brings interaction between vehicle subsystems, namely powertrain and brakes. It greatly improves vehicle stability and maneuverability on slippery surfaces and provides a necessary foundation for more sophisticated vehicle dynamic control.

Motor vehicles are generally well behaved on dry pavement under normal handling maneuvers. For operation in these conditions, noticeable improvements to vehicle handling can be made by increasing body stiffiess and enhancing the passive behavior of the vehicle's suspension. However, these improvements fall far short when arbitrary road conditions such as ice and snow are coupled with unpredictable driver behavior. Often under these conditions the vehicle will behave in a manner that is unexpected by the driver, especially if the driver is not used to driving under these circumstances. Such behavior includes the inability of the vehicle to accelerate, brake, or comer on a slippery surface as well as it's tendency to spin out of control during extreme maneuvers. Automatic controls are capable of forcing the vehicle to behave more uniformly despite the uncertainty in driving conditions and driver behavior. This increase in uniformity is beneficial to both driver comfort and safety, and provides the impetus for vehicle dynamic control.

Vehicle motion is caused almost entirely by forces generated at the tire/road interfaces. These tireforces are a function of tire normal forces, the angles at which the tires are pointing, and the rotational speeds of the tires. Tire normal forces are controlled by a vehicle's suspension, tire slip (steering) angle is controlled primarily by the steering system, and the rotational speed of the tire is controlled by the powertrain and brakes. The most sophisticated vehicle dynamic controller would have authority over each of these subsystems as well as complete knowledge of the dynamic state of the vehicle and the driver's intentions for the vehicle's behavior. It could then determine the difference between the actual vehicle state and the driver's intent and, through control actuation, attempt to force this difference to be zero. Such a system would be highly sophisticated as well as expensive, and is currently mostly in the research stage. However, an effective starting point on the way to achieving this ideal control system is in establishing control over the rotational speeds (longitudinal slip) of the tires using powertrain and/or brakes. Such a system is called a traction controller and is usually limited to the sensor set normally available to the powertrain and ABS systems.

Given the goal of an ideal vehicle dynamic controller, the objective of a traction control system follows. First, the controller determines the vehicle's dynamic state and the driver's intention. This is accomplished using available sensor signals which include wheel speeds, accelerator position, and vehicle yaw rate (typically derived from wheel speed signals). Appropriate driven wheel speed targets are then produced and the available subsystems (powertrain and/or brakes) are controlled in an effort to meet these targets. Stated concisely, the objective of the traction control system is to produce appropriate driven wheel speed targets and to meet these targets through closed loop control.

In practice, determining driver intent and targeting wheel speed is a matter of properly maintaining the tradeoff between driven wheel lateral and longitudinal forces based on a small set of measurements. In a typical traction control system, knowledge of driver intent can only be inferred from accelerator position and vehicle yaw rate (based on the difference between non-driven wheel speeds). Accelerator position indicates a driver's desire to accelerate and yaw rate indicates the degree to which the vehicle is turning. The relative magnitude of these signals determines the tradeoff made between longitudinal and lateral tire forces.

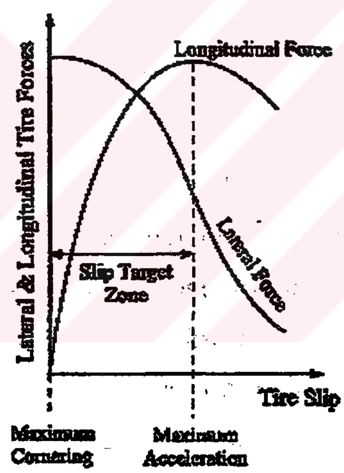


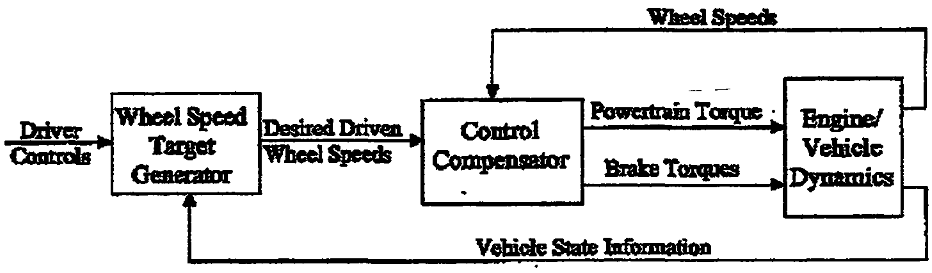
Figure 3.2 Tire Force Characteristics

Figure 3.2 depicts tire forces generated as a function of longitudinal slip for an arbitrary steering angle and road surface friction. At low slip, the longitudinal force is low as compared to the lateral. This relationship is reversed at higher slips. At very high slips the longitudinal force passes its maximum value and begins to decrease. Operation beyond this maximum longitudinal force point is of no value.

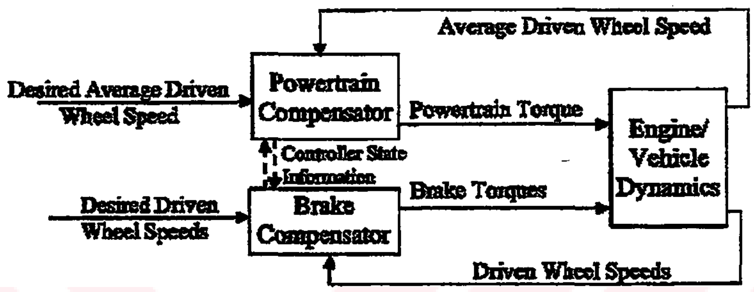
When the vehicle is involved in hard cornering (large yaw rate as compared to the vehicle's longitudinal speed) the desired driven wheel speed is targeted to produce low tire slip and therefore higher lateral tire forces. When large accelerator pedal positions are present and the vehicle yaw rate is low, larger slip levels are targeted to produce larger longitudinal forces.

The relationship between lateral and longitudinal tire forces is largely effected by road surface friction (μ). Properly targeting wheel slips requires estimation of mu which is conducted using drivetrain state information. Typically, lower μ surfaces produce maximum longitudinal forces at lower slips. μ can also vary widely under individual wheels. Therefore, μ estimation is important for traction control. One final tradeoff made during slip target generation involves driver perception of the traction control system's performance. To control wheel speeds, TC systems that use engine intervention cut engine torque, causing the engine to slow down and reducing the volume of the exhaust note. This gives the subjective impression that the vehicle has slowed down or is not accelerating well, when in fact it may be accelerating as much as possible for a given μ.

Meeting a wheel speed target involves controlling the torque applied to the driven wheels using powertrain and/or brakes. The control torque used is a function of the error between the desired and actual wheel speeds, and the torque applied to a driven wheel is given by the difference between the torque added by the powertrain and the torque removed by the brake. If the road surface friction is the same for both driven wheels, no brake intervention is necessary since an open differential maintains equal torque at the driven wheels. In this case, all torque management can be conducted using powertrain control. However, if the road friction is substantially different under the driven wheels, brake application is necessary (assuming the vehicle has an open differential) to produce the different torques which can be supported by differing surfaces under the driven wheels. Since brake intervention results in higher transmission loads and increases brake wear, proper powertrain management is important. However, brake intervention alone can be used to do traction control for both uniform and split μ cases. Typically, brake-only systems can operate only at low vehicle speeds and are prone to shutdown due to brake overheating. Engine-only TC systems are limited to applying the same torque at each driven wheel and result in less than optimal performance on split μ surfaces. The combination of powertrain and brake intervention provides the best system performance.



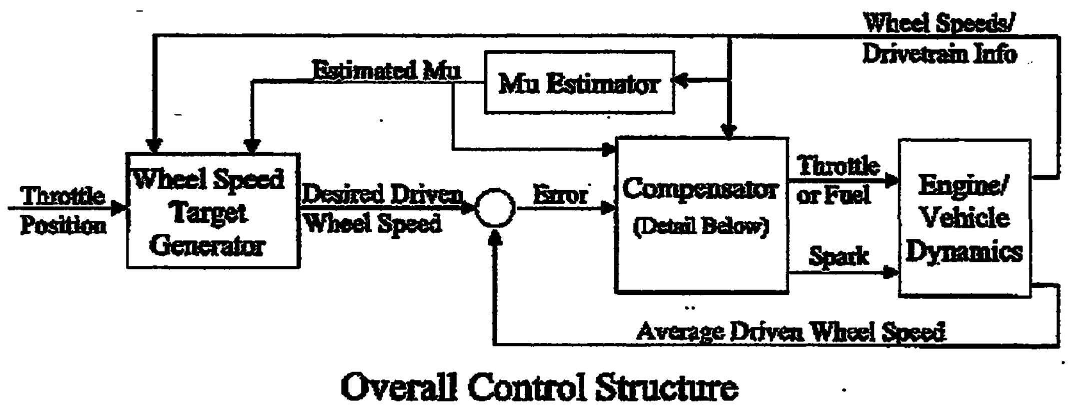
Generic Traction Control Compensator



Partitioned Compensator

Figure 3.3 Generic and Partioned Traction Control Compensation

In a generic sense, the traction control compensator takes as its input two desired driven wheel speeds and produces three desired torques, these being the powertrain (transmission output shaft) torque and two brake torques. Such multiple-input, multiple-output controllers can be difficult to design and tune properly. However, the control compensator can be simplified by partitioning its function into two separate compensators, one handling powertrain and the other handling brake. Traction control can be conducted in this manner with little interaction between the compensators. Partitioning the control function is achieved by giving the powertrain compensator the task of meeting a desired average driven wheel speed, while the brakes are used to contain large differences between the driven wheel speeds. Thus, the powertrain controller operates alone during uniform μ operation and is aided by the brakes only in the presence of split μ. Figure 3.3 depicts the generic control structure as well as the partitioned one. It is useful for each compensator to be aware of the other's operating mode (i.e. split μ, etc.), and they pass information back and forth to accomplish this.



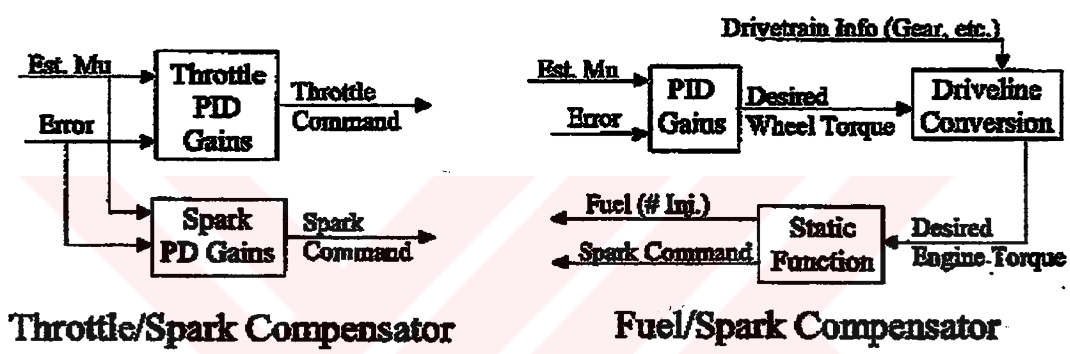


Figure 3.4 TC Control Structure with Detail of Throttle/Spark and Fuel/Spark Compensators

Given the traction control compensation partitioning described above, the overall powertrain compensator is constructed as shown at the top of Figure 43. The compensator's input is the average driven wheel speed error, which is the difference between the driven wheel speed target and the actual average driven wheel speed. Since it controls the powertrain, possible compensator outputs could include throttle angle (series throttle or full authority throttle), cylinder fueling (both on/off and air/fuel ratio control), spark timing, transmission control (shifting as well as single and double clutching) alternator loading, AC pump control, and variable cam timing. Currently, experience within Ford includes throttle, spark, and fuel control and indirect control over transmission shift timing through PCM strategy tuning. In practice, engine controls are usually paired as either throttle/spark or fuel/spark.

Figure 3.4 also shows the compensator structures for the throttle/spark (T/S) and fuel/spark (F/S) cases. The throttle's control over engine torque is substantially slower than the spark's control. This leads to the use of two sub-compensators in the T/S system, one for each actuator. Spark control in the T/S system is used primarily at the beginning of a TC event and where large transient control is most needed. This reduces the possibility of problems relating to catalyst temperature and combustion stability caused by prolonged spark retard. In the F/S system, the controller produces a desired driven wheel torque based on driven wheel speed error. This desired torque is converted to a desired engine torque using the current transmission gear ratio and torque converter boost. The proper spark advance and number of cylinders fueled are then determined using a static mathematic relationship based on engine mapping data. The commanded spark advance and number of live cylinders are adjusted if catalyst damage becomes a concern. The only tunable portion of the compensator is that which produces the desired wheel torque based on error. In both the T/S and F/S settings, the control compensators adjust their gains based on mu and transmission gear.

There are several pros and cons for each of the two engine control arrangements. Throttle/spark control is very smooth and quiet, and it has no impact on vehicle emissions. However, the T/S compensator is typically more complex since it has more gains, and a series throttle is expensive and is difficult to package. Also, spark retard, which has control over the high frequency system dynamics, lacks full authority over engine torque. The fuel/spark system is faster and much less expensive, it allows direct axle torque commands which is more intuitive for the designer, and it is available to all powertrains. However, it suffers from poor NVH, especially on ice and snow, it is capable of stalling the engine if not designed well, it has a negative effect on engine emissions, and it may require additional engine controls (apart from the traction control compensator).

In a *powertrain/brake traction controller* with powertrain and brake controls partitioned as discussed earlier, the brake control compensator can be constructed as shown in Figure 3.5. Here, the compensator inputs are the desired driven wheel speed errors, and the outputs control the pump and the various valves in the ABS/TC system. Control action is primarily focused on the valves which build and dump brake caliper pressure at the driven wheels. Because the brakes in a powertrain/brake TC system are used only during a split mu event, valve actuation can be limited to only one driven wheel (the low μ wheel). This further simplifies the controller.

Due to a lack of direct measurement, several vehicle system states/parameters may require estimation. These include vehicle yaw rate, road surface friction coefficient, and longitudinal vehicle speed.

Vehicle yaw rate is proportional to the difference in non-driven wheel speed when the vehicle is not severely under or over-steered. As described above, this estimated yaw rate is useful for determining the amount of tire slip needed to sustain lateral traction during a given turning maneuver. Because traction control systems generally do not have vehicle lateral acceleration or steering wheel angle information available to them, they are incapable of determining whether the vehicle is spinning out and therefore cannot provide direct vehicle yaw stability control. When such signals are provided and used properly, the resulting control provides greatly enhanced vehicle stability. Ford refers to such a system design as Interactive Vehicle Dynamic (IVD) control.

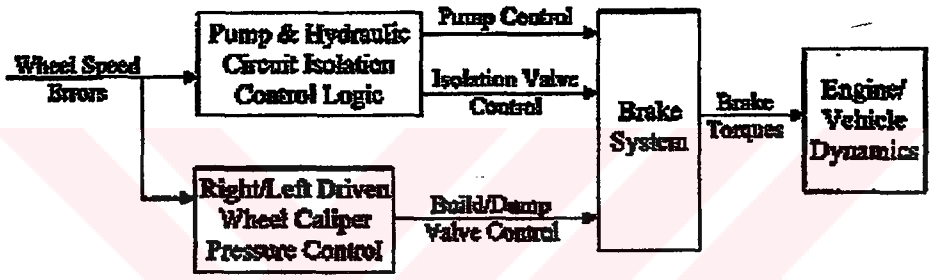


Figure 3.5 Brake compensator structure

Measurement of road surface friction (μ) is necessary for proper targeting of driven wheel speeds as well as scheduling controller gains and resetting the TC compensator at the beginning of a TC event. μ is defined as the ratio of tire longitudinal force to tire normal force. Normal force is known with sufficient accuracy from the curb weight of the vehicle. Tire longitudinal force is determined by estimating wheel torque using speed/load information from the PCM and accounting for dynamic torque losses due to engine and powertrain inertias.

Knowledge of vehicle longitudinal speed is necessary for the conversion of desired driven wheel slips to desired driven wheel speeds. All traction control systems have at least an average driven wheel speed signal available through the transmission output shaft speed sensor or by similar means. Systems limited to this signal are usually powertrain only TCs. Those TC systems which include brakes have two driven wheel speed signals available and usually two non-driven wheel speeds as well. Vehicle speed is proportional to non-driven wheel speed. Therefore, when average or individual non-driven wheel speeds are available, a direct measurement of vehicle speed is also available. In the case of a 4x4 application or in a system where non-driven wheel speeds are not available, vehicle speed must be estimated. This is accomplished by first estimating the torque at the driven wheels using powertrain information (as described above). The estimated torque is then integrated (using an appropriate vehicle mass) to estimate vehicle speed. Determination of vehicle mass and proper resetting of the vehicle speed integration are conducted when the vehicle is coasting. Preliminary results regarding vehicle speed estimation show that it works well, and due to the robustness of the FRL TC controller, straight line TC performance using an estimated vehicle speed signal is nearly indistinguishable from performance with an actual measurement.

With the availability of an average driven wheel speed signal (for example transmission output shaft speed) and reasonably accurate vehicle speed estimation, a low-cost engine-only TC system can be applied to any vehicle.

Although 4x4 vehicles are known for inherently improved traction, some performance improvements are still available with the addition of traction control. A 4x4 vehicle can spin all four wheels on ice and snow, compromising both longitudinal and lateral handling. However, engine only TC can reduce these spins, improving vehicle maneuverability. Depending on transaxle design, further improvements may be available with the addition of brake control. Such a system represents the upper limit in TC system functionality as well as cost.

3.3 Analysis of Traction Control Systems Augmented by Limited Slip Differentials

Traction Control Systems (TCS's) are becoming increasingly present in today's automobiles. These systems strive to improve the traction and stability charcteristics of the vehicle by actively contolling wheel slip. Limited Slip Differentials (LSD's) offer a passive method (no control system required) of improving the traction and stability of the vehicle,by appropriately proportioning wheel torque. This paper will investigate the compatibility of these two approaches by demonstrating the function and performance of various LSD/TCS combinations.

3.3.1 Optimal Traction Utilization

The conditions which cause a need for traction control (snow, ice, mud...) are generally non-homogeneous in nature. In these situations, the road surface can be characterized as a constantly varying "split μ". A simple split μ across an axle is described in Figure 3.6

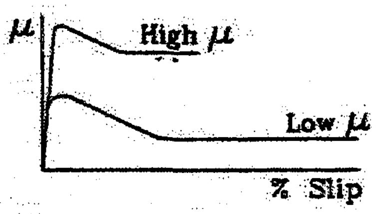


Figure 3.6 – a simple μ across an axle

These curves describe the relationship between the road surface and the tires. Actual operating conditions can fall anywhere on these curves. Maximum available traction can be described by the sum of the peaks.

Figure 3.7 outlines the expected operating conditions for several vehicle configurations. The acceleration case for as a open differential with no Traction Control System is depicted in the first graph, labeled "standard". The low micron wheel spins up reducing its coefficient of friction. The amount of torque delivered to the high micron wheel will be approximately equal to that the low mşcron wheel and thus is will utilize only a portion of the available traction.

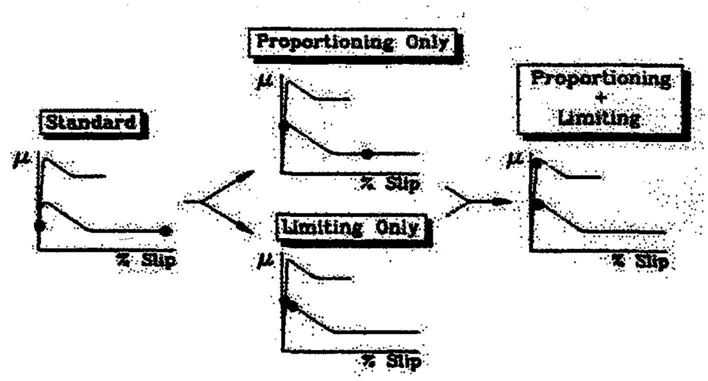


Figure 3.7 The expected operating conditions for several vehicle configurations

One why to improve the use of available traction is to proportion it. Since there is more traction available at the high micron wheel, more torque should be sent there. In the case of proportioning only, drive torque steel has the potential to exceed that available at the low micron wheel, causing this wheel to spin. However, due to the proportioning, total traction utilization has increased. This means that amount of drive torque the wheels can accept has increased.

Another why to improve the use of traction is to limit the amount of torque delivered to the wheels. Drive torque in excess of that sustainable by the available traction at the low micron wheel will go into accelerating that wheel. By limiting the torque, the effective low micron can be optimized at or near the peak. The open differential provides a torque balance between the two axles, and thus the effective micron at the high micron wheel will be increased as well.

From the final graph of Figure 3.7 it can be seen that in this situation, optimal use of available traction requires both proportioning and limiting.

In general LSD's can proportion but cannot limit. Engine TCS systems can limit but cannot proportion. Brake TCS systems are capable of propotioning and limiting.

3.3.2 Common LSD Technologies

In general, Limited Slip Differentials are passive devices which proportion torque through the generation of an axle torque difference (ΔT). Types of LSD's can be divided into two categories: torque sensing and speed sensing. Torque sensing differentials make use of mechanical friction, and thus can generate ΔT independent of wheel speed difference (Δn). Speed sensing differentials require the development of a wheel speed difference in order to actuate.

3.3.3 Performance Comparison

From our model, a side by side comparison between Brake Traction Control and Engine Traction Control, with each of the different differential, was possible. Split μ result were obtained from the normal driver model and the wet driveway sealer/drive pavement surface.

Time to Distance – Time to 15 meters was calculated for each TCS-differential combination. These results are summarized in Fig 3.8.

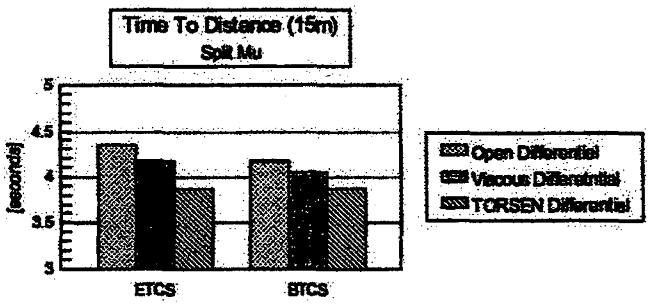


Figure 3.8 Performance results

Both of the LSD's provide improvement in time to distance. Torque sensing differentials have a greater synergy with Traction Control Systems that Speed sensing, and thus the Torsen differential showed the best results.

Average μ - Slip Conditions-_The instantaneous μ can fall anywhere on the μ-slip curve. Where it actually falls depends on the TCS-Differential Combination. From the split μ acceleration data, the average μ and average slip ratio were calculated for each simulation. The actual μ-slip curves used are shown for reference. Due to nonlinear nature of the curves, the time averaged points will not necessarily fall directly on them.

The torque sensing Torsen differential showed the least wheel slip and the greatest usage of available traction with both the ETCS and BTCS.

The average μ values for the left and right wheels were added together and are shown side by side in Figure 3.9

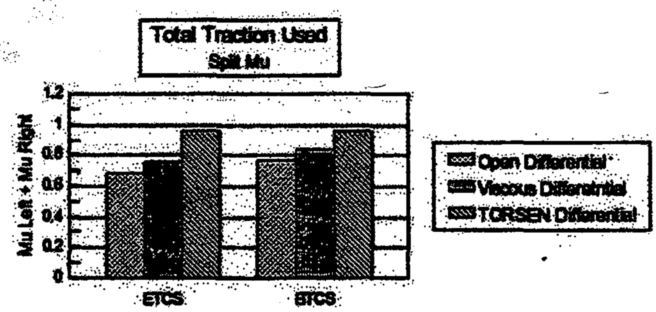


Figure 3.9 The average μ values for the left and right wheels

Brake Traction Control is able to both limit and proportion torque, and thus with an open differential it made better use of available traction than the ETCS wheel open and viscous differentials. The Torsen differential made the Engine Traction Control System better than BTCS with an open and viscous differential, and as good as BTCS with a Torsen differential.

Test data and computer models to investigate the interaction of Limited Slip Differential and Traction Control Systems are presented. The following are major points from this analysis:

Situations requiring Traction Control can be classified as needing Torque Limiting, Torque Proportioning or both. Torque Proportioning can be obtained through the use of a Brake Traction Control System or a Limited Slip Differential. Torque Sensitive LSD's (Such as the Torsen Differential) have a greater "synergy" with TCS than Speed Sensitive LSD's (Such as viscous differentials).This is because Torque Sensitive LSD's can provide TBR without wheel speed difference and, thus without wheel slip. LSD's were seen to reduce the duty cycle of both the engine and brake TCS Systems in split-μ, and in some cases eliminate the need for actuation. LSD's were seen to reduce or even eliminate hunting on equal- μ with Brake TCS. This translates to reduced NVH and improved driver perception of system control. In all cases, the performance of TCS+LSD was greater than or at least equal to the performance of TCS + open. A Torsen Differential can make the performance of an Engine TCS as good as or better than that of a brake TCS with an open differential in most split μ situations.

3.4 Development and Analysis of New Traction Control System with Rear Viscous LSD

Traction control Systems (TCSs) serve to control brake pressure and engine torque, thereby reducing driving wheel spin for improved stability and handling. Systems are divided into two basic types by the brake control configuration. One type is a one-channel left-right common control system and the other is a two-channel individual control system. This paper presents an analysis of these two types of TCS configurations in terms of handling, acceleration, stability, yaw convergence and other performance parameters. The systems are compared with and without a limited-slip differential (LSD) under various road conditions, based on experimental data and computer simulations. As a result of this work, certain Nissan models are now equipped with a new Nissan Traction Control System with a rear viscous LSD (Nissan V-TCS), which provides both the advantages of a rear viscous LSD in a small slip region and a two-channel TCS in a large slip region. As a result, this system works to improve traction, stability and overall performance under various road conditions.

Nissan was an early pioneer of rear viscous coupling type limited slip differential (rear viscous LSD) technology, which it incorporated in rear-wheele cars to improve their cornering performance and traction. Today, a number of manufacturers are outfitting their upscale models with traction control systems (TCSs), which are intended to make driving easier by improving vehicle stability under difficult driving conditions, for example, during rapid acceleration on a slippery surface.

This system combines the benefits of both approaches in that the rear viscous LSD is employed to enhance the basic capabilities of a vehicle while TCS is used to make driving easier. The system employs both a rear viscous LSD and a two-channel individual brake torque control mechanism to deliver appropriate amounts of engine torque to the rear driving wheels. The result is noticeably improved traction and cornering performance. In practical use on a slippery road surface, the system automatically adjusts the throttle opening to a level appropriate for the road conditions, thereby avoiding a situation where excessive engine torque is transmitted to the rear wheels, which could result in wheelspin. By improving rear wheel traction in this manner, the system enables the driver to maintain good control of the vehicle, while relieving him of the stressful task of controlling engine speed through accelerator inputs.

3.4.1 Effect Of Rear Viscous LSD On Driving Performance

Characteristics of viscous LSD:

Viscous LSD technology is already being used in many production models and has been discussed extensively in the literature. When a rotational speed difference occurs between the input and output shafts, a viscous LSD increases the limited differential torque in proportion to the difference in rotational speeds. The design parameters that determine the limited differential torque include the viscosity and fill rate of the silicone fluid used in the viscous coupling and the diameter and number of plates that are encapsulated in the fluid. Figure 3.10 shows changes in torque transfer characteristics in relation to changes in the shear rate produced by varying the viscosity of the silicone fluid.

In terms of its construction, the left and right driving axles are connected to the input and output shafts of the viscous coupling unit. In this case, the rotational speed difference between the left and right driving axles, $\Delta N = |\omega_L - \omega_R|$, is equivalent to the difference in rotational speeds between the input and output shafts of the viscous coupling. The limited differential torque to the left and right axles, ΔT, can be given as a function of ΔN, as indicated in Figure 3.10

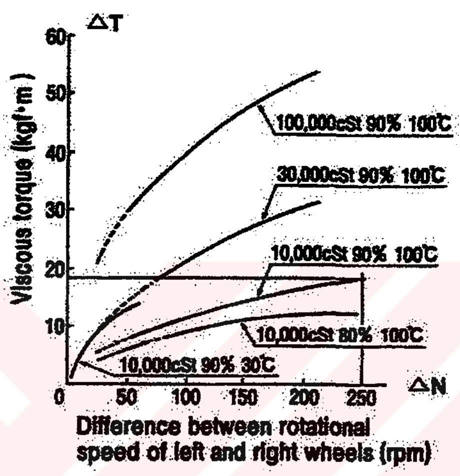


Figure 3.10 Characteristics of viscous coupling

Effects of rear viscous LSD on vehicle dynamics:

Among the various effects that a limited-slip differential has on vehicle dynamics, one of the most important is the moment in the yaw direction, M_{LSD}. As seen in Figure 3.11, this moment originates in the difference in driving force between the left and right wheels a result of the operation of the LSD. The following discussion describes the effects of a rear viscous LSD on typical indices of vehicle dynamics.

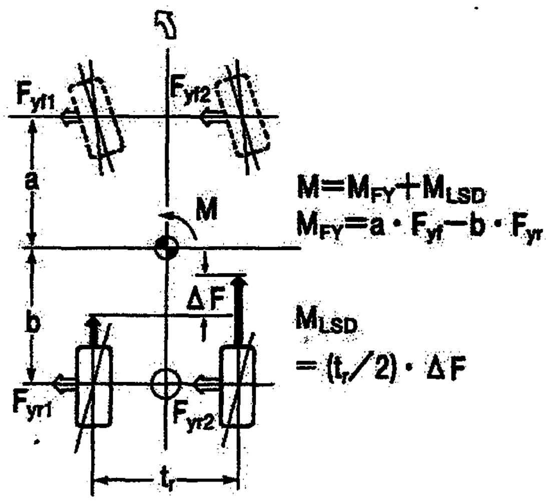


Figure 3.11Yaw moment

Cornering performance:

Under a steady-state cornering condition where lateral acceleration and driving force are not large, the driving wheel on the outside of the turn rotates faster than that on the inside, according to the concept of Ackerman steering geometry. In the case of a conventional differential, engine torque is split equally to provide the same level of driving force at both the left and right wheels at all times. In contrast, a viscous LSD directs more engine torque to the inside driving wheel which is rotating at a slower speed. Accordingly, M_{LSD} always acts in the direction of the turn and in the opposite direction. As a result a viscous LSD gives a vehicle a stronger understeer tendency under a steady-state cornering condition (Figure 3.12), making it possible to improve vehicle stability. Following the same line of thought, when changing lanes at a steady speed M_{LSD} acts in both the turning and opposite directions, thereby increasing the vehicle's tendency to understeer and improving yaw convergence as a result.

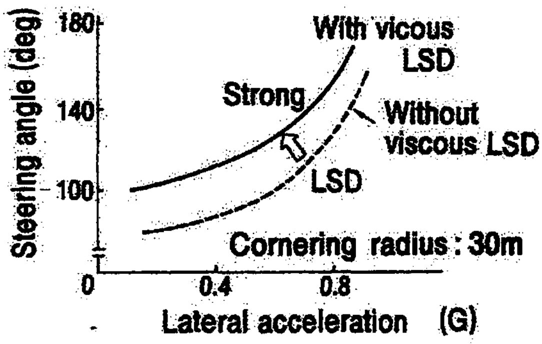


Figure 3.12 Comparison of Handling

Tuck-in performance

When a driver lets off on the acceleratbr to decelerate a vehicle while cornering under a condition of high lateral acceleration, the resulting increase in braking acceleration causes a load shift from the rear to the front wheels. As a result, the moments generating side forces at the front and rear wheels become unbalanced (Figure 3.13), and the vehicle shows an oversteer characteristic. At this time, the wheel load at the inside rear wheel decreases. due to the effects of a load shift induced by body roll or braking, resulting in a tendency for the wheel to lock. If that happens, its side forces decrease. In the case of a conventional differential, there is equal braking force at the left and right wheels and the moment generating braking force is equal to zero. In contrast, a viscous LSD functions to reduce the difference in rotational speeds between the left and right rear wheels. The application of limited differential torque serves to prevent the inside rear wheel from locking. As a result, the side forces at the inside rear wheel increase, and the moment generating braking force at the left and right rear wheels shifts toward the minus direction. By strengthening the understeer characteristic of a vehicle, a viscous LSD works to avoid wheelspin and contributes to increased stability.

Cornering performance on high μ surface:

Consider a situation where a driver accelerates while cornering under a condition of low lateral acceleration. When the vehicle reaches a high lateral acceleration state, the effects of body roll cause the load at the inside rear wheel to decrease, resulting in eater slip . As a result, the driving force at the inside wheel levels off. With a conventional differential, the outside rear wheel also experiences slippage and its driving force peaks, causing the vehicle to reach its acceleration limit more quickly. In contrast, a viscous LSD reduces the driving torque to the outside rear wheel that is slipping. The limited differential torque works to suppress slipping of the outside rear wheel, enabling the vehicle to deliver higher acceleration performance during cornering which exceeds the acceleration limit of a conventional differential .

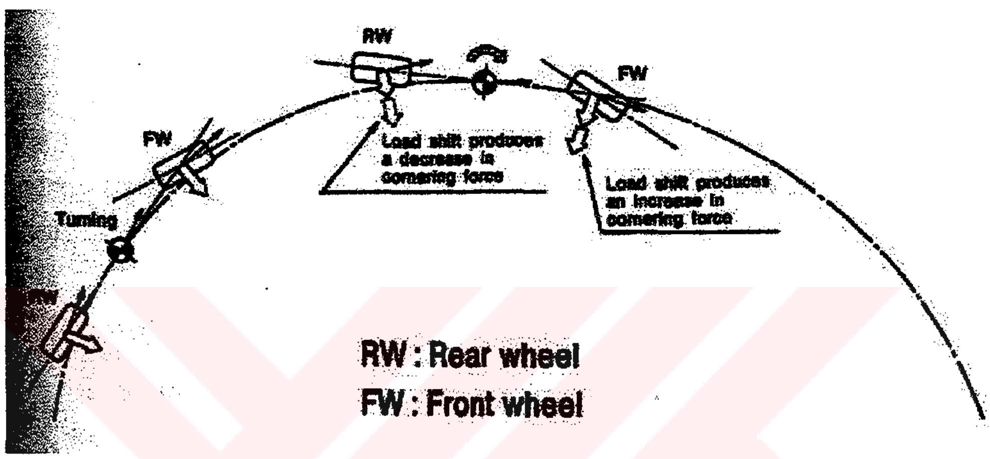


Figure 3.13 Tuck-in Behavior

In the case of a viscous LSD, the limited differential torque saturates near the cornering performance limit, i.e., in the region where there is a sufficiently large difference between the rotational speeds of the left and right rear wheels. This makes it possible to obtain cornering performance that strikes a balance between acceleration during cornering and yaw rate changes.

High-speed stability:

When traveling at high speed a vehicle should provide sufficient yaw convergence and stability against external disturbances, such a crosswind or inputs from an irregular road surfase. Since a viscous LSD has an inherent convergence mechanism for reducing rotational speed differences between the left and right driving wheels. M_{LSD} works to cancel out moments generated by external disturbances The comparison is based on time histories of changes in physical quantities that reflect vehicle behavior. The data on the yaw rate, lateral acceleration and steering angle correction all indicate that the vehicle with the viscous LSD provides better stability owing to the good yaw convergence achieved with M_{LSD}.

Traction:

The effects of a viscous LSD are especially evident on split-μ surfaces where the friction of coefficient nf the road surface differs between the left and right wheels. Figure 3.14 illustrates a hypothetical situation where a road surface is clearly split between high and low μ levels. In the case of a conventional differential, only that portion of the engine torque which is appropriate to the low friction road surface is used effectively as driving force, and the excess portion is consumed as wheelspin. This means that the driving wheel on the high friction side receives only the same level of driving force as its counterpart on the low friction side. In contrast, a viscous LSD generates limited differential torque in real time when the left and right driving wheels start to rotate at different speeds. A portion of the engine torque that would otherwise be directed to the faster revolving wheel on the low friction side is transmitted instead as limited differential torque to the high friction side. This enables the engine torque to be used more effectively because it serves to increase the driving force on the high friction side.

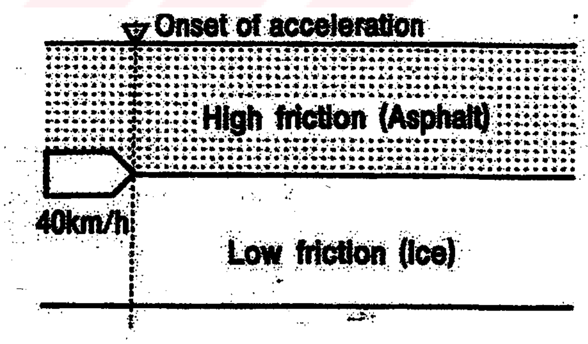


Figure 3.14 Stability on Irregular Road Surface

3.4.2 Investigation Of Combined Effect Of TCS And rear Viscous LSD

It was seen in the previous section that a viscous is more effective than a conventional differential improving high-speed stability and tuck-in performance, in addition to providing better traction on road surfaces with varying coefficients of friction as well as improved cornering performance. However, pite its recognized effectiveness in a small slip region, a viscous LSD is not fully effective in a large region where both driving wheels experience slip. A traction control system, on the other hand, is capable preventing the kind of large slippage that occurs on Slippery surface when the driver presses strongly on the accelerator. By helping to maintain vehicle stability under such conditions, TCS thus makes a vehicle easier to drive.

An investigation was made of the effects of combining TCS, which is effective in a large slip region (i. E., when actual wheel slippage exceeds the slip control threshold value), and a viscous LSD, which is effective in a small slip region (i. E., when actual wheel slippage is below the threshold value). The following discussion will first describe performance differences related to the differential based on a comparison of a TCS provided with a conventional differential and one provided with a viscous LSD. The differences due to combinations with different brake pressure control systems, i.e., either one- or two-channel configurations, will also be described. Then, the performance differences between one- and two-channel TCS configurations when used with a viscous LSD will be presented. These comparisons are based on the results of road tests and simulations carried out under various driving conditions.

Effects of viscous LSD in combination with TCS:

A computer simulation was conducted in which it was assumed that a vehicle was accelerated while traveling on a split- μ road surface, where the effects of a viscous LSD are most pronounced. Four types of vehicles were examined in the simulation:

(1) Conventional differential + one-channel TCS

(2) Conventional differential + two-channel TCS

(3) Viscous LSD + one-channel TCS

(4) Viscous LSD + two-channel TCS

For the sake of simplicity, the two-channel systems were assumed to provide completely independent control over the left and right wheels. The simulation conditions were a split-μ road surface (high μ=1.0; low μ=0.1) and a step-like acceleration input from a driving speed of 40km/h. (Figure 3.14)

Performance differences due to TCS control system:

The foregoing discussion has clarified the benefits of a viscous LSD and the effects of a viscous LSD on TCS performance. This section will examine differences in performance between one- and two-channel TCS configurations when used together with a viscous LSD. Low and high friction surfaces will be considered separately to clarify the differences for different traction conditions.

Performance differences between TCS systems on low friction surface:

A simulation was conducted in which it was assumed that a step-like steering input was applied during straight-line acceleration (Figure 3.15). The purpose of this simulation was to examine performance differences in relation to stability during cornering, which is the major objective of TCS.

During acceleration while cornering, the driving wheel on the inside of the turn begins to slip owing to its smaller wheel load. With the two-channel TCS, the driving force of the outside wheel increases at that time owing to the LSD effect of single-side braking when brake control is applied to the inside wheel. With the one-channel TCS, brake control is applied to both the inside and outside wheels simultaneously at the time slip occurs, resulting in a noticeable loss of driving force at the outside wheel. Consequently, a vehicle is more likely to show an oversteer tendency with the two-channel system because of the traction moment around the center of gravity . On the other hand, since the two-channel TCS quickly suppresses the slipping of the inside wheel independently, it limits the reduction in side force due to wheel slip. In contrast, since the slip suppression effect of the one-channel TCS is smaller, side forces are reduced more. In other words, a vehicle with the two-channel TCS is more apt to show an understeer tendency because of the side force moment around the center of gravity.

In driving on ordinary low friction surfaces, i.e., excluding extreme situations of acceleration on split-μ surfaces, there is virtually no difference in braking control timing between the one- and two-channel systems. This is related to the fact that the viscous LSD renders the driving wheels nearly rigid (rpm =0).

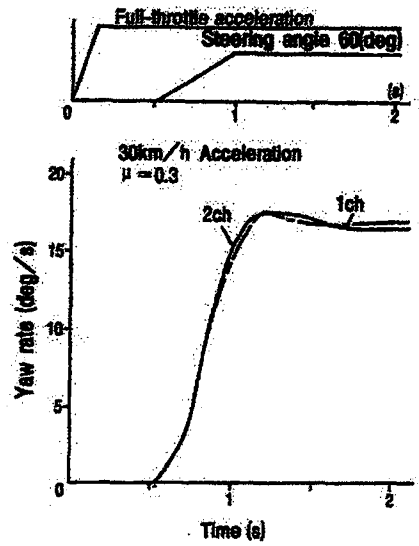


Figure 3.15 Stability in lane changes

A comparison of stability in terms of the yaw rate indicates that both the one- and two-channel systems provide the same level of performance, even though the yaw rates differ slightly (Figure 3.15).

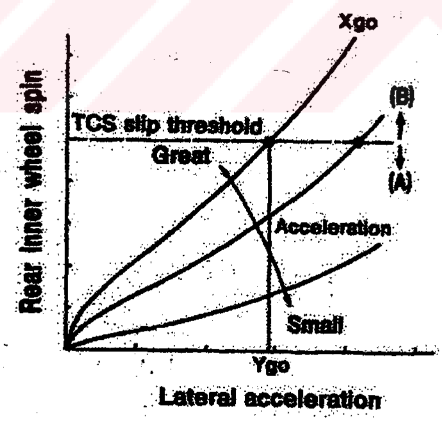


Figure 3.16 Inner wheel spin

When a viscous LSD is used, there is little overshoot. This indicates that a viscous LSD provides good yaw convergence during cornering.

Performance differences between TCS Systems on high friction surfaces:

Figure 3.16 shows a slip situation that occurs while accelerating during cornering under a certain level of lateral acceleration. Considering an ideal TCS, region (A) is the performance domain of an ordinary rearwheel.drive car equipped with; a viscous LSD. Region (B) is a performance domain that cannot be obtained with a TCS. This is because it is impossible to attain lateral acceleration greater than Y_{go} from a condition of longitudinal acceleration X_{go}. In addition, under a condition of lateral acceleration Y_{g_0} it is impossible to obtain longitudinal acceleration greater than X_{go}. This means that slip above the dashed line cannot be allowed. Given the allowable amount of slip that will still maintain stability on a low friction surface, acceleration capability peaks under a state of high lateral acceleration and the vehicle cannot be accelerated as desired. An investigation was made of the differences in performance between the two types of TCS under a high lateral acceleration condition when the allowable slip level was set higher than the limit for assuring vehicle stability on a low friction surface.

A driving test involving the execution of an inverse J-turn test was conducted as shown in Figure 3.17. This test was designed to evaluate differences between the two TCS systems in terms of cornering acceleration and the vehicle's ability to trace a target line. The course consisted of a semicircle segment (A → B → C) and a straight away segment (C → D). Between points A and B, the vehicle executed a steady-state turn under lateral acceleration of 0.6 G. Full-throttle acceleration was applied at point B. During cornering acceleration between B and C, an evaluation was made of the vehicle's ability to trace the target line as the driver made steering corrections as needed. At point C, a steering correction was executed to change the vehicle's orientation from cornering to straight-line travel. Between points C and D, an evaluation was made of acceleration performance coming out of a turn and of yaw rate convergence as the vehicle's orientation changed from cornering to a straight-line path.

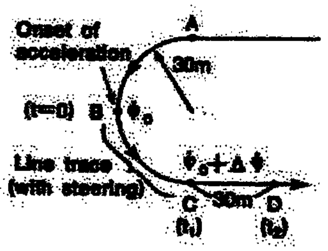


Figure 3.17 Stability in J-turn

Figure 3.17 compares the vehicle behavior obtained with the two systems between B and C when the vehicle was accelerated as indicated above. The dashed reference line indicates the relationship between a yaw rate change induced by a steering correction (constant turning radius) and the time required to travel between the two points. Above the reference line the turning radius increased (oversteer) as the vehicle was accelerated and below the line it decreased (understeer).

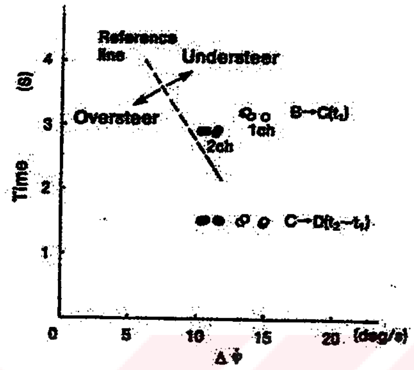


Figure 3.18 Comparison of acceleration and tracking performance

The results indicate that the two-channel system provides better tracking capability, as the turning radius stays closer to the target line even when steering corrections are made. In addition, cornering acceleration is better with two-channel control, as the time required to travel from B to C is slightly less than with the one-channel system.

In evaluating vehicle behavior between C and D, i.e., the transition from cornering to a straight-line orientation, better convergence is obtained as the yaw rate approaches 0 degree/second at the time the vehicle resumes straight-line travel. With two-channel control, the yaw rate is smaller than with the one-channel system and is also more stable, as it shows less variation. As for acceleration performance, no difference is seen between the one- and two-channel systems.

From the foregoing results it can be concluded that the two-channel system provides better tracking capability and acceleration performance when a vehicle is accelerated while cornering on a high friction surface. The reason for this can be explained as follows. Even on a high friction-road surface, body roll occurs during cornering under a condition of high lateral acceleration. As a result, the load at the inside driving wheel is reduced causing the wheel to slip. As the engine torque becomes larger, even a viscous LSD cannot effectively suppress the slipping of the inside wheel.

It can be concluded, therefore, that the difference in performance of the two TCS control configurations on a high friction surface is determined by the driving force of the inside and outside rear wheels. Twochannel control improves a vehicle's tracking capability becauce the weaker understeer characteristic requires smaller steering angle corrections. Two-channel control also allows better acceleration performance than the one-channel configuration because it enables the gripping outside wheel to use the driving force more effectively.

3.4.3 Nissan Traction Control System

The foregoing discussion has shown that a synergistic effect can be obtained by combining a viscous LSD, which enhances the basic performance of the chassis, and a TCS, which supports the driver's ability to control the vehicle and thereby improves ease of operation. As a result, the cornering performance, stability and traction of a vehicle can be enhanced on all types of road surfaces (Figure 3.19). These are precisely the improvements that are provided by Nissan's new traction control system, the Nissan V-TCS. The construction and features of the system are explained below.

The Nissan V-TCS combines a viscous LSD with a traction control system. The latter consists of the following components: wheel speed sensors, TCS controller, throttle controller, throttle actuator, TCS brake hydraulic unit, TCS operation indicator and TCS warning indicator. The layout of the components in the vehicle is shown in Figure 3.19.

Wheel speed sensors:

Each wheel is equipped with a speed sensor that measures the rotational speed.

TCS controller:

The controller evaluates wheel spin, road surface condition and operating conditions based on signal inputs received from the wheel speed sensors and other sources. It then outputs command signals to the TCS brake hydraulic unit and throttle controller to provide traction control appropriate to the vehicle's present status. It also incorporates the control function for four-wheel ABS to provide integrated braking and traction control. This controller is provided with self-diagnostic and fail-safe functions. When trouble is detected, the warning indicator in the cabin lights, the system control over the throttle and brakes, and it diagnoses the failure location.

Table.1 Benefits of V-TCS

		Traction on slippery road surfaces	Traction on irregular road surfaces	Stability in lane changes	Cornering tuck-in stability	Crosswind stability
V-TCS	Engine control	◎	○	○		
	Brake control	○	◎	◎		
	Rear viscous LSD	◎	◎	◎	◎	◎

◎ : More effective ○ : Effective

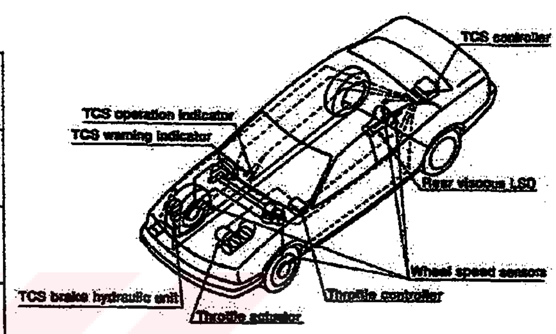


Figure 3.19 Benefits of V-TCS & vehicle layout of V-TOS

Throttle controller:

Based on the command signal received from the TCS controller, this controller outputs a signal to drive the throttle actuator which optimally controls the opening of the sub-throttle. This controller also incorporates a fail-safe function and self-diagnostics. If it detects a problem in the throttle control system, it alerts the TCS controller to release control of the throttle immediately .

Throttle actuator:

This actuator provides analog control over the opening of the sub-throttle according to the command signals received from the throttle controller anA thereby modulates engine torque. The sub-throttle is positioned upstream from the main throttle which is controlled by the driver's accelerator inputs.

TCS brake hydraulic unit:

Based on signals received from the TCS controller, this hydraulic unit provides optimum control over the slip ratio of the left and right driving wheels by increasing, maintaining or decreasing the brake pressure at each wheel.

TCS operation and warning indicators:

When the TCS system is operating, the operation indicator alone illuminates to alert the driver to the fact that the road surface is slippery and that the vehicle is approaching its critical limits. If the fail-safe function is activated, the TCS warning indicator also lights to tell the driver that the TCS system has been deactivated. The driver can turn off the TCS system by pressing the ON/OFF switch on the instrument panel. In this case, only the TCS warning indicator is illuminated.

During acceleration in a low slip region (i. e., below the TCS threshold value) and under steady-state driving conditions, the viscous LSD automatically works to suppress rotational speed differences between the left and right driving wheels. This benefit of the viscous LSD results in better acceleration, stability and improved yaw convergence.

In a large slip region (i.e., where TCS is activated), the TCS is effective in providing improved stability and acceleration by suppressing slip, while at the same time the benefits of the viscous LSD are also obtained.

3.5 The Corvette Acceleration Slip Regulation (ASR) Application With Preloaded Limited Slip Differential

The 1992 Corvette Acceleration Slip Regulation (ASR) system manufactured by Bosch Corporation, functionally integrates engine spark retard, a throttle cable relaxer and brake intervention to provide optimized acceleration and vehicle stability. The physical integration of the respective components was accomplished as follows: a) ABS and ASR hydraulics were combined by adding four hydraulic valves to the ABS 2U brake hydraulic modulator, b) the throttle relaxer combined a DC motor, connector spring, cams and cables, c) a spark retard table added to the engine control module (ECM) and d) three microprocessors were combined into one ECU , which houses the Bosch control strategies.

The ASR system developed for Corvette is capable of simultaneous or separate usage of engine torque control and brake intervention. There are vehicle speeds and road conditions where engine torque will be utilized without brakes to improve vehicle stability. Also there are wheel acceleration rates whereby brake intervention will be used to control wheel spin. The ASR hydraulics will control individual rear wheel pressures, a change from the ABS "select low wheel" hydraulic control. One affective engine torque control method is to restrict the air inlet. Corvette uses a cable extension mechanism to close the throttle during ASR control modes. Third system provides the driver with accelerator pedal feedback during excess wheel slip control modes, and reduces engine torque. Fast engine torque reduction, for short durations, are accomplished using an optimized method of spark retard. The degree of retard is tailored to reduce excess temperatures and increase drivability. Brake application is a slow and less brake application is effective at slow speeds during excess wheel spin. With individual rear brake control it is possible to utilize the traction available on split coefficient road conditions and improve acceleration. During ASR control mode, the ECU automatically controls the brakes, without driver intervention; however , the driver must still steer the car.

A switch allows the driver to turn the system "off" and "on". The system default to the "on" position after ignition recycle.

3.5.1 ASR Components

The '92 ASR requires several new components as well as integrating some new features into existing components. They are as follows; see Figure 3.22.

NEW COMPONENTS: (1) Throttle relaxer, DC motor and cam assembly, (2) Revervoir tube from master cylinder to motor pump, (3) Off-mode switch (passive), (4) Module for splicing into TPS signal, (5) Cruise control disconnect relay, (6) ASR telltale lamps; service, active, off.

3.5.2 Components With New Integrated Features

1.Pedal cable with adjuster

2.Throttle body cable with adjuster

3.T.V Cable with adjuster & progressive cam opening

4.Cruise control cable with cam slug end.

5.Master cylinder& reservoir, with fluid level float and switch, and positive opening center valve in the rear brake chamber

6.Separate brake pipes for left and right rear calipers

7.Electronic control unit with 55 pin connector, new microprocessors for hydraulics, throttle close down and spark retard.

8.Wiring harnesses with new routing and connectors

9.Hydraulic module with two rear brake isolation valves, master cylinder isolation valve, pressure relief valve and reservoir isolation valve.

10.Accelerator pedal with positive stop.

CARRY-OVER COMPONENTS-Four wheel speed sensors and tooth gears.

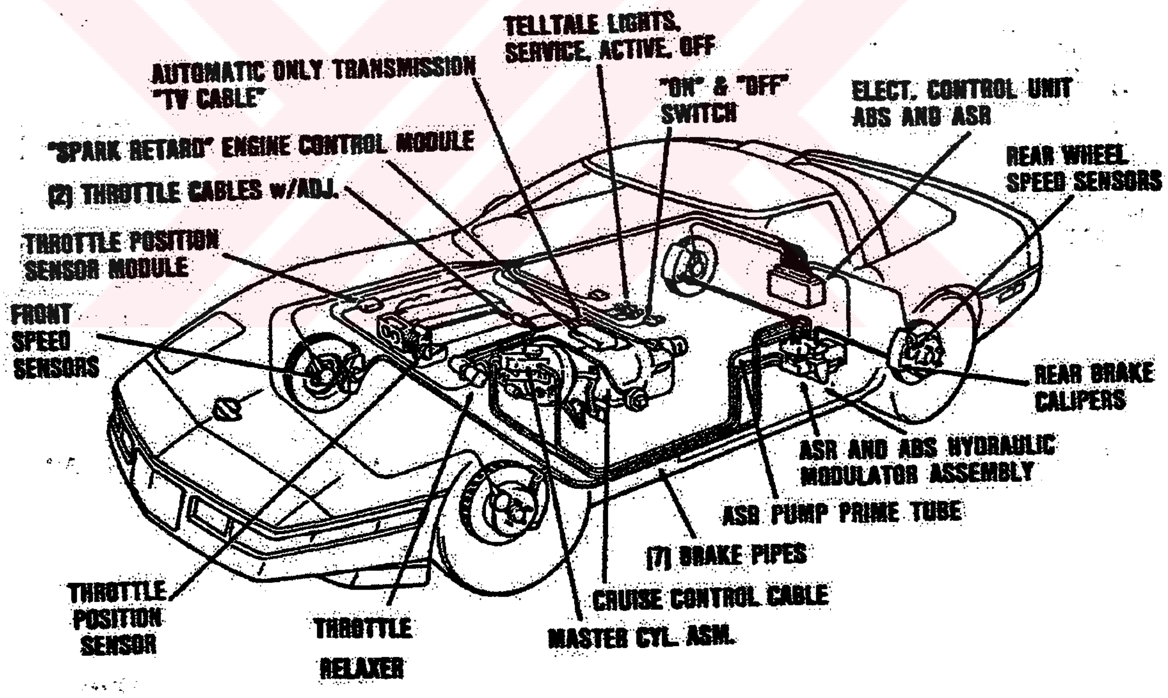


Figure 3.20 Corvette 1992 ASR& ABS

3.5.3 ASR Control

The ASR performs a number of functions during ASR control mode. The driver's accelerator pedal demand can be over-ridden to decrease throttle. The

ABS/ASR electronic control module monitors the four wheel speed sensors. When the rear wheel speed exceeds the front speed by a predetermined value contained in the control algorithm, ASR control is enabled. (1) A signal is transmitted to the spark advance which reduces engine torque. Continuous monitoring of wheel speeds by the electronic control module determines if there is still excess rear wheel speed. (2) If so, the throttle relaxer closes the throttle to further reduce engine torque. (3) The electronic control module also contains ASR control logic to apply the appropriate rear wheel brake pressure. This is accomplished by energizing the modulator motor pump assembly and actuating the appropriate valves to reduce exceeds wheel spin. (4) The throttle position is determined from the signal provided by the TPS module. (5) During ASR, cruise control is disabled and "ASR ACTIVE" telltale is illuminated in the driver's information center. (D.I.C) The electronic control unit disables the ASR control in a progressive manner when the rear wheel speed approaches front wheel speeds. The spark is ramped back to the base spark table, the throttle is ramped back to the drivers desired throttle position, the brake solenoid valves and motor pump are de-energized. The active lamp is disabled. The driver must resume cruise if the cruise system was engaged prior to the ASR event.

3.5.4 Effect Of Preloaded Limited Slip Differential With ASR

The corvette is a front engine rear drive vehicle and does not use the conventional open differential. The standard equipment differential is the Dana limited slip differential with preloaded clutches at each side gear. The manual transmission vehicles use model 44 with a 216mm ring gear 2.5:1 clutch bias. The automatic vehicles use the model 36 with a 197 mm ring gear 2.2:1 clutch bias. Each side axle clutch pack is preloaded to 216/271 Nm. The conventional rear axle is designed to average the speed and equalize the torque to each wheel. Engine torque is split equally to provide the same tractive torque to each of the wheels. The affect of the preloaded clutches is to prevent side to side speed differences until the preload is exceeded by the tractive forces.

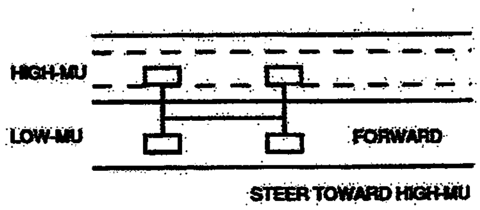


Figure 3.21 Slip coefficient surfaces

Preload torque can be overcome in turns when the inside and outside wheels turn at different speeds or during acceleration on split coefficient surfaces. The dynamic torque transfer resulting from the side gear separating forces will reduce the speed of the spinning wheel while transferring additional torque to the opposite wheel, which in turn increases traction forces. Among the many effects a preloaded limited slip differential has on vehicle dynamics is that both rear wheels will slip when the clutch preload torque is greater than the tractive torque. When both rear wheels have excess slip the lateral forces used to stabilize the vehicle are also reduced.

Vehicle stability and acceleration can be enhanced by controlling excess wheel spin with ASR system having engine torque management and a two channel rear brake hydraulic system. The limited slip differential reduces the amount of ASR brake pressure required to reduce wheel slip on coefficient surfaces.

3.5.5 ASR Performance On Split Coefficient Surfaces

Performance comparison with and without ASR on split coefficients dry asphalt and wet jennite are shown in Figure 3.22. The performance without ASR is dependant upon driver skill and can make it very difficult to make meaningful comparison. Also, wet jennite has a significant amount of variation due to water depth, wind, and drying time between runs. However, accepting all of these variables, the ASR out performed the skilled driver.

3.5.6 ASR Performance On Wet Epoxy

Performance comparisons with and without ASR on wet epoxy are shown in Figure 3.23. As mentioned before, the performance without ASR is driver skill dependant and a skilled driver can closely approach the performance with ASR. The difference is the workload and stress imposed upon the driver not using ASR. And, of course, the unskilled driver now has capability approaching a very skilled driver.

3.5.7 Cornering Performance With Limited Slip Differential (Lsd)

During steady state cornering, at less than max lateral capability, and with partial throttle, the outside driving wheel rotates faster than the inside driving wheel, therefore overcoming the LSD preload. A limited slip differential (LSD) will then direct more engine torque to the inside driving wheel which is rotating at a lower speed. For example, with a preload of 271 Nm. and rear axle weight of 761 Kg, μ must be greater than 0.19 g. As a result of the moments about the center of gravity (C.G.), LSD gives the vehicle a stronger understeer tendency, during steady state cornering, making it possible to improve vehicle stability.

However, this may not hold true on high μ surfaces at max lateral acceleration and wide open throttle (WOT). A high HP front engine vehicle with rear drive can oversteer if the weight shifts to the outside wheel, unloading the inside wheel and allowing the inside wheel to have excess slip. During this limit condition, the LSD transfers more torque to the outside wheel, causing an increase in the yaw moment around the C.G. With excess engine torque the LSD cannot effectively suppress the spinning of one wheel. The lateral forces used to stabilize the vehicle are also reduced with a spinning wheel. The driver is required to make a steering input to stabilize the vehicle. However, inside wheel lift is not the case for Corvette. Due to the ratio of the front to rear roll stiffness, to lift the inside wheel requires lateral acceleration greater than 1.0g. We enhanced vehicle control by eliminating excess wheel spin with ASR. The control system having engine torque management and a two channel rear brake hydraulic system, provides the means for acceleration slip regulation and gives vehicle an understeer tendency.

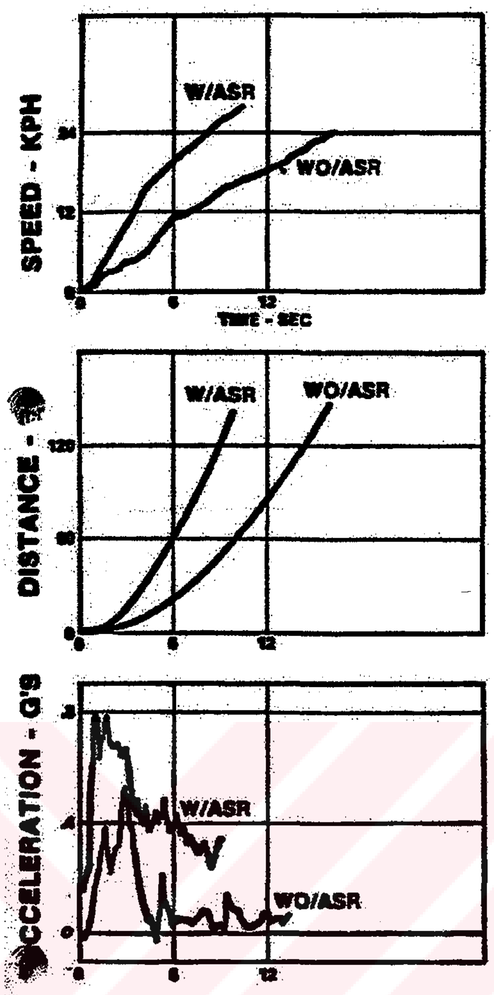


Figure 3.22 Split coefficient performance dry asphalt & wet jennite

3.5.8 ASR And Vehicle Stability

A vehicle's stability results from the interaction of the tires and the road. The vehicle trim has been previously defined is SAE J670e "the vehicle operating condition within a given environment, and may be specified in part by steer angle, forward velocity, and lateral acceleration." Any one of these factors can change the vehicle's behaviour. The vehicle stability must be examined separately for each environment and trim. Neutral stability exists at a prescribed trim if, for any small temporary change in disturbance or control input, the resulting motion of the vehicle remains close to, but does not return to, the motion defined by the trim. Asymptotic stability exists at a prescribed trim if, with small temporary change in disturbance or control input, the vehicle will approach the motion defined by the trim.

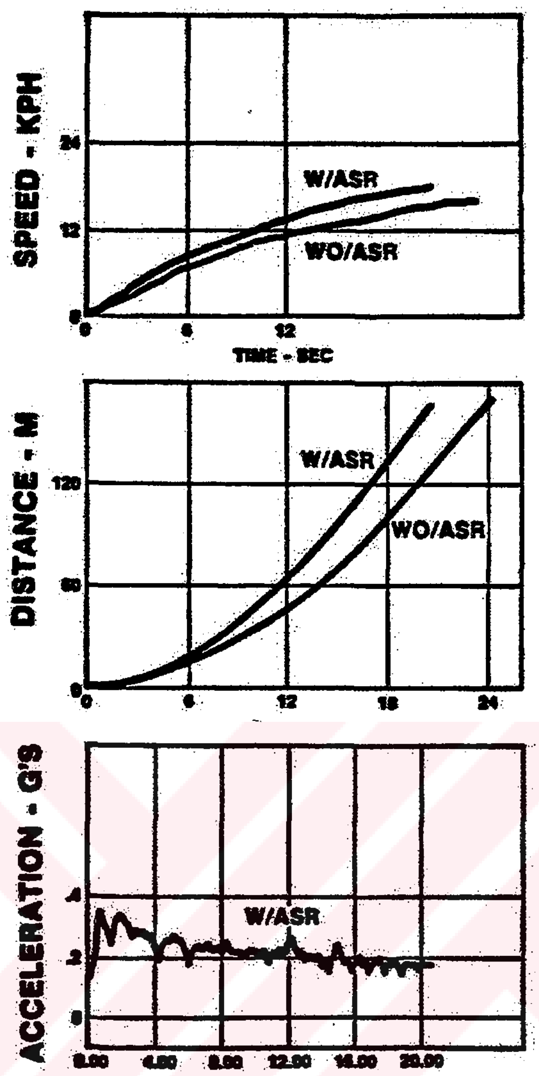


Figure 3.23 Both drive wheels on wet epoxy

Since a vehicle is three dimensional, what affects stability is sometimes confusing : ie, wheel loads, lateral and tractive forces. During excess wheel slip, there are less lateral forces available to stabilize the rear end of the rear end of rear wheel drive (RWD) vehicle. ASR control is enabled after the excess wheel slip exceeds the threshold for the reference speed. ASR does not guarantee neutral or asymptotic stability, due to the fact a vehicle can be stable under one set of conditions and unstable in another. This can be explained as follows:

1) On split-μ, where it is applied more traction to the high-μ wheel, the vehicle yaw's toward the low-μ requiring a small amount of steering input to stabilize the car.

2) Acceleration in a turn when at the limit of lateral capability, reduces the lateral forces on the drive wheels, allowing yaw around the center-of gravity. The amount of yaw results from the road coefficient, centrifugal force, steer angle and driver reaction.

3.5.9 Vehicle Dynamic Analysis

The rear axle torque difference produced in a turn by a limited slip differential results from one wheel turning faster than the other. This torque difference creates a yawing moment on the car that acts in a direction to oppose the yawing velocity or turning rate. For example, in a right turn, the outside rear wheel travels faster, imparting higher torque to the inner wheel, producing a CCW moment to oppose the CW turning moment. This is considered a "damping moment". Miliken Reseach Associates examined the significance of the damping moment produced from torque bias by comparing it with the yaw damping moment produced by normal tire cornering forces. Their findings showed the effects of differential torque bias are most important when lateral acceleration is less than 0.2 "g".

3.5.10 Quick Throttle Release In A Turn

Further studies conducted by Miliken Reseach Associates included modeling analysis at higher lateral accelerations an quick throttle release in a turn. They did a comparison of a LSD and OCD (open-center-differential). The "drop throttle" engine drag torque was varied from 133 to 540 Nm. As the drop throttle torque increases, two things happen: (1) the load is shifted more forward, (2) the torque on the lightly loaded inner wheel approaches the maximum friction force on that wheel and it starts to spin up. For a LSD, if the inner wheel becomes the faster wheel, the differential attempts to switch torque to the outer wheel. This decreases the torque on the inner wheel. Because of the complexity of the LSD in high lateral drop throttle conditions, the modeling did not go beyond incipient spin of the lightly loaded inner wheel. Corvette requires the damping moment of the LSD for high lateral and high coefficient quick throttle release conditions. It assists the driver in vehicle control.

Miliken's studies showed vehicle lateral acceleration at low friction and quick throttle release torque is less for LSD when compared to OCD, because of the loss of lateral force on the inner rear wheel. At high friction and high lateral acceleration, LSD improves vehicle response, decreases side slip angle & reduces yaw rates because the inner wheel spin does not occur.

3.5.11 Throttle Control System

The function of the throttle control system is to pull the throttle open and signal the automatic transmission of the throttle demand. The system is activated either by the driver pushing the accelerator or by cruise servo actuation. With the incorporation of ASR, the driver demand can be over ridden "only" to decrease throttle opening. The main components and operation are as follows see Figure 3.24.

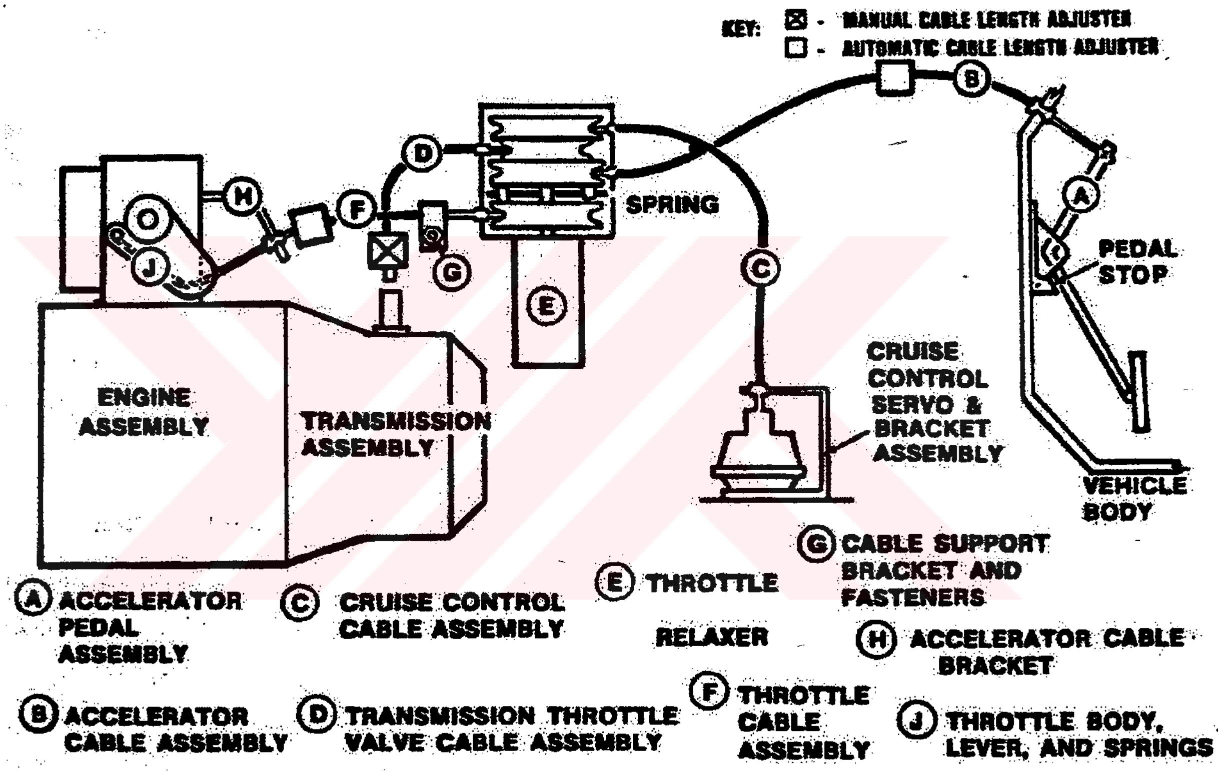


Figure 3.24 Throttle control system

Accelerator Pedal Assembly: The accelerator pedal assembly translates driver pedal load to cable. For ASR, a pedal stop has been added to assembly to reduce over travel (beyond wide open throttle) which could overstress the throttle relaxer linkage spring and transmission throttle valve (TV) cable spring.

Accelerator Pedal Cable Assembly: The accelerator pedal cable assembly translates driver demand from the pedal to the throttle relaxer. This cable incorporates an automatic cable length adjuster, which coordinates the accelerator pedal WOT (wide open throttle) stop to the throttle relaxer. Adjusting the cable to stop reduces throttle relaxer over travel and limits load that can be transmitted to the TV link.

Cruise Cable: The cruise cable transmits the cruise system demand from the servo to the throttle relaxer. This cable is adjusted the same as today, by inserting a pin on the cable end terminal into one of six holes on the servo blade and securing it with a J-clip.

Automatic Transsmission Throttle Valve Cable: The automatic transmission throttle valve cable, (TV) transmits throttle position from the throttle relaxer to the transmission. It must be adjusted so that WOT at the throttle relaxer corresponds to WOT in the transmission. The cable adjuster is a manual type which means that a spring in the adjuster body applies force to the conduit while the button is depressed.

Throttle Relaxer The throttle relaxer is a DC motor driven cam and gear device and gear device that reduces throttle when electrically commanded by the ECU, while the driver demand can be un advisably high. The relaxer is installed in series with the cable assemblies. It contains three cable cams, linkage spring, drive gears, and an electric motor. The outer most cable cam is the cruise cam. It is design to be inert unless the cruise system is operating. During cruise mode it will contact and rotate the accel/TV cam.The accel pedal cable and the TV cable attach to a one piece dual sheeve cam. The TV cam has a .8 ratio. The linkage spring provides a torsional preload holding the accel/TV cam to the throttle cam. See Figure 3.24. The throttle cam pulls the throttle cable. The drive gear when driven by the relaxer electric motor contacts the throttle cam and forces it towards the idle position. The drive gear is spring loaded to the WOT position.

The Throttle Cable: The throttle cable transmits driver demand from the throttle body. The throttle body has an integral automatic cable length adjuster to synchronize WOT at the throttle relaxer.

The Throttle Control Logic: The control logic to close the throttle and reduce engine torque is provided by the ECU. Actuation time from wide open to closed throttle is approximately 250ms at the room temperatures of 20 degrees Centigrade. The cable end fittings provide foolproof alignment of cables and cams. A plastic cover is removable for service. There is a special adjustment procedure required to insure that the transmission shifts properly and that the throttle reaches WOT. Due to the dual sheave TV pedal cam, the TV cable does not follow the throttle body position, as it does on previous models. This prevents cyclic transmission shifting during ASR mode.

Hydraulic Modulator: The hydraulic modulator has a DC motor driven pump with seperate circuits for front and rear brakes. The pump has a dual purpose; during ABS it transfers fluid from the wheel brake calipers back to the master cylinder, and during ABS it transfers fluid from master cylinder reservoir to the rear wheel brake calipers. Therefore wheel slip can be optimized by controlling brake pressure during deceleration and acceleration, with improved vehicle directional stability and traction utilization.

Hydraulic Valves: The ASR portions of the hydraulic circuit were incorporated with ABS hydraulic valves. An additional 3-way valve was added to the rear brakes so that each wheel is controlled separately. This required an additional rear brake line. A hydraulic operated "load valve" is used to isolate the master cylinder line from the pump during brake apply and ABS control. The load valve is spring loaded to the open position (5 bar+2-0). A 2-way "pilot valve" is electronically operated to isolate the master cylinder from the pump during ASR operation. When this valve is cycled closed, the pump can not direct fluid is passed through the "pressure limiting" valve. The ECU (electronic control unit) control the opening and closing of the valves to minimize the fluid volume shift. If there is a fluid or leaking valve during ABS mode, the excess fluid is pumped back to rear brake master cylinder center valve.

Excess Brake Fluid: The master cylinder secondary piston center valve is designed to open with maximum pressure applied. If the driver applies brake pedal force while the pump is attempting to push the excess fluid into the master cylinder, maximum pump pressure could occur. (200 bar), if there was not a positive opening center valve design.

Asr Brake Fluid: The fluid for ASR brake pressure apply is siphoned from the master cylinder reservoir, via prime tube and pump located in the left rear tube. This tube is 6mm O.D. and is routed with the 4.75mm ABS brake pipes. During servicing of the hydraulic modulator, this tube must be purged of air. A bleeder screw is located in the upper block of the modulator, located behind the seat in the left rear tube. The master cylinder reservoirs fitted with seperate chambers, including one for the ASR prime tube and fluid level can affect ASR operation if air were to be sucked into the brake circuit. The fluid level float will illuminate the "brake" light prior to air injection during ASR mode (or pump safety check at ignition on).

Master Cylinder: The master cylinder (m/cyl) was redesigned to allow for additional ASR displacement and incorporation of a new center valve in the rear brake chamber. This resulted in the front brake function positioned in the primary chamber with the rear brake function in the secondary, a change from past Corvettes. The proportioner valve and differential pressure switch design are carried over .The m/cyl dia.is 23.8mm increased from 22.2mm. This 15% increase in area requires a brake pedal ratio change and booster recalibration to obtain a desired subjective brake pedal feel during a stop. The center valve is designed to open when the secondary piston returns to rest. This is accomplished when the center valve pintle contact a cross shaft at the rest position. This ensures that there is pressure relieve in the event of excess fluid being pumped back to the m/cyl. If the driver applies maximum brake pedal force while the ABS pump is returning excess fluid to the master cylinder the pump may develope its maximum pressure. The center valve will relieve this pressure when the secondary piston returns to the rest position.

Fluid Reservoir: The reservoir is simple unit with a screw type cap, small diaphram with air bleed, and a reed type switch activated by a floating magnet. The reservoir has to withstand the evacuation vacuum and 1000 kpa fill pressure at the plant. There is an external nipple provision for an 8mm hose adaption (5mm I.D.). This nipple provides reservoir fluid for the ASR pump via the prime tube. The compact style reservoir will allow single evacuate and fill point for the primary, secondary and ASR prime tube. There is access for a pressure probe to the primary chamber, for repair pressure bleeding at the plant

As special note on the reservoir reminds service personnel to follow the bleed procedure when servicing or repairing the vehicle. The prime tube may require bleeding if air is injected during low fluid. The prevent air from entering the prime tube during low fluid, the ABS pump is disabled.

Low Fluid Switch: Low fluid signal wire requires a diode so there's no feedback from the park brake like circuit. In the event there is low fluid, the red "Brake" like will illuminate and the "SERVICE ASR" and "SERVICE ABS" lights will illuminate. The ABS/ASR will be disabled during low brake fluid conditions. Trouble code 83 corresponds to the low brake fluid signal. When detached during ABS or brake intervention also will shut off after the control function is complete. An electrical filter will prevent a flicker signal to shut down the system.

3.6 Electrical System

The requirements for the electrical system are to interconnect the electrical/electromechanical components, provide a driver interface securely mount the wiring, electrical control unit throttle relaxer, throttle position sensor (TPS) module, relays and necessary fuses.

3.6.1 Electronic Control Unit (ECU)

The electronic control unit physically incorporates two redundant *microprocessor for ABS/ASR and one microprocessor for the throttle adjuster, into* one unit with 55 pin connections. There are 45 pins being used. The ECU logic performs ASR and ABS calculations for control actuations. See Figure 3.25. It does this by actuating the following:

-Brake solenoid valves

-Master cylinder valve

-Motor pump

-Throttle relaxer

-PCM spark retart

-Disengage cruise control & torque converter clutch

The ECU also provides driver information by actuating lamps in the driver information center DIC. The DIC will illuminate amber letters on black background for the following:

-Service ASR

-ASR active

-Service ABS

-ABS active

-ASR off

3.6.2 Engine RPM

The LT1 tach filter signal and LT5 distributor module signal are read by the ECU to determine engine RPM. The ECU looks for a tach signal at 10 kph and if it is missing at a vehicle speed greater than 10 kph, ASR is turned off.

3.6.3 Linear Lateral Accelerometer (LLA)

Revisions were made to the linear lateral accelerometer monitoring. There is an automatic learning function which allows for LLA offsets due to build and manufacturing tolerances. This function starts and speeds greater than 20 kph , and does not continue when the speed and decel are below 20 kph. Therefore the car can be parked on a hill side grade, and it does not affect the learning function.

3.6.4 Rear Brake Intervention

It was discontinued rear brake ASR intervention after the vehicle speed exceeds 80 kph (50mph). Above 80 kph, engine torque control results from spark retard and throttle close down.

3.6.5 Slip Regulation

Logic for slip regulation gets a reference velocity derived from the non-driven wheels. A sophisticated slip threshold calculation considers vehicle acceleration, vehicle speed, cornering and vehicle starts. Select high/Select low (SH/SL) control changes the sensitivity of the brake torque control. During SL (Select low), the driven wheel is being compared with the corresponding non-driven wheel on the same side of the car. SH(select high) the mean value of both driven wheel speeds is being compared with the mean value of both non-driven wheel speeds. During start-up there is math logic to determine if the vehicle is in first gear, and if so, slip regulation is "SH". Above 30 kph the slip regulation is select low. See Figure 3.25.

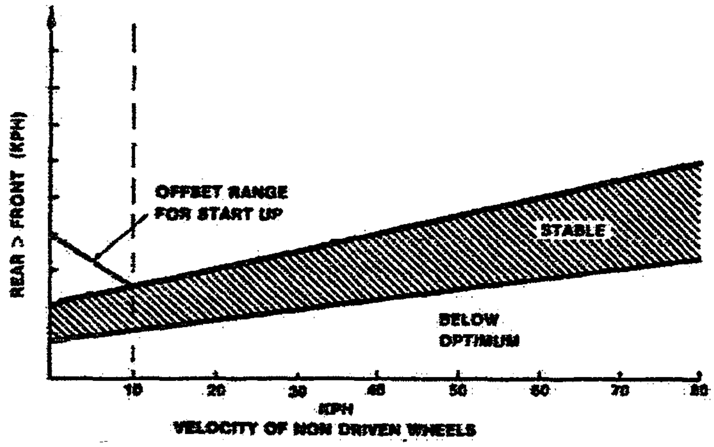


Figure 3.25 Control during excess wheel acceleration typical slip threshold logic contained in the ECU

3.6.6 Learning Idle Position

The production intent logic for learning idle position will include a default idle position, which is upper TPS (throttle position sensor) signal tolerance. In the event of a TPS replacement or throttle body replacement, a special code must be redirected to the ECU so that the zero relearning is initiated. The logic does not allow for learning-up to the TPS upper tolerance level. It does allow for thermal drift adjustments. Also, the learning logic does not allow the "learning-up" in the event of a mechanical restriction, such as not returning to idle. Nor does it learn-up during extended cruising at the same idle position. LT-5 and LT-1 have different TPS tolerances, and therefore require different engine codes in the ECU.

3.6.7 Brake Fluid Level

If low brake fluid in the master cylinder reservoir is detached by the ECU, via the float circuit, the ABS/ASR pump may be shut off. The logic is as follows:

-If detected during ABS, both ABS and ASR systems shut off after completion of ABS modulation.

-If detected during ASR, the ECU shuts off the brake portion immediately, and shuts off ABS and ASR systems after completion of modulation.

-If detected during normal driving, shut off both ABS/ASR systems immediately. If the master cylinder float or reed switch malfunction, this may also cause the "brake" light to illuminate. Since the "brake" light has several inputs, a diode isolates the ECU so only low brake fluid is detected.

3.6.8 Pilot Valve Switching

To prevent fluid volume shift when switching from ASR mode to braking mode, the "pilot valve", which isolates the master cylinder, has certain timer controls. The logic is as follows:

ASR Completed Without Brake Apply: During caliper hydraulic pressure is supplied by the motor pump. After ASR mode is complete, the fluid must be returned to the master cylinder. A flag in the ECU starts a countdown after the ECU determines that no more brake is required and that the pilot valve can switch from ASR to brake apply. During this period, the caliper 3-way valve is positioned from pressure reduce to pressure increase, and the motor relay is turned off.

ASR Followed By Brake Apply: During brake apply the load valve shuts off the prime tube fluid supply. The ECU starts a countdown to when the pilot valve can switch from ASR to brake pressure increase. For several ms (milliseconds) the rear wheel solenoid pressure decreases and the fluid returns through the pump and the pressure regulator to the reservoir. Before the pilot valve switch point, the motor relay turns off and the rear wheel solenoid valve switches to pressure increase.

ASR Followed By ABS Brake Apply: The ECU starts a countdown process for several ms. The rear wheel solenoid is positioned for pressure decrease and immediately following, the rear wheel solenoid and pilot valve are switched to pressure increase. The pump motor relay remains "on".

3.6.9 Brake Lamp Switch (BLS)

The ECU uses the brake switch input to determine if the brakes are applied. This switch signal can disable the brake intervention of ASR, if detected prior to ASR mode. When the brakes are applied the master cylinder reservoir load valve is positioned to block the pump suction line; therefore, the ASR brake intervention cannot occur.

3.6.10 Sticking Throttle

The ECU detects that the throttle did not close. If the TPS value desired at close down was never reached, the ECU detects a failure in the control loop and disables ASR and turns on the "service ASR" lamp.

3.6.11 Yaw Moment Control (YMC)

The purpose of introducing YMC in the ABS algorithm was to assist the driver to maintain vehicle control when braking on split coefficent road surfaces. The strength of the yaw moment control can be tailored to the vehicle. The control of the high mu wheel is mirrored off the control of the low mu wheel. There is no YMC actuation below 50 kph. At vehicle velocities above 120 kph, the front wheels may be controlled with "quasi select low", to improve vehicle control. That is simultaneous control of the front wheel brake pressure on the low and high μ wheels.

3.6.12 Front Tires Hydroplaning

During hydroplaning conditions,the tire has less contact with the road. In the event of a brake apply during hydroplaning, the wheel may react as if on ice. There may be ABS control required and if the front wheel pressure is at the pressure is at the pressure reduce actuation for more than a set time , the ABS logic assumes that the wheel is hydroplaning , and full master cylinder uncontrolled pressure is allowed to the front wheels. This is done to reduce vehicle speed to the extent possible. The pressure in rear brakes remains at the low pressure for a period of time, to improve vehicle stability when exiting the hydroplaning condition.

ASR may also function when the rear-to-front wheel speed differential is exceeded when the front wheel impacts puddles of water or ice slush on the road. The accelerator pedal feedback gives the driver an indication of the road conditions.

3.6.13 Description Of On/Off Switch(Passive Mode)

The ASR on/off switch, located above the headlamp switch assembly, allows the driver to turn ASR "on" and "off". During ASR off (passive mode) the ABS remain functional. "Off" mode is required if the driver desires additional wheel spin during sporty acceleration launches, or if the car becomes mired in mud or snow. A lamp in the driver information center (DIC) indicates to the driver that the system is off (passive). No LED is included at or in the switch. The switch functions as a momentary contact push button, and the system changes between "passive" and "on" each time the push button is pressed. An ignition key cycle will automatically turn on the system. A button failure in the depressed mode can be detected by the ECU. If the switch is held down for 15 seconds or longer, the system automatically defaults to "on"; and cannot be switched to passive without ignition recycle. While ASR is functioning , the driver can press the "off" switch, but the system will not turn off until the wheels are stable. The DIC will illuminate the "off" light immediately when the driver presses the OFF switch. If while the traction control system is in the off mode, the driver presses the on/off switch to turn the system on, the system will turn on immediately..

3.6.14 Description Of Tri-Mode Cruise Control Disable:

A double throw relay turns "off" the tri-mode cruise control during an ASR actuation, and turns "on" the "ASR active" lamp. This circuit requires an active high sourcing output from the ECU and sustains the signal until the ASR event is completed. A filter in the signal from the ECU is required so the ECU can identify harsh bumps and not false trigger the cruise "off". The cruise control will not automatically resume status after an ASR event. The driver must manually set or resume cruise operation after ASR.

3.6.15 Pcm Features And Asr Spark Retard

The ABS/ASR controller gives a signal to the PCM (powertrain control module) for spark retard. Ignition retard can affect driver comfort, engine stall, catalytic converter temperatures and vehicle driveability. In the PCM is an engine RPM incriment table and corresponding retard values. LT5 has two power tables while LT1 has one. LT5 and LT1 have a maximum ASR retard value of 35 degrees. It was determined that limiting retard to TDC (top dead center), improved catalytic converter temperatures. During development, it was determined that the LT1 requires a limit on retard above 4000 rpm to reduce misfire with high limit resistance components. At the end of the spark retard signal the PCM base spark value is ramped to it actual value. A typical slope is 5.0 deg/ms. If the spark retard signal ends before it has been asserted for 40 ms, the spark retard signal will not be the considered to have ended until 40 ms have past. If the spark retard input is active for longer than 4 sec., the spark retard will end. If the spark retard input continues, it shall not be considered to be asserted until the ignition is recycled.

3.6.16 Servicing ASR

Only a small portion of the service operations will be discussed in this paper:

1.Self diagnostic

2.Trouble codes

3.Cable adjustment

4.Replacement of TPS or throttle body

3.6.17 System Monitoring/Code Setting/Self Diagnostics

The ASR/ABS ECU contains the system self diagnostic capability that can detect and isolate system failures. Most diagnostic routines are run continually when the vehicle is in motion. When a failure is detected , the ECU sets a trouble code that represents that failure, turns on the appropriate status indicator lamp in the DIC, and disables the system. Except for a serial data Code 72 fault condition, the ECU continues to communicate on the Serial Data Link (SDL) when a trouble code is set.

3.6.18 System Trouble Codes

There are twenty nine trouble codes that may be set by the ECU . All of the codes except serial data Code 72 will cause the ECU to disable either the ABS system (allowing power-assisted breaking only) or the ASR system (allowing non modified traction and directional stability) depending on the code set, either one or both of the indicators "SERVICE ASR" and /or "SERVICE ABS" will be on.

3.7 Stability And Traction

The Traction Control System (ASR) enables a normal driver to retain control of his vehicle under all road conditions while accelerating. As with the ABS, first priority is given to improve directional control and steerability. But also the traction capability should be increased.

The directional control and steering is given by reducing the driving torque, in a way, that the drive slip remains in the stable area, where the cornering coefficient is high enough to assure lateral stability of the driven axle.

The traction improvement is achieved especially on ti-split surfaces through a differential-lock function via brake intervention. ASR consists of a hydraulic modulator with the possibility of brake pressure generation, an ECU and 4 WSS.

3.8 Vehicle Dynamics

During critical situation, ABS and ASR improve the vehicle behaviour, mainly in longitudinal dynamics. The VDC-system improves additional the vehicle's lateral dynamics at the stability limit. So the risk of skidding is reduced drastically, even under excessive steering maneuvers. That enables the driver to maintain control of the vehicle also under critical traffic situations.

This effect is not restricted to the flill braking (ABS) or acceleration (ASR), but also partial braking, engine drag and free rolling is supported through the VDC-system.The principle of the VDC is to control the yaw rate and the slip angle of the vehicle. The influence to the yaw moment of the vehicle is done by controlling the longitudinal slip of the tire through wheelselective braking intervention.

Longitudinal and side force (FL, Fs) are dependent of the tire slip, respectively of the slip angle and the normal force. Changes of the tire slip lead to changes of the longitudinal force and if there is a slip angle, the lateral force is influenced. This quality is used to vary the tire forces in longitudinal and lateral direction and for influencing the yaw moment and the lateral force of the vehicle.

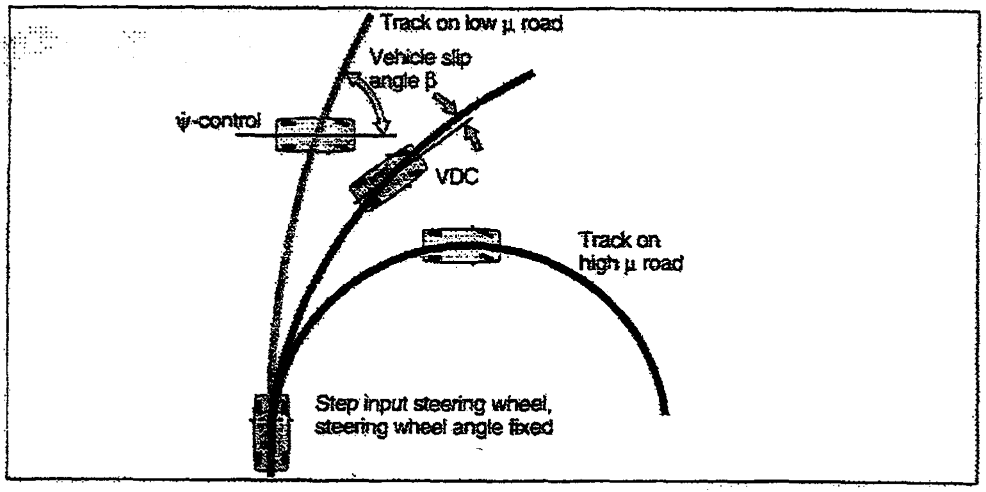


Figure 3.26: Lateral vehicle dynamics on high- and low-μ roads resulting from different control concepts : yaw rate control (ψ-control) as compared with combined yaw rate and vehicle slip angle control (VDC)

Figure 3.27 shows the tire forces. Considering only one tire, eg front left is enough for explaining the principle. The resulting tire force F_R (λ=0) of a free rolling wheel is equal to the cornering force F_S (λ =0) which comes out of the corresponding slip angle. If additional a brake force F_B (λ) alfects the tire (assuming normal force and slip angle remain constant) the cornering force F_S (λ) is reduced and the resulting tire force F_R (λ) is formed through the Vector-Addition of Fs (λ) and F_B. Near the stability limit the amount of F_R remains constant. This means the effect of a change in the brake slip is a rotation of the resulting tire force, and this leads consequently to a change in the yaw moment of the vehicle.

To control the vehicle in the dynamics stability limit, it is nessecary to measure the driver's intention and the vehicle' s reaction. Therefore the steering angle and the yaw rate (opt. aq) are measured and the slip angle of the vehicle is calculated.

According to the driver's intention and the surface condition the vehicle's behaviour is controlled through the wheelselective braking intervention combined with the motor intervention.

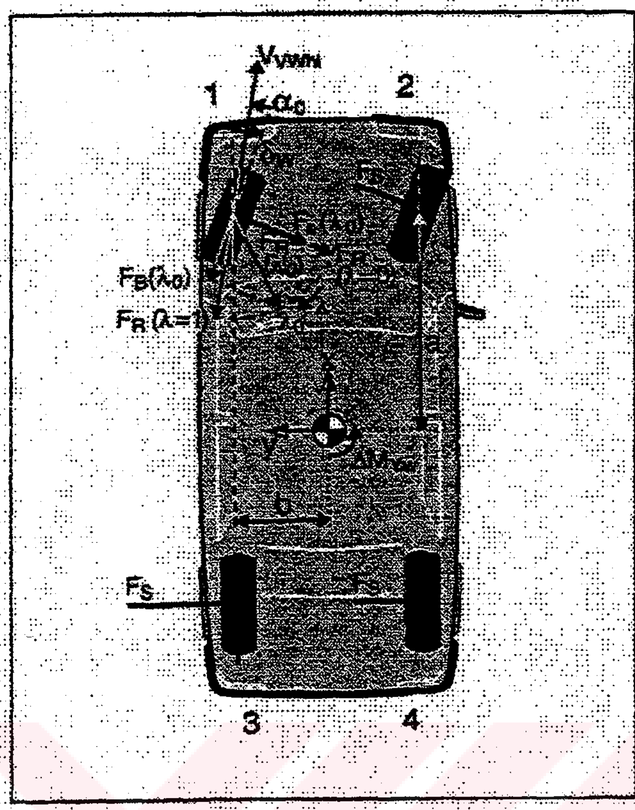


Figure 3.27 Effect of brake slip on the longitudinal and lateral tire forces at a fixed slip angle (α), and its influence on the vehicle yaw moment

A VDC-system consists of an ASR-hydraulic-modulator with precharge pump, an ECU, a steering wheel sensor, a yaw rate sensor, a brake pressure sensor, 4 WSS and optional a lateral accelerometer.

3.9 Evolution Of System Concepts

3.9.1 System And Hydraulic

The main features of the first ABS-system (ABS2) which was launched 1978 by RB were:

-Add-on-system

-Recirculation principle

-Closed hydraulic systems

- Three states of pressure modulation (increase, hold, decrease)

- Control algorithm with main control variables

  -wheel deceleration

  -wheel acceleration

  -wheel slip

These features are kept till todays ABS5-systems and also all other important ABS-suppliers use this principle.The biggest development progress was made on the components side (eg change from 3/3 Modulator valve to 2/2), and concerning size, weight, and cost enormous success was reached.

3.10 ECU

The development of the ECU must be mentioned particulary. At the beginning of the ABS era the HU was in the engine compamment and the BCU was in the passenger compartment of the car. Both components were connected via an expensive wire hamess. In 1989 RB offered as the first supplier an ABS system with attached ECU (A-ECU). The advantages of this concept are

- Cost reduction through easier wiring
- Reduced size and weight
- Quality improvement

Because the environment condition in the engine compartment are higher, RB decided to use the very robust and reliable hybrid technology for the ABS-ECU. That this technology compensates the disadvantage of higher environmental requirements and reaches the same quality level as a separate PCB-ECU under interior conditions is proven by over 1 Million delivered A-ECU's.These arguments and the positive field experience led to the big success of the A-ECU, so that today about 50 % of all RB-ABS/ABSR-systems are delivered with A-ECU. And we expect till 2000 a share of 80%.

The next technologic step was to develop an ECU in a hybrid design. This year RB will start with the ABS5. 3-system with an A-ECU in µ-hybrid technology which offers further size reduction and also cost savings. But not only the A-ECU made progress. Also the S-ECU (separate ECU) was developed further. The

ABS/ABSR2 S-ECU was a frame design. The heat of the power components was carried off through the cooling frame to the housing.

The current ABS/ABSR5 S-ECU is designed as a full SMD-concept. The power components (in SMD packages) are cooled through the PCB to the base plate. To reduce the thermal resistance, Via's under the components are used.

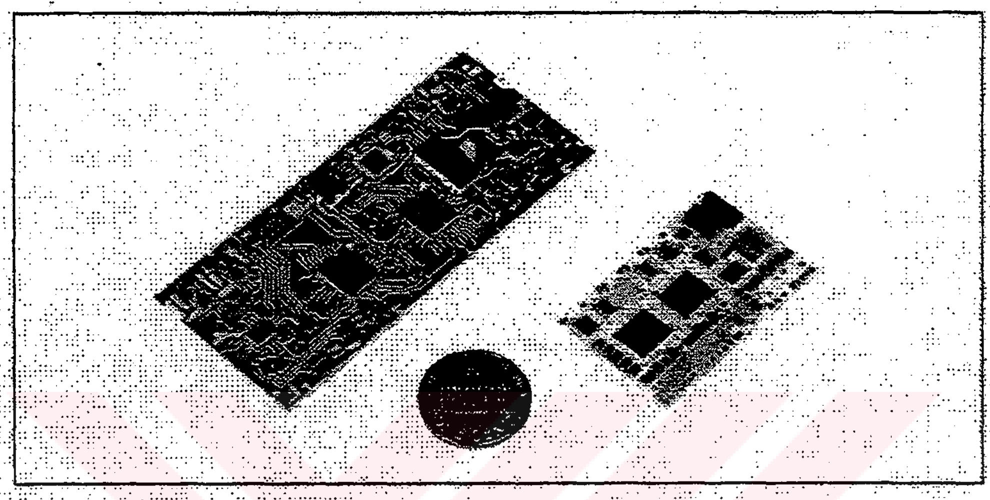


Figure 3.28 Comparison of the same ABS circuit in standard hybrid and microbybrid technique

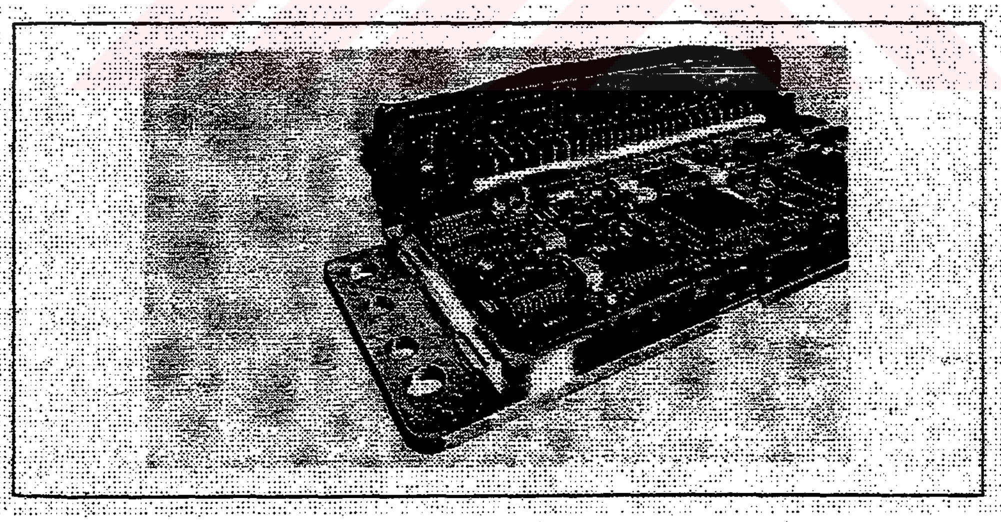


Figure 3.29 ABS/ASR5 separate ECU

3.11 Third Generation Antiskid System : Safety Diagnostic Features Of The E.C.U.

As a controller of a safety system, the E.C.U. of an antiskid system must give all the guarantees of safety with respect to external interferences or its own eventual failures, but also it must be able to detect failures in the other parts of the system in order to warn the driver and place the system in the configuration preserving the greatest safety. The synthesis of the self-testing performed by the E.C.U. guarantees the reliability of the function and gives, in case of failure, the necessary information for a quick repair of the system : it is the self-diagnostic feature of the system.

Bendix has chosen, for its third generation antiskid system, to devote a large part of the hardware and software in the E.C.U., to achieving the maximum safety and a full and reliable self-diagnostics.

The architecture of the E.C.U., based on two microprocessors of different nature checking back other mutually, has been derived by an analysis of the possible failures in the control logic and of the criticality of the consequences with respect to the function of the system.

Tests are performed on every sensor and actuator by the E.C.U. In case of a failure, the vehicle driver is warned and a particular failure mode is adopted by the E.C.U., depending on the component which has failed but also on the nature of this failure. The software has an important role in the detection of failures: it enables in direct checking, which is not only based on measured values of voltages and currents, but also on the global coherency of the information received by the E.C.U. By a high level of filtration, the Software also avoids false detection of failures which would quickly degrade the reliability in a noisy environment. The self-diagnostic function is based on the existing detailed results of the self-tests contained in the internal memory of the E.C.U., completed by a possible dialogue at two levels

- A visualisation of the flashing of the function lamp, of a reduced number of codes can be read without any special equipment.
- A serial link channel by which it is possible to access complete diagnostic data with an external diagnostic tool. Special procedures allow test sequences to be generated in the system or other information to be accessed, such as memorized temporary failures.

The antiskid function increases the level of safety of the braking function. To guarantee that level of safety, the system must be able to react with its full efficiency at any time. In case of a defect, the driver must be immediately warned so that he can adapt his driving, and the system must reconfigure itself to maintain its efficiency as it may and in any events the braking function self-checking is a necessity for an antiskid system.

The complexity of the device implies, also, that it provides by itself a sufficient aid to fault detection and localization : a sophisticated autodiagnostic function is a must.

3.11.1 The Complete System

The Bendix Third Generation Antiskid system insures the two functions

-Braking.

-Antiskid.

3.11.2 General Description Of The System

- The system consists in the following components:

-An electro pump unit, supplying the hydraulic power to the system.

-A braking pressure generator which generates the braking pressure in the branches of the circuit as a function of the effort applied on the pedal.

-Four reluctance sensors, each installed in front of a toothed wheel fixed on a road wheel of the vehicle the frequency of the quasi-sinusoidal signal delivered by the sensor multiplied by the right coefficient, gives the speed of the wheel.

-A set of "go/no go" electro valves allowing the braking pressure to be modulated wheel by wheel.

-An electronic control unit (E.C.U.) which controls the system.

3.11.3 The Function Of The System

It is controlled by the E.C.U. which

-Measures the wheel speeds at each moment, and calculates the corresponding slip levels.

-Deduces from these values the risk of locking for each wheel.

-Reduces the braking pressure for the corresponding wheel, by the use of the decay electrovalves.

-And, subsequently, until the braking ends, controls the level of braking pressure per wheel, in an adaptative manner, to maintain the wheel slip at its optimum level.

To achieve this modulation, a second type of electro valves enables the rate of variation of the pressure to be reduced. These are the restriction electro valves.

By combining the commands of the two types of valves, four basic rates of variation of the pressure can be obtained:

-Fast build.

-Slow build.

-Fast decay.

-Slow decay.

By applying command pulses of different types, and by modulating the length of these pulses, the E.C.U. can achieve all the rates of change of pressure which are necessary, depending mainly on the nature of the road surface to achieve the correct level of slip of the wheels, this value having been determined by the E.C.U. itself.

3.11.4 The Functional Architecture Of The E.C.U.

It consists in:

-The interface for filtering and shaping the sensor signals.

-The microprocessor as a control logic unit.

3.12 Development of ABS and Traction Control Computer

A new ABS and Traction control system (TRAC system) has been developed and put into mass production in a new model LEXUS LS1400. The TRAC system controls Sub-Throttle Valve and brake hydraulic pressure independently for left and right wheels.

To realize the ABS and TRAC system, it is necessary for the Electronic Control Unit (ECU) to process complex algorithm and high speed calculation. The ABS and TRAC ECU for LEXUS LS2400 is constructed by 3 TOYOTA custom 8-bit single chip microcomputers. Each CPU performs wheel speed calculation, ABS control and TRAC control, sharing the common data through high speed serial communication.

An advanced ABS and Traction Control (TRAC) system has been developed in '90 model LEXUS LS400. Recently, more vehicles have been equipped with on demand for safety. ABS operates efficiently shorten stopping distance and improve stability steerability in braking. On the other hand, TRAC system operates in starting or accelerating a vehicle to pull out proper traction force and lateral force according to the road surface condition. Therefore TRAC system improves the acceleration performance and prevents vehicle from liding sideways on slippery road. Some TRAC system as been proposed and mass-produced by some automobile suppliers. The TRAC system in LEXUS LS1400 is equipped with engine output torque control with Sub-Throttle Valve.

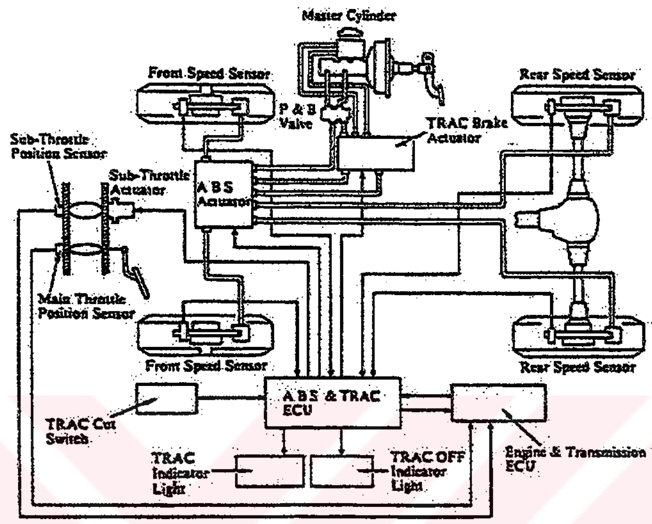


Figure 3.30 LEXUS L5400 ABS & TRAC System Diagram

3.12.1 System Configuration

To start the design of ECU, it is necessary to study the demands from the system, for instance, the transaction time of CPU, the required capacity of ROM and RAM, and reliability. The ABS and TRAC system of LEXUS LS400 is shown in Figure 3.30. The 4 wheel Speed Sensors are attached to each wheel to measure each wheel speed individually. The vehicle speed and driven wheel speed which are fundamental parameters to TRAC control, are calculated with signals of the 4 wheel The TRAC Brake Actuator changes rear brake hydraulic path from Master Cylinder to Accumulator during TRAC operation. The high pressure brake fluid in Accumulator flows into rear wheel cylinders when the Accumulator Cut Solenoid Valve is switched on. The pressure in each wheel cylinder is controlled by 3-Position Solenoid Valves for common use with ABS.

The Throttle Body has secondary throttle valve which is set up at upper position than the Main Throttle Valve and is driven by the Sub Throttle Actuator (stepper motor). Therefore, the Sub-Throttle Actuator controls the engine output torque in TRAC operation. The stepper motor is driven with the step resolution 0.30

and maximum speed 1500pps, that is to say, with maximum speed of 200msec from full open to full close.

3.12.2 E.C.U. Architecture

The system requirement is decomposed into ECU hardware and software. At first, electric characteristics of input and output signals are studied to fix the input and output interface circuit and to choose the functions required on CPU.

Wheel Speed is calculated with the frequency of the magnetic pick up wheel Speed Sensor signal. Engine Revolution is calculated by the pulse signal output at every 30 CA (Crank Angle) of engine revolution. The Main and Sub Throttle Angles are detected by the Throttle Sensors of potentiometer type attached to the Throttle Body. These analog signals are changed to digital signals through 8-bit resolution AD converter. The other inputs are level signals.

Output signals to ABS Actuator and Sub-Throttle Actuator are controlled at constant current by ECU. The other outputs are level signals.

Not only the input signals, but also the important signals concerning the safety are monitored by ECU itself and the fail safe function is necessarily included. These signals are ABS Actuator output signals, TRAC Brake Actuator output signals and Relay drive signals.

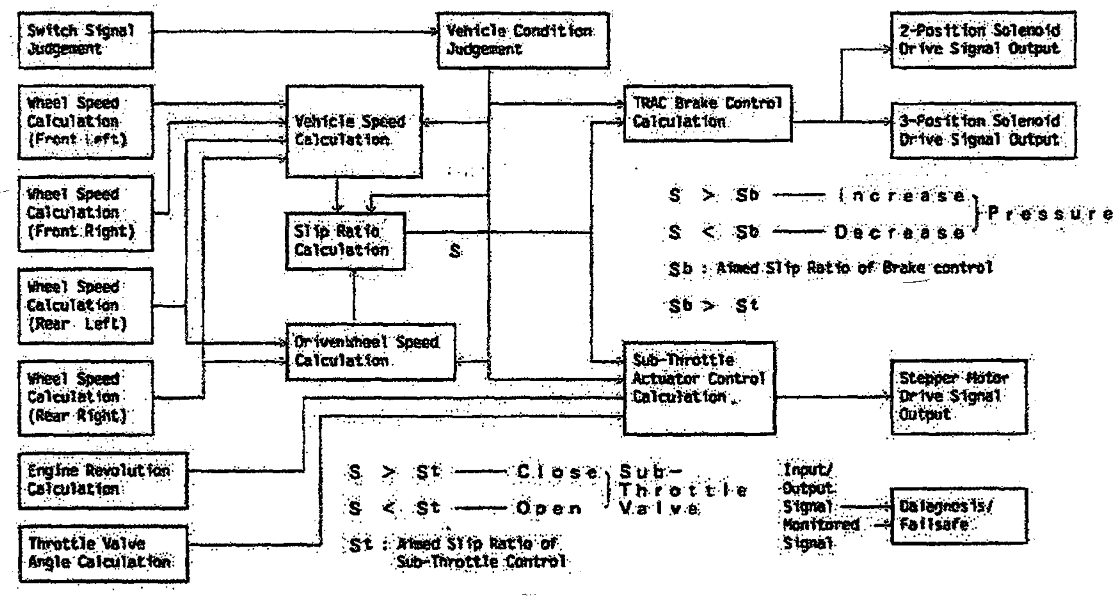


Figure 3.31 TRAC Operation concept

The ABS and TRAC operation concept are studied to fix the software specification. Figure 3.31 shows the TRAC Operation Concept similar to ABS operation concept except Sub-Throttle Actuator control. It is necessary in accuracy of measurement and response time that the transactions to process Wheel Speed, Engine Revolution,Solenoid Drive and Stepper Motor Drive signals are executed in interrupt routine.

The reliability and noise immunity of the ECU must be considered in the design. The system functions are shared by each CPU. CPU has Bk byte HON capacity and it shares the function of processing the wheel speed signal,calculat ion of wheel speed and the diagnosis of ABS system. A-CPU has 12k byte ROM capacity and it controls ABS system and TRAC brake actuator. T-CPU has 12k byte ROM capacity and it processes TRAC brake control and TRAC Sub-Throttle Valve control.

Data transfer between CPUs is designed with high speed (lMbps) serial communication which has enough noise immunity.

3.12.3 CPU Communication

LEXUS LS400 ABS and TRAC ECU is composed of three 8-bit single chip CMOS microcomputers developed for vehicle use, and the individual CPU executes high speed data communication via serial communication buffers which have some shift registers. To introduce multi-CPU structure, we intended to connect CPUs tightly so that three CPUs process like a single chip CPU. Merits of tightly connected CPUs are averaging CPUs load, adding monitoring function among CPUs, improving of processing ability and reliability.

One data block is composed of three to six bytes and one data block is sent continuously. 4 bits ID code identifies the data block and also indicates the order of transmission. One communication block data is checked by one byte check-sum data which is predetermined so that the summing of data from Data 1 to Data m becomes 5AH. Also ID number and the length of data bytes corresponding to ID number is checked by the receiver PU to check whether the communication is performed correctly.

First, each CPU sends communication permission signal (C/P) and waits. When all CPUs have sent permission signals interrupt pulse signal IRP is generated from the gate to each CPU. Then communication interrupt routine starts in each CPU and the communication is performed. The program execution in each CPU is synchronized by IRP signal and the CPU communication and program execution are performed in the predetermined time, because the C/P is generated at the scheduled part of the program.

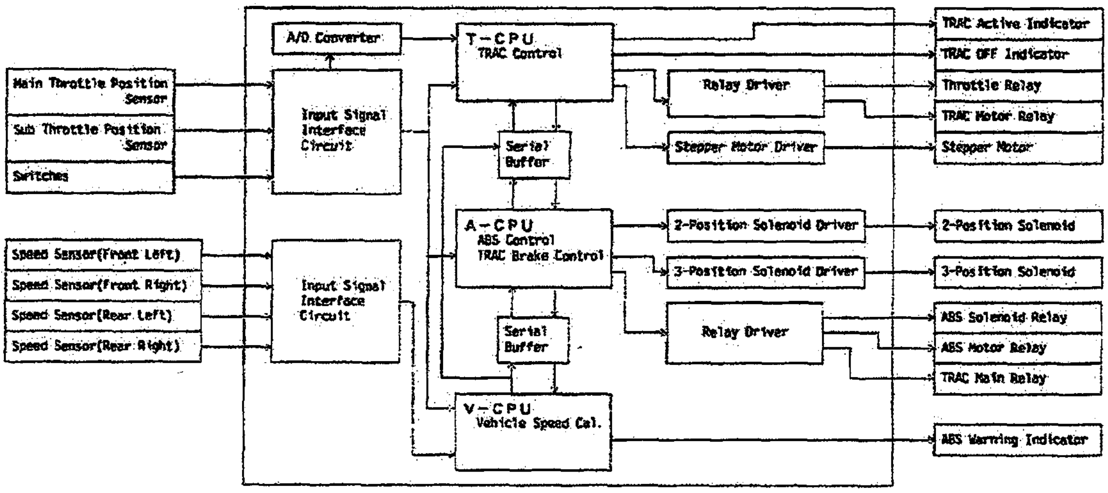


Figure 3.32 ABS &TRAC ECU block diagram

In each 6 ms period communication data blocks 1 to 9 are transmitted and received, and if any CPU has failed and the communication is not performed correctly, then the other CPU can detect the communication error. The block diagram of ECU circuit is shown in Figure 3.32.

3.13 Advanced Interactive Driveline Control

A research program involving three companies working to integrate the driveline control on a 16 ton two axle (4x2) vehicle using a high speed data link is described. The driveline is defined as incorporating three functions, engine management, transmission control and anti-lock (ABS) power induced wheel spin control, otherwise known as anti-slip regulation (ASR). Each function is controlled independently by appropriate Electronic Control Units (ECUs).

In February 1989 a three company research project was launched to investigate and demonstrate the improvements in performance possible from the interaction of the three driveline functions referred to above.

The first phase was to attain or better the performance currently achievable with electro-mechanical links and also to indicate any performance benefits. This phase included investigations into the physical layer and message structures required in the absence of any agreed formats at the time.

Phase two of the project was to investigate the broader aspects of an intelligent interactive driveline and mod ify the message format in line with emerging standards.

The purpose is to describe and demonstrate the benefits of using a high speed data link in the interactive control of three driveline systems on a truck. Conventional driveline systems use electromechanical links between engine, transmission and ABS/ASR ECUs. In order to improve driveline performance we believe the interaction between ECUs needs to be improved. The Controller Area Network (CAN) protocol was chosen for the high speed data link between the engine ECU, automated mechanical transmission ECU and a combined ABS and ASR ECU, which would allow these improvements to be made.

It describes the hardware defined and the message specification laid down in phase one when no suitable standards existed, along with the revised message specification in phase two as suitable standards emerged. The studies included simulations of the data bus traffic and a FMECA study of the message specification to evaluate the integrity of the system and highlight any critical areas of the specification.

In the first phase the aim was to develop a system which was at least functionally equivalent to known engine, transmission and ABS/ASR systems interacting via electro-mechanical linkages. Subsequent work was to explore possible improvements which the increased interaction between these systems would allow.

Only where interaction occurred did the panties require information as to basic operating principles of other ECUs, this enabled detailed operation of individual ECUs to remain confidential but allowed sufficient knowledge to be transferred between companies to enhance individual functions. This restriction in the transfer of knowledge is an important feature of the project as far as commercial confidentially of individual ECUs is concerned.

3.13.1 Vehicle And E.C.U. Description

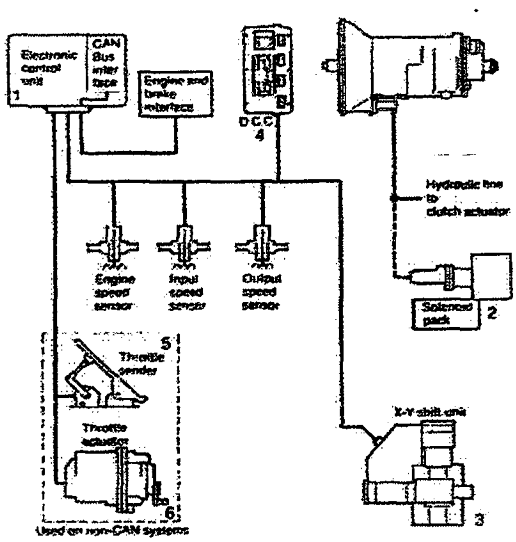
Vehicle The demonstrator vehicle used throughout the project was a 16 ton and two axle (4x2) long wheel base rigid truck, fitted with a sleeper cab and flat bed body. The engine was a 6 litre, 6 cylinder 180 bhp, turbocharged and after-cooled direct injection diesel unit. This was mated to a 330mm ceramic dry plate clutch and a 6 speed automated mechanical gearbox which drives a single speed, single reduction axle via a split props shaft. This vehicle configuration provided ihe base for fitment and implementation of the data bus and for exploring the issues of interaction when using high speed data communications on a real vehicle.

Engine Controller: The engine was fitted with an electronically controlled diesel engine management system, currently under development for the engines of both commercial vehicles and passenger cars .

The pump was calibrated to match the delivery and injection timing characteristics of the standard mechanical injection system so that the same engine torque figures were obtained. but with improved transient response. The governor characteristics were adjusted to match those of the original pump. The driver input was via a potentiometer connected to the accelerator pedal. In using the interactive data bus the electro-mechanical fueling demand control equipment previously fitted for transmission and traction control were not required, and were therefore removed from the fueling actuation.

Transmission Controller: The transmission fitted was an Automated Mechanical Transmission (AMT) system as shown in Figure 3.33. This system is currently under development and converts a mechanical transmission into a fully automated transmission. The main features of the controller are the ECU, Clutch Actuator, X-Y Shift Unit and Driver Command Console. The ECU receives info rmation from its own sensors to determine the correct gear ratio. The ECU then controls the clutch, X-Y unit and fueling. The clutch is controlled via a pneumatic servo device through a conventional release system which ensures a smooth clutch take up. The physical action of engaging the gears is performed by the electro-mechanical powered X-Y actuating cylinder. The fueling control is accomplished via the interactive data link. The driver is also able to select functions, such as cruise control, via the driver command console.

The automation of mechanical transmissions, largely by eliminating the variability of driver gear selection, ensures consistently fast and smooth shifts with reduced driver and transmission fatigue. The system also maintains the use of known mechanical transmissions. Using the interactive data link, the normal mechanical inputs from the accelerator pedal and mechanical fueling override controls were not required and therefore removed.



Mk 2 A.M.T. Control System

Figure 3.33 Automated Mechanical Transmission System

Braking System: The ABS/ASR controller is a development of an existing four channel category 1 ABS system.

The system is capable of individual wheel control for vehicles fitted with air braking systems, and includes the ability of controlling a retarder if fitted. For the purposes of ASR the vehicle was fitted with a brake apply valve to control the driven axle brakes so as to regulate wheel spin at low speeds. Using the interactive data link any mechanical fueling override controls were not required and therefore removed.

As will be seen the major vehicle improvements were the removal of the fueling override hardware, all these functions being achieved via the interactive data link.

3.13.2 Message Specification And Prioritisation

Initially there were no suitable message specifications or timing requirements for use on CAN, so the three parties involved devised a communication specification for messages required on the data bus. This was based on the type of message each ECU required and could provide. Rates of transmission were a compromise between program loop times of each of the ECUs, the minimum and maximum acceptable update rates and bus loading. The suitability of the final communication specification was verified by bench testing prior to implementation on the vehicle.

The basic message requirements for interaction include an indication of driver fueling demand, which in phase one was given as a percentage of accelerator pedal position, corresponding fueling override requests from the transmission and ABS/ASR ECUs to override driver fueling demand during gear changes, ASR activity etc, and a number of command messages used to hold off fueling overrides from the other ECU. There were also a number of extra messages available for use by other ECUs such as ECU health status, available from all ECUs, the vehicle reference speed available from the ABS/ASR ECU, current gear selected from the transmission ECU and idle indicator from the engine ECU. These extra messages can then be used to validate data, reduce sensor count and introduce greater interactive control, which an electro-mechancial interactive system could not achieve. Figure 3.34 shows the intial data flow diagram used to integrate the information both required by and available from all ECUs.

Some flexibility was required in terms of timing and rates of transmission. All the ECUs in the Although most ECUs work with program periods of approximately 10-15 ms some signals such as driver pedal demand, from the engine ECU, were only available every 15-64 ms; this means that a spread of data repetition rates has to be acceptable. Once the repetition rate has been established for a particular message, this repetition time can be used to time-out messages, except that is for the engine ECU, which has a repetition rate as a function of engine speed, so a maximum period needs to be defined.

Data such as engine pedal data and all the slower rate system status messages were repeated continually but override and override inhibit information were sent only during relevant activity with a defined sign off message for these type of messages. Prioritisation initially gave fueling override priority to the ABS/ASR ECU. However later discussion shows how both ABS/ASR and transmission ECUs required override inhibit signals to set their ECUs priority during fueling control.

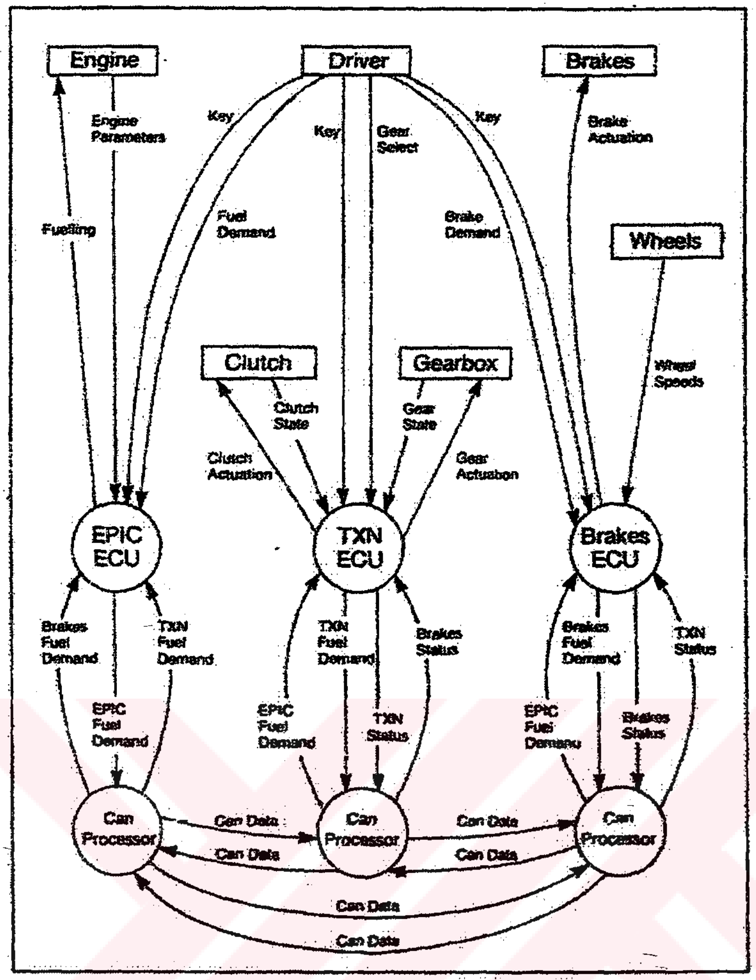


Figure 3.34 Data flow diagram of system

3.13.3 Sensors

For an ABS- and ASR-system 3 (or 4) WSS are enough. Some cars (eg 4 WD) however need an additional acceleration sensor, and for VDC supplementary sensors are necessary. These are

- Yaw rate sensor
- Steering wheel sensor
- Pressure sensor opt.
- Acceleration sensor opt.

Wheel Speed Sensor (WSS): For WSS the inductance type (passive) is standard on the market. The development progress was to reduce weight and cost and to adapt the WSS to different customer requirements (fixing flange, wire harness, tipot pole piece), Figure 3.35. Active and wheel-bearing integrated sensors are offered from some suppliers. But of course of some functional and cost disadvantages the market acceptance is open. RB succeded in improving the measuring elements and we will introduce active sensors for mass production in future.

Acceleration Sensor (AS): Since 1989 RB delivers AS. The principle of today's sensors is a spring mass system and a Hall-element. The signal conditioning electronic is integrated into the sensor housing. For the future RB develops a micro-mechanical sensor and we think that the market will go to the same direction.

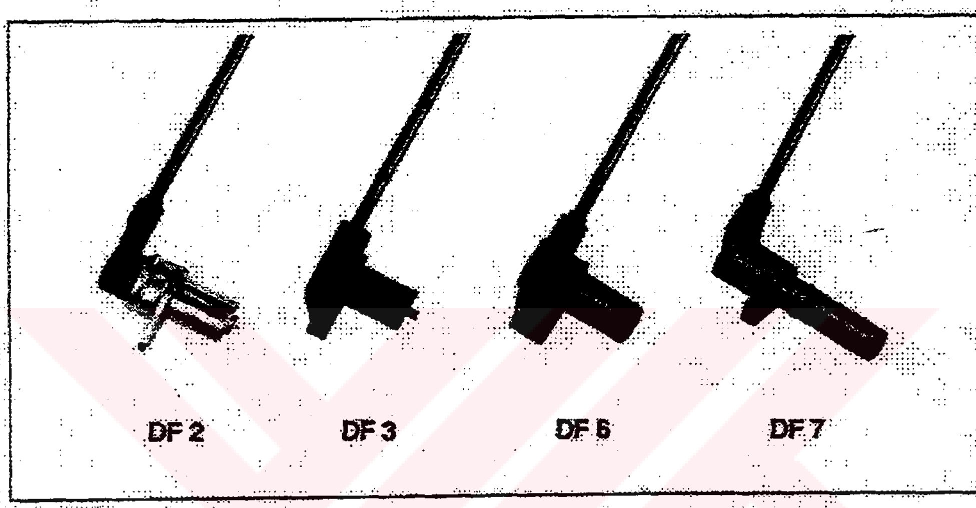


Figure 3.35 Development of wheel speed sensors

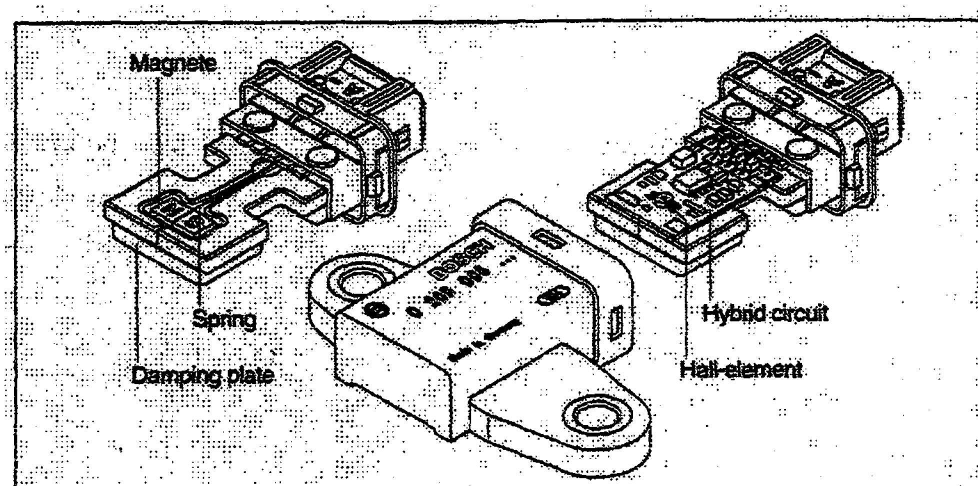


Figure 3.36 Acceleration sensor

Pressure Sensor (PS): For ABS/ASR application, RB produces since 1985 PS in Bourdon-Tube-technique. For VDC, RB has developed a compact piezoresistive sensor.

-Steering wheel sensor (SWS)

-RB is going to develop a SWS for VDC-applications.

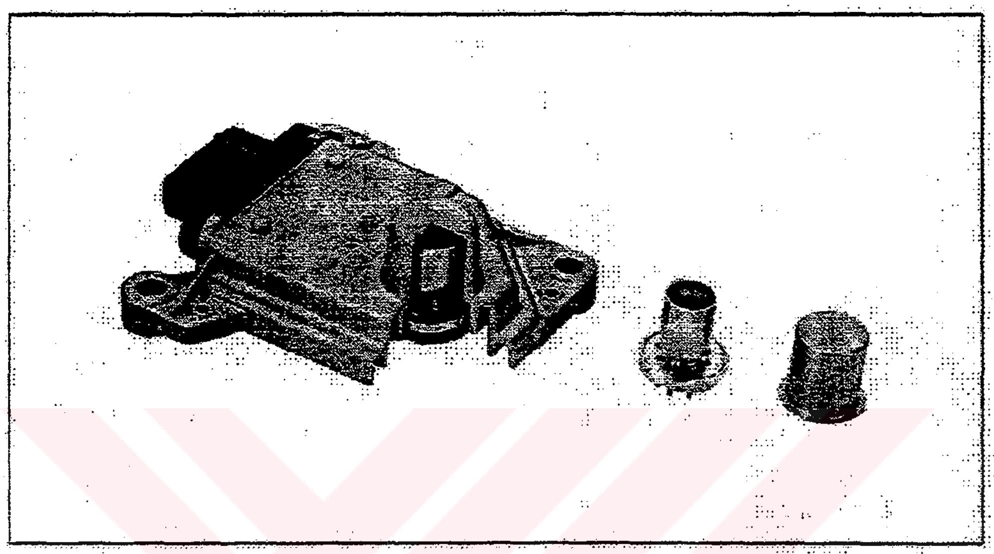


Figure 3.37: Yaw rate sensor (YRS)

Specific for VDC a YRS was developed. The measurement principle is based on the vibrating cylinder. The necessary electronic is integrated into 2 ASIC's. With that concept RB will be the first supplier, who fullfills all automotive- and safety-requirements and is able to produce this sensor in high quantities.

In the first years after introduction of the ABS (and later ASR) only luxury cars were equipped with these systems. But during the last years the market for ABS/ASR Systems has grown very rapidly and today many of medium size and small cars are equipped with ABS, partial also with ASR.

3.14 Recent Trends In Traction Control

Implementation of a typical "foolproof" type TCS to keep the slip ratio of the driven wheels within a constant range has been proceeding. Therefore, let us take an overview of the technological trends in this field since 1989, when systems which in corporated a variety of new features were introduced. First, the way in which current vehicle control systems are handled in today's transportation society is shown in Figure 3.37.

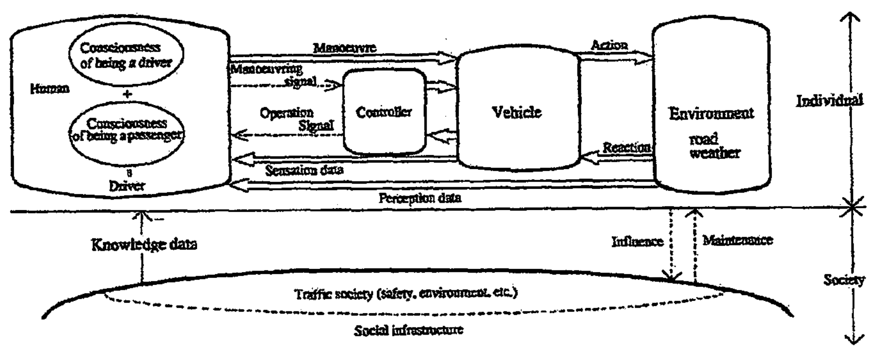


Figure 3.37 Conceptual view of vehicle control system in traffic society

This figure shows the roles and relationships of the vehicle controller in a mobile society, and this society seems to consists of mainly five elements, i.e., "man" "vehicle" "controller" "environment" and "traffic society". Each of the elements seems to have the principal and subordinate relationships indicated by the size of the elements in the figure.

For example, the smallest element in this system, i.e. the controller, is presently almost completely dependent on the vehicle, with the amounts of signals received from the person and feedback signals being very small. As a result, even if the controller compensates for a mistake in the car arising from human, environmental or mechanical factor, the control barely exceeds the ability of the vehicle itself to exert a direct influence on the performance of the whole system.

People are the main factor behind traffic on roads. Even so, for a large number of people when they are driving a car, what can be termed the self-awareness and subjectivity of their consciousness as a driver and the unconsciousness and habituality of their consciousness as a passenger are not clearly separated. Thus, the data signal from the controller is usually barely considered, and while the steering and inertial force from the vehicle are felt tactually to a slight degree, the change in behaviour of the vehicle is visually appresiated mainly from the road and the view from the vehicle. The driver does not objectively understand the conditions of the road and the weather, and compares them with traffic information and consciousness gained from past experience. When the driver's consciousness is strongly that of a passenger, he perform his programmed operation and if a mistake or an unexpected condition occurs, a correction is made based on the feeling of responsibility as a driver.

Based on the state of these mutual activities, let us consider how current TCSs function and for what purposes. Systems A through D which are detailed here under are new types of traction control systems developed since 1989.

3.14.1 Nissan ETS System (System A)

This is a 4WD system, with variable torque distribution to the front and rear wheels .The features of this system can be broadly stated as follows:

Adoption of a 4WD system based on rear-wheel drive;

Traction force distribution control based on the difference in rotation speed between the front and rear wheels;

Optimized control under a variety of conditions by means of lateral acceleration detection; all-round control in combination with a four-wheel anti-lock brake system.

Of these, the features (1), (2) and (3) related to the subject are explained in Figure 3.38.

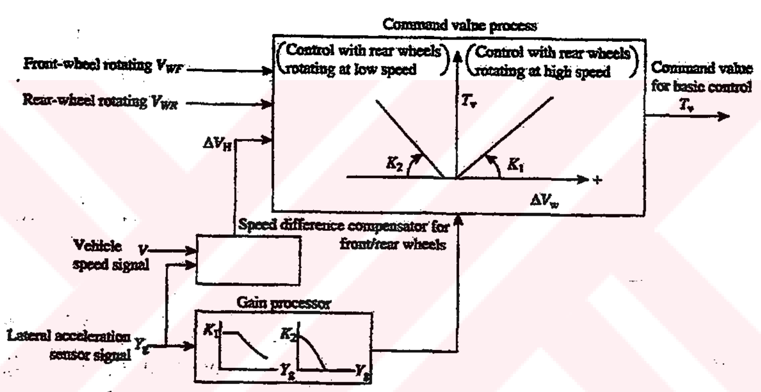


Figure 3.38 Basic control block diagram of Nissan E-TS (system A)

First , the difference in rotation speed between the front and rear wheel (ΔV_H) occuring as a result of the the side slip angle of the vehicle only is calculated from the lateral acceleration and the vehicle speed signal. Next, the difference in rotation speed between the front and rear wheels ΔV_W (= ΔV_{WR} - ΔV_{WF} - Δ V_H) occuring as K_2 for the lateral acceleration (K_1 is the gain when the rotation speed of the rear wheel is greater, and K_2 is for when it is smaller) are included to calculate the basic control command value (T_V :torque distribution signal to the front wheels).As shown Figure 3.38, K_1 and K_2 decrease as the lateral acceleration increases. Because of this, when the vehicle is turning on roads with a high frictional surface, the torque distribution to the front wheels is reduced, so that the lateral force of the front wheels is approximately maintained, while the rear wheel torque can be increased or decreased to allow the lateral force of the rear wheels to be controlled by the drive power. As a result, the driver can actively control the driver's behaviour by their accelerator operation.

3.14.2 Porcshe Tiptronic System (System B)

This system is basically the same as the automatic transmissions used up to the present.

A point to note is the Δt shift control logic. Data processing by the control unit with regard to this is shown in the block diagram in Figure 3.39.

Firstly there are the gear shifting characteristics. In this system , the mode selection is automatic within the range from SK1 (economy) to SK5 (sporty) by means of the opening and closing speed and the position of the throttle valve. The result of this is that if the opening and closing speed of the throttle valve is high, the SK5 (sporty) shifting pattern is selected and on entering a corner up shifting is prevented. Then, during cornering, shifting changes are prevented for a uniform period of time, depending on the amount of lateral acceleration. Using this control the driver's requirements can be reflected in the timing of the gear shifting.

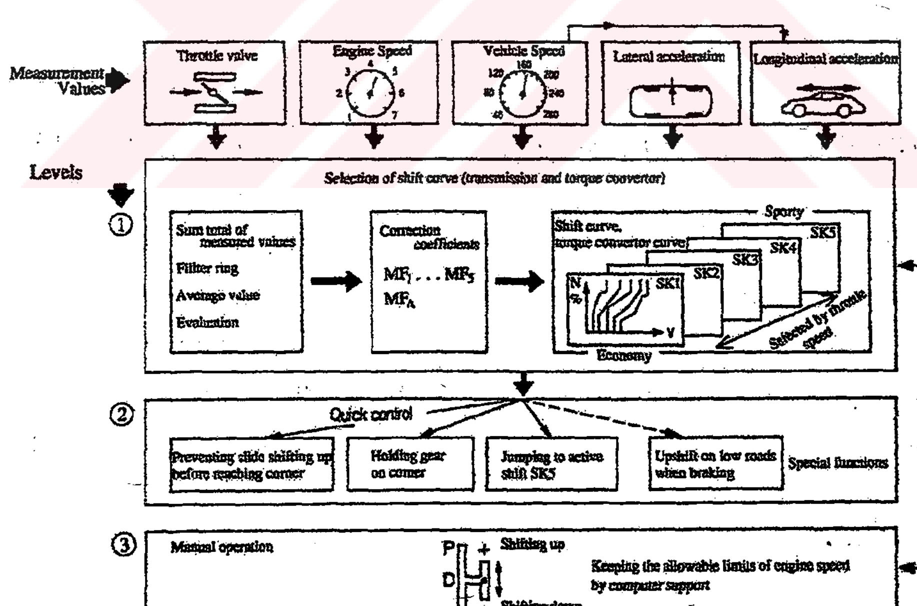


Figure 3.39 Control block diagram of Porsche Tiptronic (system B)

Additionally, in decelerating on roads with low frictional coefficients, if the rear wheels tend to become locked, the transmission changes up to reduce deceleration torque in order to prevent a reduction in the lateral force of the rear wheels.

3.14.3 Mitsubishi TCL System (system C)

As shown in Figure 3.40, this system consists of two main controls. The first is a normal traction control function that keeps the slip ratio within a constant range (slip control). The second function improves the trace performance by controlling excessive traction caused when the accelerator pedal is depressed too far during turning (trace control).The nature of this trace control is as follows.

The anticipated lateral acceleration is obtained from the steering wheel angle and vehicle speed.

The level of lateral acceleration at which the driver can drive with confidence in relation to the vehicle speed (within the tyre gripping range) is initially set as reference degree of lateral acceleration. The target engine torque is then reduced when the anticipated lateral acceleration exceeds the reference lateral acceleration.

A revision factor resulting from the amount of acceleration intended by the driver, obtained from the throttle opening angle and the engine speed, is added to this target engine torque to obtain the target engine torque for trace control.

With this, acceleration during turning is maintained at the level of lateral acceleration with the driver can drive with confidence, and the stable trace control during cornering is made possible.

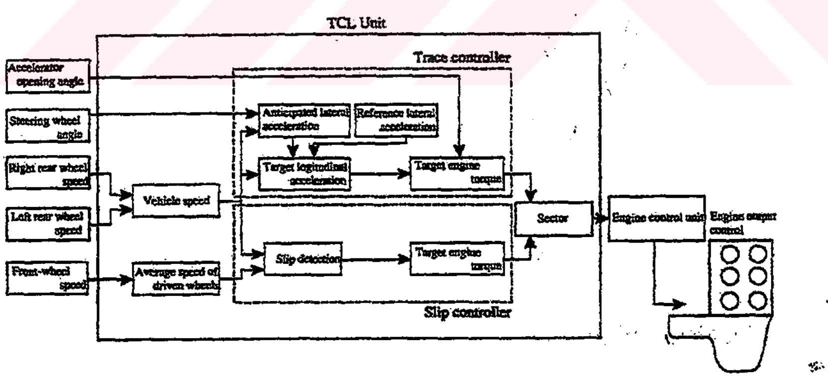


Figure 3.40 Control block diagram of Mitsubishi TCL (System C)

3.14.4 Honda TCS System (System D)

As shown in Figure 3.41, this system consists of four control sections. Those are the acceleration control, the handling control and the grip control sections. The main section is that of acceleration control, which performs the function of typical slip control.

The handling control section, which provides one of the sub controls, section which calculates the amount of transient under steer/over steer characteristics and sends the result to the acceleration control section. This value is used to change the target value and the control gain for the slip control to provide slip control that takes into account the changes in steering characteristics.

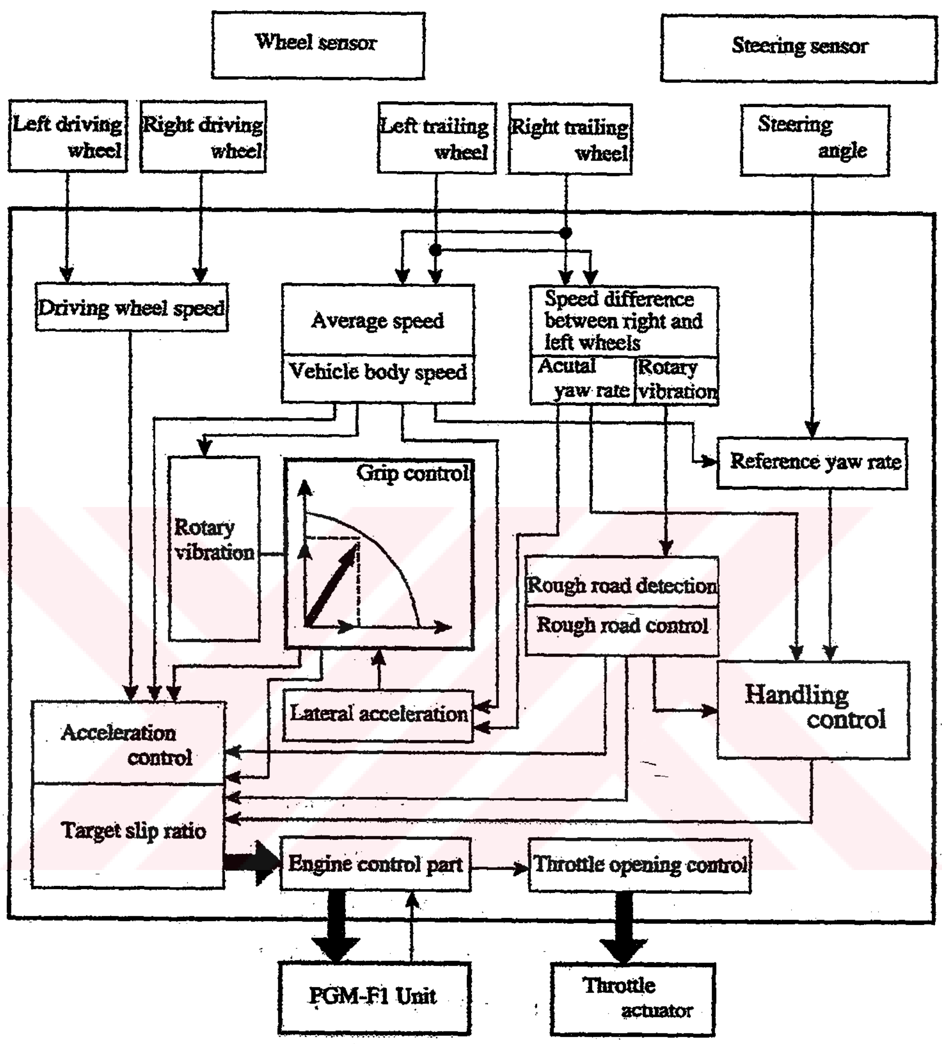


Figure 3.41 Control block diagram of Honda TCS (System D)

Another subcontrol is the grip control section. This control section makes an estimate of the vehicle's longitudinal acceleration and lateral acceleration in order to monitor the force of the rear wheel tyres. Then, after the lateral acceleration is multipled by the weighted coefficient for the rear wheel load, the result is squared and added to the square of the longitudinal acceleration. The square root of the resulting total gives an estimate of the value of the friction force, which further gives an estimate of the friction coefficient between the tyres and the road surface. These data are used to minimize the target slip ratio when driving on slippery road surfaces such as icy roads to get maximum degree of performance.

3.15 Fundamental Form Of Traction Control

The above four types of TCS consists of a variety of internal control sections, with mutual principal and subordinate, or equal relationships between these control sections. The way in which each control section can be broken down into basic patterns is explained below. The assumptions behind the pattern of these controls are shown in Figure 3.42.

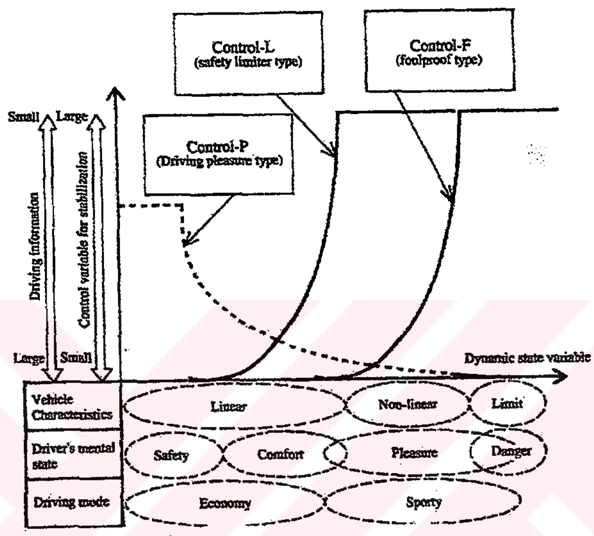


Figure 3.42 Three fundamental forms of control

The vertical axis in this figure represents the control variables. The controlled dynamics of the vehicle become more stable in from the bottom to the top. Incidentally, if the vehicle movement becomes more stable and movement changes are reduced, the driver's focusing image states of the vehicle motion (operation selection range) dissipate in the background of the driver's consciousness. As a result, the driver's subjective maneuvring is reduced. Therefore, it can be said that stabilization of the vehicle motion is equivalent to a decrease in the driving information which cause disparities in the actions of the driver. Accordingly, this vertical axis corresponds to (the reciprocal value of) the driving information in the human-vehicle system. The horizontal axis represents the dynamic state variables. From left to right, the vehicle characteristics change progressively from linear to non-linear until the limit is reached. The meaning attached to this axis is that form the left to right, the driving mentality changes from safety to comfort, to pleasure and then to danger; the driving mode changes from economy to sporty. These curves are shown in Figure 3.42. Each is given its own name below (P=pleasure, F=foolproof, L=limiter), and these form the basic pattern of control.

-P control(driving pleasure type);
-F control (robust foolproof type);
-L control (safety limiter type).

A solid line indicates that control and information transfer occurs as indicated by the line in proportion to the state variable. A dotted line shows that control is performed with conditions attached, or that either control or information transfer fails or occur.

Control P reduces the control variable for stabilizing the vehicle behavior, in proportion to the dynamic state variable by which the vehicle characteristics approach the non-linear range while moving towards the limit. However, the driving information is increased. For instance, the driver can predict that the limit is being reached when the lateral G force moving the vehicle becomes non-linear, because the driving information is increasing. Therefore, before the controller requests F control, i.e., foolproof control, it is the driver's skill which is responsible for controlling the vehicle. Thus, P control is regarded as a kind of man-machine system in which the driver also actively participates in a part of the controller's action.

The shape of L control in the figure is almost symmetrical that of P control. This means that L control stabilizes the vehicle motion far earlier that F control; for example, at the stage where the vehicle dynamics exceed the linear region, in order to achieve a reliable degree of driving safety that does not rely on the driver. This is therefore a safety limiter type of control that gives priority to social responsibility over the context of the individual inclinations of the driver. Thus, L control gives insufficient information for driving from the point of view of the driver's consciousness, and P control gives insufficient control for stabilizing.

3.16 Classification Of Types Of Traction Control

The control features from system A to system D are discussed using three basic types of traction control, shows how the basic type of control is applied to the main control and subcontrol of each system, and classifies the results.

The main control is something that can be brought into effect independently. When the main control is not functioning, the subcontrol will not be brought into effect. According to this method of classification, it is possible to say that the composite pattern of system A is similar to that of system D. In system B, the main control and subcontrol types are the reverse of those in system A . However, in system C, the main control is the same as that of system A and it has the special feature of being equipped with L control which can be operated independently of the main control.

In this way, the four representative TCS' s from A to D can be narrowed down to systems A,B and C, which posses various unique features.

As shown in Figure 3.43, as system A does not normally control to stabilize the vehicle behavior, it is able to transmit satisfactory information to the driver through the basic chassis performance. When the vehicle motion enters the non-linear domain and the changes in the vehicle behavior become non-uniform, the system begins to operate. Once control begins, it is implemented so that the driver can continue their driving pleasure, and in an emergency it operates as a foolproof system. In short, system A seeks to strike a balance and rhythm between safety and pleasure, while taking the relationship between human and vehicle into consideration. Issues which steel remain to be resolved include such things as whether foolproofing will be brought into effect to its maximum extent after changing to 4WD, and whether the system will be able to appropriately select the points of convergence noted above during driving on a variety of road surfaces and in a variety of driving situations.

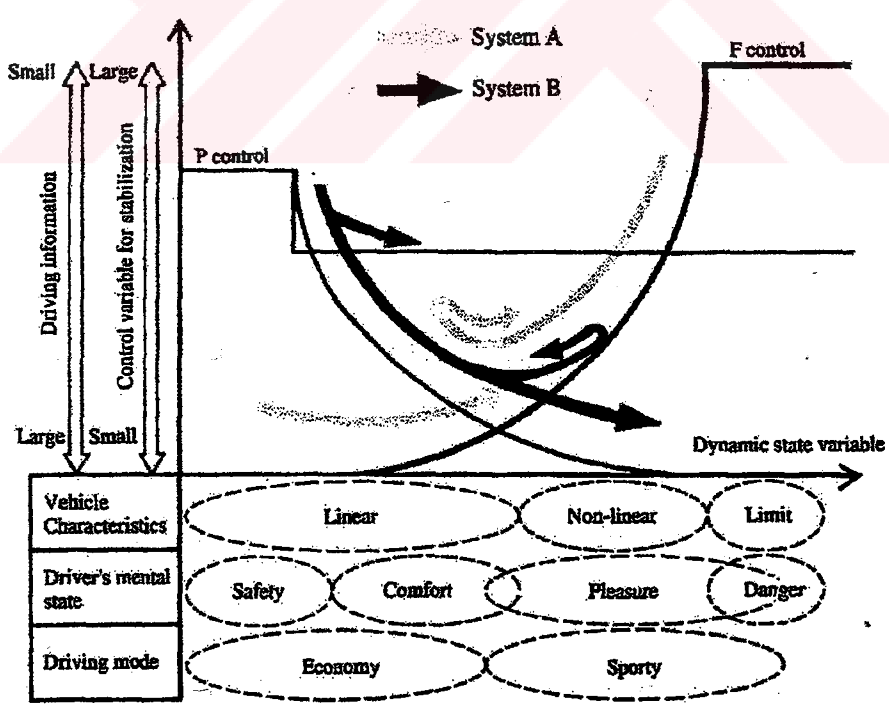


Figure 3.43 Theory of balance between safety and pleasure

System B is a type of control which is the reverse of that of system A. This is because system B is not intended to be a dynamic control system but a maneuvering operation system. Figure 3.43 also shows the control action of system B. This system continues the open-loop control for normal driving conditions and strives to bring pleasure to the driver. However, when vehicle movement enters a certain domain, control is stopped do that the control function itself does not disturb the vehicle dynamics. If the movement exceeds this domain, a foolproof operation will be attempted even through the control might not be perfect. In short, the maneuvering operation system also tries to ensure that the balance between safety and pleasure will not be lost. As noted previously, system C has the same foolproof control as system A but has one more main control. This system is thus a type of safety limiter which gives preference to the transportation society rather than to individual driving pleasure, and thus operates in a different control context. As mentioned before system D resembles system A in as much as the main control is a foolproof control. However, the subcontrol is a pleasure type by effectively augmenting the performance of the tyres, and it is a foolproof type by limiting vehicle movement. So in these respects it can be differentiated from system A.

3.17 Hierarchical Relationships In Traction Control Systems

As explained before, by using a classification system for the fundamental forms of traction control, one aspect of the meaning behind the operation of each type of traction control system can be expressed. Nevertheless, the meaning of individual operations under a variety of driving situations is supported by larger meanings which encompass the whole domain of smaller factors. These meanings can then be considered to consist of even greater and deeper meanings which are linked in the manner of a hierarchy. Accordingly, the fundamental forms of each type of control element will be treated as a hierarchical construction, and the meaning and role of each will be re-examined.

By this means, we believe that the position of and relationship between control systems which are currently being used in actual vehicles can be understood clearly.

First, there are three logical layers in the hierarchy which can be considered according to the limits of the extent of the world as perceived by the driver, or in other words, the extended processes of the limbs, body and the outside world, from the center and extending toward the periphery. They are; the sliding movement of the tyres, which the driver is relying upon and manipulating; the movement of the vehicle which the driver is driving, and the natural environment and the transportation society in the midst of which the driver finds him/herself.

Following this, the provision of control elements is carried out, with system D given as the example. In the control logic for the TCS, the initial layer of the fundamental form of control consists of:

(1-A) Over suppression control of slip ratio limit. Then, the control element referred to as "handling control" is also utilized, but this is a form of control for determining the target value for the slip ratio of the tyres while control is being performed. It has two functions as follows:

(1-B) variable control of target slip ratio which is within the first layer of the hierarchy; and (2-A) reference vehicle response following system which is the second layer, and has the role of maintenance of order in this layer.

Next, the control element which is known by the name of "grip control" is also utilized. The role of this element is in the rationalization of elements such as the target slip ratio in response to the grip conditions between the tyres and the road surface detected by the overall acceleration (lateral acceleration in particular) of the vehicle. If this is looked at in a different way, it can also be called a control when varies the reference vehicle response in accordance with the vehicle movement conditions such as the lateral acceleration of the vehicle. Accordingly, this control can also termed:

(2-B) variable control for reference vehicle response, which also in the second layer of the hierarchy.

There is a certain range within which controls listed up until now are technically possible as controls inside the vehicle. If the levels are exceeded, a solution would no longer be possible with purely technical arguments and methods.

Below, we examine the third layer of the hierarchy. If driving safety in the transportation society is taken from the point of view of vehicle driving conditions, then the existence of:

(3-A) over suppression control of vehicle driving conditions could be established like an L control; but (3-B) variable control of vehicle driving conditions (driver's freedom responsibility) also exists and the two must be balanced. These should be determined primarily on various levels such as the customs, governments, religions and culture of each respective country, and it is considered that they could not be represented on a conventional scientific and technical level except by way of concrete methods and procedures.

Incidentally, if these relationships are shown graphically (Figure 3.44), issues that we as engineers are currently dealing with and the issues that need to be dealt with in the future, or in other words the borders of technology, seem to become clearer. Before examining these issue, an explanation will be given of Figure 3.44. In this figure, three logic levels are shown, and are numbered in the order 1,2,3 starting from the bottom. Each level consists of a pair of control elements, referred to as A and B, respectively. As explained before, each of the type A controls can be called adaptive controls in the level in which they are found. Type B controls are not only variable controls, which cause changes in the response characteristics for type A controls. They also harmonize within the driver based on higher-level logic, by letting the driver use the freedom of variable control of the level desired even if they do not provide explanations for higher levels.

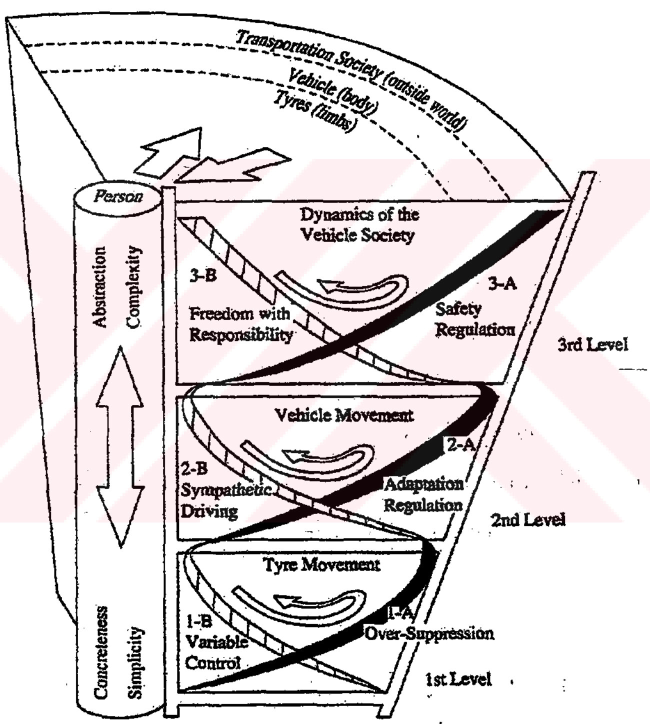


Fig 3.44 Hierarchical relationships and rhythms in control logics

That is to say, the first logic level consists of F control in position 1-A, and P control in position 1-B, and the second level consists of F control in position 2-A and P control in position 2-B. Then, the third logic level consists of the society-oriented L control (3-A), which goes beyond the level of the individual. In the current situation where vehicles are operated by people, there is no control existing to which 3-B can be applied.

In this way, traction control operates at multiple levels within a hierarchical structure defined by vehicle movement and social dynamics (and is therefore not just concerned with tyre performance) . The respective levels are considered to be mutually connected. Because the range becomes greater and the degree of complexity increases as we progress to a higher level, the control information that can be used becomes increasingly abstract, and the setting of control variables, central values and threshold values becomes more and more complex. Accordingly, in control which crosses over the boundary of a level, the restrictions of a high degrees of abstractness ignore the context (meaning and process) of an intermediate level, and control may more strongly into a lower level. Because of this, a double-binded contradiction can easily occur. Moreover, in the real world these levels are stacked up in a way that surrounds the driver and they can only be perceived from the inside, so that identifying the type and numbers of levels could be considered to be very difficult.

3.18 Harmonizing Traction Control With Other Systems

Up to the previous section, traction control has been divided into different types based on fundamental forms, and these fundamental forms have been used to search for the meaning behind traction control from several different angles. In this section, these basic forms will be applied to the harmonization relationships between traction control and other systems, and the future of overall control systems centering on traction will be examined.

Vehicle control systems adjust the "relationship" among the man-vehicle-society/environment system, and thus can be said to assist in the total harmonization of this relationship. Let us then position the operation of the fundamental forms of the control elements mentioned previously into the system operation process of the man-vehicle-environment relationship (Figure 3.45). Thus P control can be considered to be the element which operates through the personal process of receiving information from the vehicle and environment resulting in maneuvering the vehicle. F control is the motion process where the vehicle receives the maneuvering force from the driver and the disturbance from the environment, and then moves. L control is principally the surrounding process where the environment and the transportation society feed information to the driver and external forces at upon the vehicle.

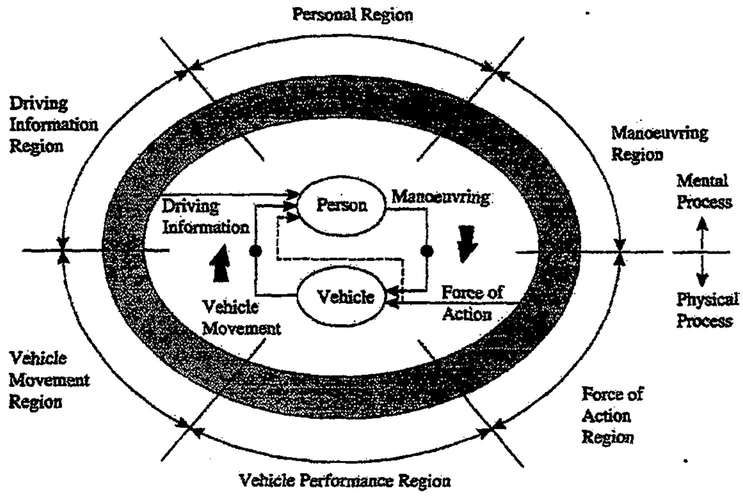


Fig 3.45 Mutual interaction in the human-vehicle- environment system

These will be considered in terms of three examples of vehicle control systems based on the three fundamental forms P, F and L in this changed point of view (Figures 3.46,3.47, 3.48).

Active suspension: In this system, the vehicle uses the F control system (as described above) to commonsate for and suppress vehicle vibration caused by uncomfortable variable forces from the environment. This system carries out the main control using a skyhook damper driven by hydraulics, and added to this is the transient control of steering characteristics corresponding to P control, and also vehicle movement control such as roll and pitch control. This control system utilizes micro-movement control, i.e. the vertical changes to the position of the wheels, in order to try spontaneously to create a macro-ordering, such as the exacted steering characteristics and the desired vehicle movement.

Yaw rate feedback-type 4WS: In also, yaw rate feedback-type 4WS has been implemented not only in order to improve vehicle steering characteristics, but also compensate for and suppress vehicle movement tendencies arising from disturbances, such as crosswinds. In mechanical-, electrical- and hydraulic-type 4WS systems, not only is the transient control of steering characteristics corresponding to P control carried out, but also the effects from unexpected disturbances from the environment such as crosswinds are also compensated for as a part of F control. This system always attempts to realize and maintain a macro-ordering of a constant reference of steering characteristics.

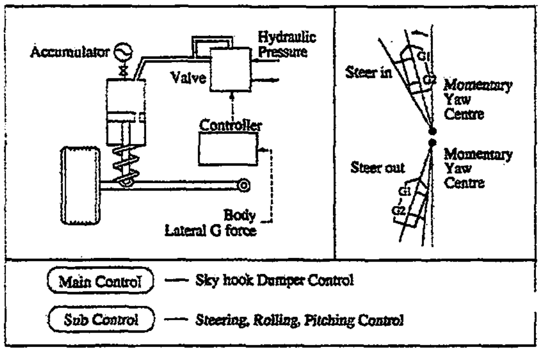


Figure 3.46 Nissan hydraulic active suspension

ABS: This system is the oldest example of F control, and it has become widely used. recently, a type of ABS which senses the lateral acceleration of the vehicle has been implemented. The braking force applied to all four wheels during a turn is controlled and balanced using sensors. Accordingly, the handling performance and braking performance are both said to be maintained, and this can also be said to be the case of P control. Nevertheless, the essential characteristics which defines this control is that the ABS self-adjusts the micro-control, such as wheel slip control, in response to the macro-driving conditions such as the lateral acceleration of the vehicle.

As can thus be seen, P, F and L controls are all present in the many vehicle control systems, including TCS's, in current usage: P control is a control which applies desirable qualities such as a tool from the person to the vehicle; F control is a control which returns compensation from the vehicle to the person and the environment; and L control can be called a control which safely protects the person and the vehicle from the environment, in particular the transportation society. These three forms of control adjust the mutual actions between the person, vehicle and environment, respectively, and provide a total ordering and harmonization.

In addition to corresponding to all of the principal orthogonal components of the forces acting on the tyres, the three control systems mentioned above and the TCS (a total of four systems) are also independent in terms of their movement functions. Therefore, if these four systems are integrated to maintain the ordering in the area of vehicle dynamics in the second layer, they would be expected to form a single comprehensive harmonization control.

These four control systems have been given the following names.

-Four-wheel anti-lock brake system (ABS);

-Rear wheel steering system (RWS);

-Traction control system (TCS);

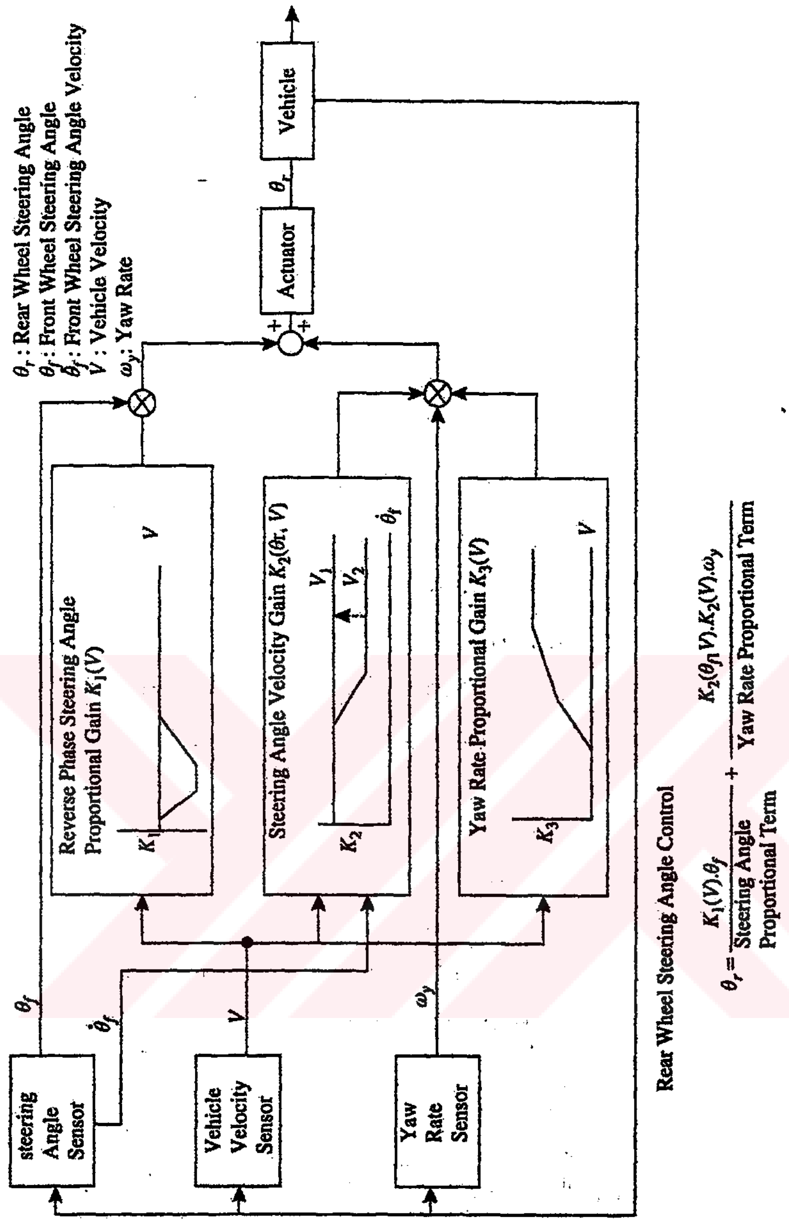


Figure 3.47 Toyota 4WS control block diagram

-Active suspension system (SUS).

Regarding these control systems, the four-wheel steering system (4WS) which has been implemented in actual vehicles is here included as a RWS system. That is to say, the front wheel steering system in a wide sense, and the maneuvering operation system in this chapter includes mechanical systems such as the steering wheel, accelerator, brakes and transmission system, and other electronic assistant systems.

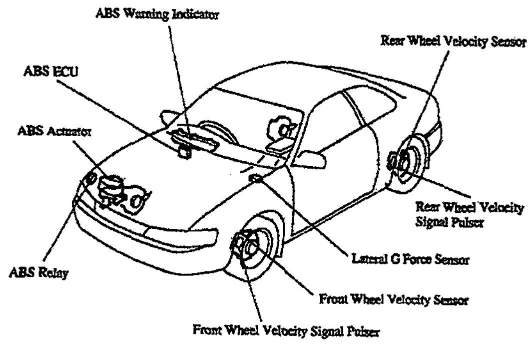


Figure 3.48 Toyota 4WS ABS

The features of comprehensive control for vehicle dynamics are different from conventional total control which depends on signal transmissions between cooperating systems. The result of the elemental systems at the micro-level spontaneously generating and ordering at the macro-level is that a field is created where all elemental systems exert an effect, and through the application of this field, other elemental system groups carry out self – adjustment, so that the application starts to become apparent not only as elements but as whole system. The ordering then becomes stronger, and a new ordering is continually being generated. That is to say, information is transmitted through this ordering, and the information is received by the union of the fields. This situation is illustrated in Figure 3.48.

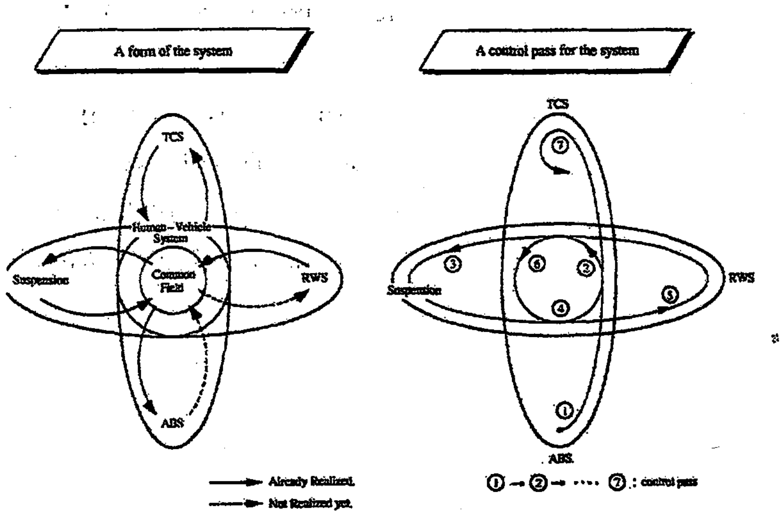


Figure 3.49 Circular- type cooperative control system

The advantages of a universally comprehensive control are that signal transmission is simply rendered unnecessary; elemental systems have universal interactions, and the mechanism is thus made independent. This means that, if an element is suddenly taken out of the system, or if it is replaced with a more advanced element, or even if the number of elements is increased, only the macro-control performance is affected, and the total control will automatically continue to function as always. This is a very important quality, and can be applied to vehicle dynamics control in the following way.

As is shown in Figure 3.49, a target operation such as cornering is considered. When the full force of the brakes is applied and the vehicle enters the ABS operation range, the universal ABS first selects the optimum transient ordering of the steering characteristics for the braking action from several alternatives in line with the driving rhythm of the driver, and then commences the wheel anti-lock operation in order to maintain this ordering . At this time, the conditions of load transfer caused by braking are formulated, the resulting vehicle movement is sensed and the auto-adjusted universal rear wheel steering system and active suspension system controls are activated and the control is adjusted in response to the diving. Because this causes the optimum steering characteristics to be formulated during the cornering operation, the universal TCS which senses this in the field selects the optimum steering characteristics when straightening up after the turn in response to this field and carries auto-adjustment control. The result not only for the TCS but also for the driver contributes in to producing a typical control according to a pattern of control; or in other words, there is a greater possibility of predicting those vehicle movements which will occur next, with no losses in the flow of overall driving during cornering. This is the reason why it is possible to achieve a high level of both handling performance and traction performance in the human-vehicle-environment system. Moreover, direct electrical signal transmissions are no longer needed in any case.

Figure 3.50 makes an assumption of what will play a part in vehicle control systems in the near future. The size of the controller in this figure is much greater than that shown in Figure 3.46.Themeaning of the control as another cultural system shown an increase in response to the requirements of individuals and society from the relationship of the existence of the vehicle as a machine. With respect to L control, which did not feature so prominently in the examples given earlier in this

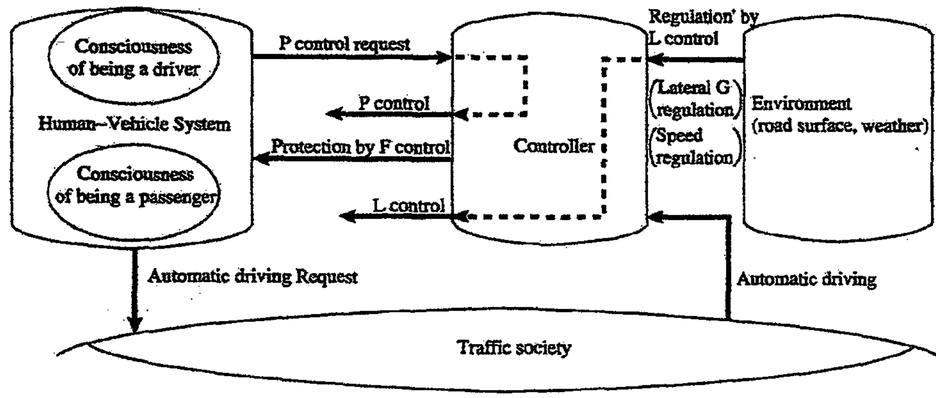


Figure 3.50 Role of the vehicle control system in the near future

discussion, the fields where this control should be applied will become more clearly defined within the context of the maturing of society; and L control should make a renewed appearance in the transportation society. It is in a society in which the road environment and the traffic flow are monitored by the social computer as shown in the figure that the validity of this will be demonstrated. And what is more, the control which is the optimum target control for a level becomes more concrete, more localized and more limited in its time frame. The reason for this is not that the simple actions of people or the movements of objects themselves are good or bad, but that within the relationships and differences between these actions and movements, the variety of other activities that support them, the background which specifies the time and place, and the context. Judgements should therefore be based on this overall perspective.

Accordingly, controllers for vehicles must progress and develop in both the vertical direction in terms of logic levels, and in the horizontal direction in terms of harmonization control; the fields of movement must become more concrete and the moving action must become more stable and skilful.

3.19 ABS-Traction Control, State of the Art and Some Prospects

Closed loop vehicle control comprising driver, the vehicle and the environment achieved by the automatic wheel slip combination of ABS and ASR.

To improve directional control during acceleration, the Robert Bosch Corporation has introduced five ASR-Systems into series production. In one system, the electronic control unit works exclusively with the engine management system to assure directional control. In two other systems, brake intervention works in concert with throttle intervention.

For this task, it was necessary to develop different highly sophisticated hydraulic units. The other systems improve traction by controlling limited slip differentials. The safety concept for all five systems includes two redundant micro controllers which crosscheck and compare input and output signals.

A Traction Control System can be achieved through a number of torque intervention methods. The most important are the ability to:

- adjust throttle angle
- interrupt fuel injection
- brake the drive wheels.

Within future traction control concepts priorities of traction, directional control, comfort and cost objectives will be influenced by the individual drive train (FWD, RWD, 4WD).

Driving a motor vehicle by accelerating, steering and braking is a form of closed loop control. The driver as observer, controller and actuator is unable to cope in many situations. Effective closed loop control can only be accomplished as long as the system is in an easy controllable state.

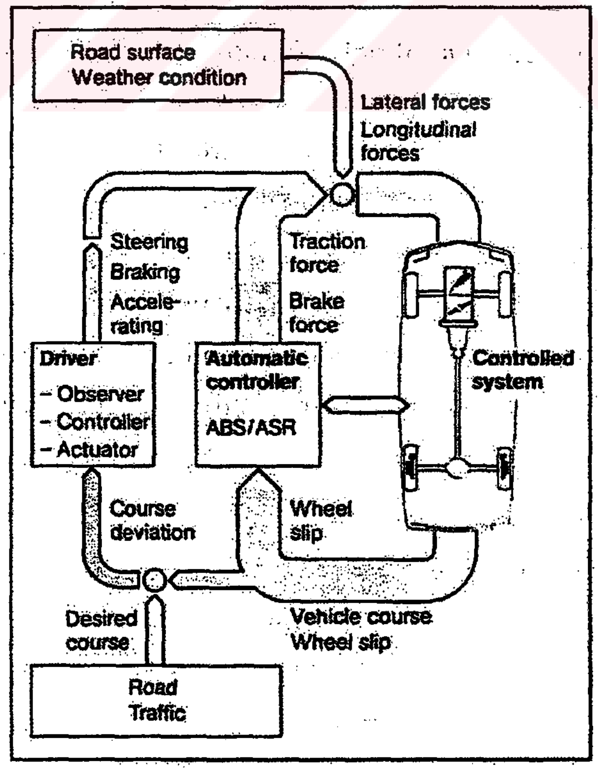


Figure 3.50 Closed-Loop Control with ABS/ASR

The most important interface between the vehicle and the environment is the coefficient of friction between the tires and the road. The ability to drive the vehicle will be lost or at least considerably impaired, if excessive wheel slip occurs when braking or accelerating. As the level of motorization and traffic density increases, the demands on the driver of a motor vehicle become more and more stringent. Consequently it has become a major goal to improve the handling and driveability of vehicles. In the diagram above, the closed loop control is completed with an automatic controller.

This controller can intervene more rapidly and more accurately than the driver. It relieves the driver of some important and very difficult control functions. The task of ensuring directional control during braking is handled by the already familiar ABS. To improve directional control and traction during acceleration, Bosch has different ASR systems in series production.

3.19.1 Systems in Production

Directional control, traction, and steerability can be handled in a number of ways and the system can be designed for different demands. Regardless of the chosen intervention method, the control strategy is important to fullfill these demands. Bosch ASR controllers are able to adapt to different driving situations. To optimize the control function we utilize the following information:

- vehicle speed, to give traction priority at low speeds and directional control priority at high speeds.
- the speed difference of the non driven wheels, to detect a cornering maneuvre. The directional control has priority while cornering.

Vehicle acceleration and throttle position. In situations of low vehicle acceleration and slight throttle angles the control strategy is more sensitive.

Available Bosch systems demonstrate substantial improvements in driveability and handling.

3.19.2 System To Ensure Directional Control

One system ensures directional control merely by intervening in the engine management system. This intervention is accomplished through an Electronic Throttle Control System which reduces the drive torque via throttle and fuel/ignition cut out for quick response.

An additional engine drag torque control loop (MSR) is able to optimize the negative slip, if the driver inadvertently reduces the engine speed or shifts down on low friction coefficient.

The interface between the ABS/ASR-ECU and the Throttle Control - and Engine Control-ECU consists of six signals. The signals 1, 2 and 3 transmit pulse width modulated analogue data. Signal 1 is used for monitoring the electronic throttle micro controller and the accelerator pedal position. If a driven wheel starts to spin, signal 2 will be activated to reduce the throttle position. Now the driver's wish to increase the throttle position is limited. If the traction control system detects negative slip on a driven wheel it is possible to open the throttle to a predetermined position with signal 3. In both cases the traction control system takes over the responsibility to determine the maximum transmittable drive torque. The driver's wish is only considered if the resulting condition is stable.

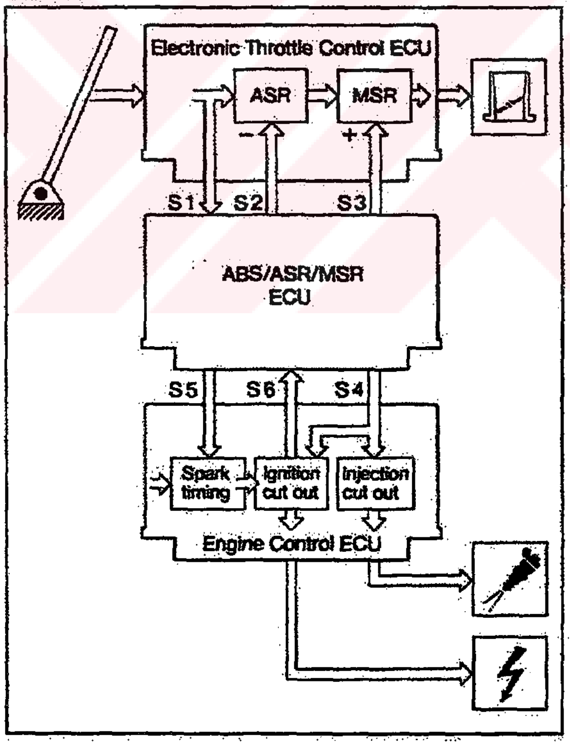


Figure 3.51 Traction Control ECU-Interfacing

In situations where the drive torque at the driven wheels suddenly increases, for example if the driver inadvertently opens the throttle on ice, in addition to the reduction of the throttle position, the ignition will be cut out with the digital signal 4. Interrupting ignition is the fastest method of reducing drive torque and is time limited for a given application. In order to protect the catalytic converter, fuel injection would be simultaneously suspended. To optimize the comfort and minimize ignition cut out time, a digital signal 5 is used. This retards the spark advance. Finally signal 6 is used to monitor the ignition cut out function.

As more and more vehicles are equipped with electronic motor management systems and ABS, only an Electronic Throttle Control System and a special ABS/ASR-ECU are necessary to improve the directional control of a motor vehicle. To improve traction on split friction coefficients, a limited slip differential can be added.

3.19.3 Systems To Ensure Directional Control And Traction

Two systems in production not only ensure proper directional control, but considerably improve traction on various friction surfaces.

Brake intervention is superimposed on throttle valve control. Ignition/injection cut out are not used, however an Electronic Throttle Control System is used. The brake intervention for these two ASR-Systems has been developed to achieve a fast and comfortable brake force response at the driven (rear) wheels.

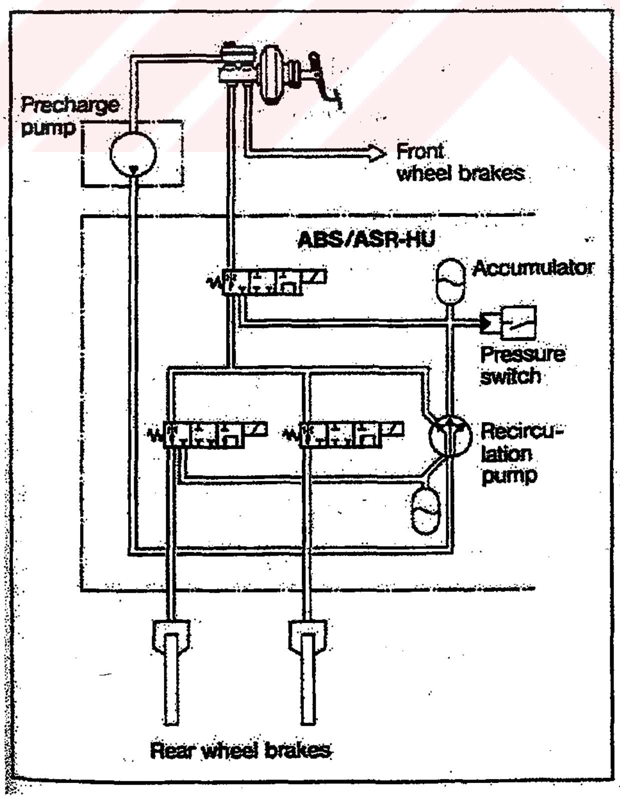


Figure 3.52 ABS/ASR-Hydraulics

Both systems require an accumulator to achieve a pressure increase time of less than 200 ms (0 to 50 bar). A pressure switch is added to monitor the accumulator charge.

One System has been hydraulically integrated to use the same wheel circuit solenoid valves for either ASR control or ABS. The recirculation pump is extended with a third pump piston. The noise level specifications of our customers have been achieved by noise-conscious design. The precharge pump allows more flexibility in packaging. This system is designed for rear wheel driven vehicles with a front/rear brake circuit division.

This system is designed for different brake circuits (front/rear or diagonal) and for rear or front wheel driven vehicles.

3.19.4 Systems To İmprove Traction

Two controlled differential lock systems were developed by Bosch and are currently in production. One system is based on a rear wheel drive vehicle with the control of the rear axle differential lock. The other system is based on a four wheel drive vehicle with an additional differential lock control at the center differential.

The solenoid valves shown in the hydraulic schematic are of the same type as used in ABS. The control logic, based on the four wheel speed signals from ABS, can be divided into three functional parts:

- Optimization and limitation of speed difference at the driven to achieve better traction.

- Optimization and limitation of the axle speed difference to achieve improved traction.

- Ensuring directional control with lock function on high friction while cornering, if the driver throttle position too much.

For the last function it is necessary to analyze the signal of a lateral acceleration sensor. The differential lock is activated in following situations:

- negative slip at one or both rear wheels and
- a high value of lateral acceleration.

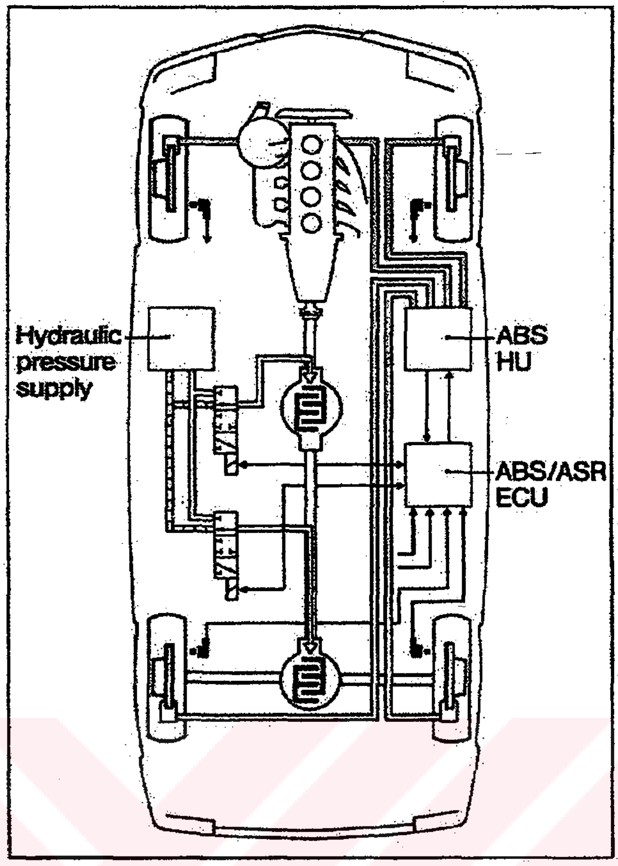


Figure 3.53 Limited slip differential control

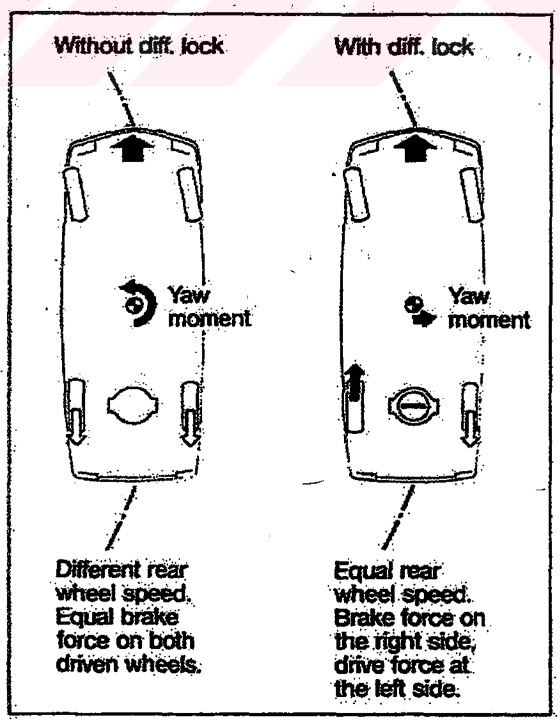


Figure 3.54 Trailing engine oversteer

Without this differential lock function there are equal brake forces while cornering and different wheel speeds at the rear wheels. With a differential lock function there are equal wheel speeds and different forces at the rear wheels. At the inner wheel there is a drive force, at the outer wheel there is a brake force. In this case of differential lock activation, the resulting yaw moment minimizes over steering tendencies.

3.19.5 Important Possibilities To Optimize The Drive Torque

Within fixed limits and a given drive concept it is possible to increase the drive torque which can be transmitted to the road by

- activating differential locks or
- braking the spinning wheel.

These possibilities to increase the transferable drive torque cannot guarantee directional control while accelerating. For this demand, additional methods are necessary to reduce the drive torque.

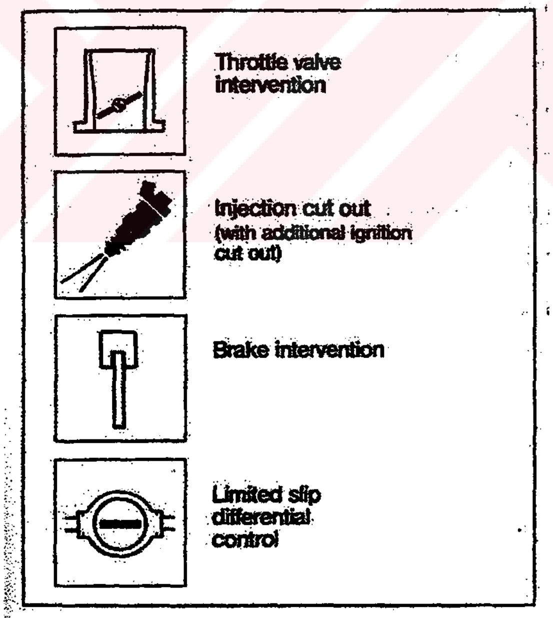


Figure 3.55 Four important interventions for Traction Control

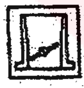
The most important intervention to reduce the drive torque is the reduction of the engine torque. This intervention is the only possible method of implementing a Traction Control System that is able to guarantee directional control of the vehicle under all conditions without Intervening with any other components of the drive train. This engine torque reduction can be realized by

- reducing the throttle valve position
- interrupting the ignition or injection
- retarding the ignition timing.

To retard the ignition timing in the permissable range normally reduces the engine torque only slightly and is therefore only a supplemental intervention. In order to protect the catalytic converter ignition cut out without an injection cut out is not recommended. Active brake intervention is an additional method to reduce the drive torque at the driven wheels. The "State of the Art" however does not include a suitable method of reducing drive torque by opening the clutch or changing the transmission ratio.

3.19.6 Possible System Configurations

The demands regarding the response time from intervention to reaction at the driven wheels depends on the drive concept. Every vehicle manufacturer has an own philosophy regarding the optimization of traction, directional control and comfort therefore various system configurations exist.

Traction Control with throttle valve intervention decouples the valve from the accelerator pedal with an Electronic Throttle Control System or a special actuator which only reduces the throttle position. The driver's wish to put more power to the road will only be fulfilled to the extent of which is physically possible. If only the throttle valve is controlled, the throttle valve actuation time, the engine inertia and the elasticity of the drive train will cause a relatively large wheel slip over a longer period of time. In other words the directional control of a rear wheel drive vehicle, especially with a high power to weight ratio, cannot be ensured by controlling only the throttle valve. In the case of a front or four wheel drive vehicle, a throttle intervention with a short actuation time may be sufficient.

A system with throttle control and the amplitude and the fuel injection intervention duration of the slip drastically. Therefore this combination is suitable to ensure the directional control of a vehicle independent of the drive concept.

Generally it is also possible to implement Traction Control simply by intervening in the fuel injection and ignition systems. This system utilizes a sequential fuel injection with cylinders being individually cut out and the spark timing being adjusted during control. Although this type of system is able to guarantee directional control of every vehicle, certain sacrifices are inevitable with regard to comfort, especially on ice and during engine warm up.

A Traction Control System with engine torque reduction and additional brake intervention is able to guarantee directional control of the vehicle under all conditions. The requirements of brake intervention differ according to the method used for engine torque control. For rear wheel driven cars with engine torque control only by throttle valve reduction, the brake intervention must be especially rapid. To achieve these requirements a highly sophisticated hydraulic unit has to be used. The demand for a fast pressure increase can be reduced, if the directional control of the vehicle can be ensured by controlling the engine torque alone. In this case the brake intervention has simply the function to improve the traction on split friction coefficients.

The demands on the brake intervention for front or four wheel drive vehicles are not high. Therefore a simple brake intervention combined with throttle intervention is sufficient for these vehicles.

A "brake only" Traction Control System would appear a suitable method of controlling the wheel slip. The brakes are able to withstand extremely high loads for a limited period of tine or within a limited speed range and are consequently able to convert a large amount of energy into heat. The availability of a high performance Traction Control System on the other hand is usually required to be unlimited with regard to time and speed.

Therefore, brake intervention without engine torque reduction is a feasible solution for vehicles with a relatively low power-to-weight ratio and specially designed brakes. If the "brake only" intervention is restricted to the "drive away" speed range with limited "on" time, it can be used as a replacement for a differential lock.

A Traction Control System with an engine and differential lock intervention is partly similar to the system with the brake intervention method. It

increases the traction, especially on roads with mixed friction coefficients. The differential lock intervention is not able to improve the directional control of the vehicle while accelerating. To ensure the directional control, the engine intervention alone must be sufficient.

Compared with conventional differential locks, switchable or adjustable locks offer major advantages. They do not impair operation of the ABS and permit high locking ratios if necessary without impeding curve handling. While cornering on high friction coefficients, the differential lock minimizes the over steering behavior of rear wheel drive vehicles if the driver reduces the throttle position too quickly. Due to the high cost of controllable differential locks as compared to brake torque control, this concept is not expected to be widely utilized.

3.19.7 Systems For 4WD-Vehicles

To improve directional control it is necessary to analyze the wheel slip at every wheel. Since all four drive wheels can spin when accelerating on low friction coefficients, computing the vehicle speed is complicated. This can be solved with an additional sensor for vehicle acceleration or for the vehicle speed over ground. Many different 4WD concepts exist. Therefore, each application of 4WD Traction Control Systems will be custom designed and the prediction of general trends is difficult.

3.19.8 Systems For RWD-Vehicles

The major demand for this drive concept is the improvement of driving safety. The directional control and vehicle stability especially on low friction coefficients has to be ensured. This demand can be fulfilled with a fast engine intervention or the combination of throttle reduction with a fast brake intervention.

The combination of either brake intervention or differential lock control with throttle intervention, and if necessary with injection cut out lead to a highly sophisticated system which ensures stability and improves traction. An additional engine drag torque control, especially for vehicles with a manual transmission will be added. To increase the traction, the use of a differential lock is well known. Traction may also be improved by brake torque control.

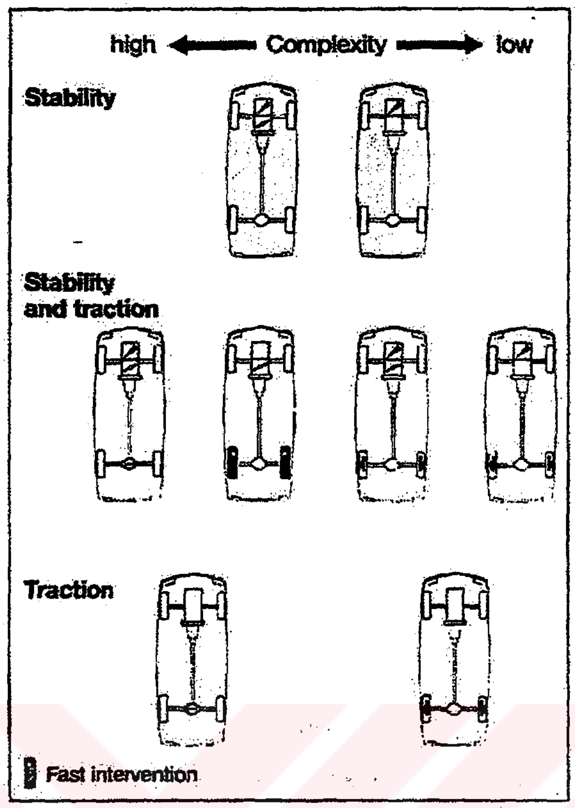


Figure 3.56 Traction Control Systems for RWD-Vehicles

Three of these systems are in production. Depending on the demands for stability, traction, comfort, and costs one or more of the other systems will be developed. It is expected that the combination of engine control and brake torque control will be the most popular system for the future. Although adequate system performance can be achieved by using controllable differential locks, cost advantages of brake torque control concepts will not permit a wide spread application of controllable differential locks.

3.19.9 Systems For FWD-Vehicles

The major demand for this drive concept is the improvement of traction. Systems with engine torque intervention only will ensure the steerability without a considerable increase of the traction. As the demand for the control of the wheel slip deviation at the front driven wheels is not strong, a fast throttle valve control seems quick enough to ensure the steerability. For the same reason the combination of brake torque control and throttle control without injection cut out will ensure the steerability.

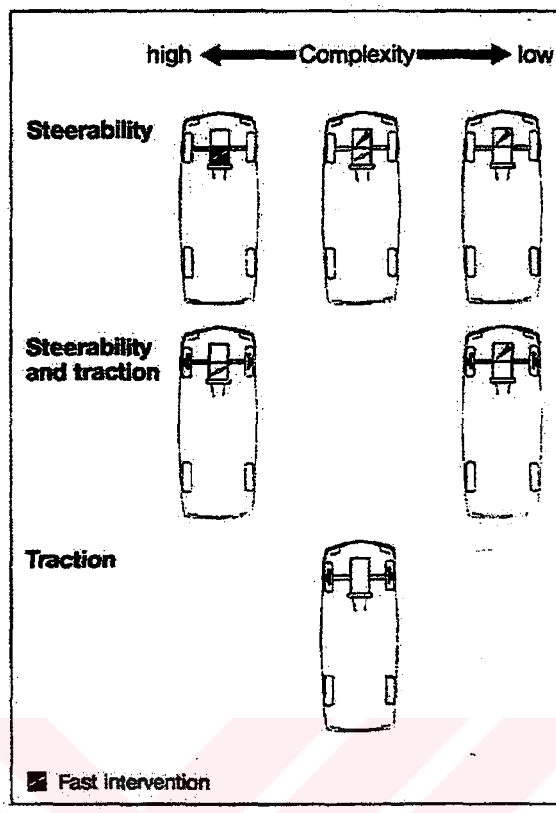


Figure 3.57 Traction Control Systems for FWD-Vehicles

To improve traction, a system with brake intervention must be chosen. The combination of brake intervention and engine torque reduction leads to a highly sophisticated system. It is expected that in the future only systems with brake intervention will be widely accepted. One of these will be the brake only "drive away" system.

3.20 Development Of New Control Methods To Improve Response Of Throttle Type Traction Control System

A description is made of new control methods to improve response ot wheel slip regulation. These methods enabled a new Traction Control (TRC) system based on throttle control rather than brake pressure to be developed. Major points are as follows:

(1) Use of fuel injection cut-ott to minimize delay

(2) Additional adaptive throttle control logic

By these means, a response nearly equal to that with brake pressure control is achieved at lower cost and with a considerable weight saving. Furthermore, the system, by suppressing noise and vibration, enhances the driver's control ability.

It a vehicle is accelerated on a slippery surface; wheel slip may reduce the acceleration and cause unstable behavior, manifested as oversteer in the case of RWD or excessive understeer in the case of FWD. Although 4WD option otters a significant improvement, it is expensive and increases weight. Thus the majority of vehicles are 2WD. When the road is snow covered, adhesion may be improved by means ot chains or special snow tires, but such measures are not so effective on ice.

Therefore, to resolve the problem of wheel slip, many passenger cars are now available with some form of Traction Control (TRC) system, by which the power applied to the driven wheels is regulated in response to the state of wheel spin. This paper describes new control methods to improve the response of a throttle type TRC.

3.20.1 Traction Control Methods

The most obvious controls for a TRC system are throttle position and brake pressure. Brake pressure control is advantageous in terms of response as it directly affects the driven wheels. Moreover, if the brake pressure is independently controlled for each driven wheel, the effect of a limited slip differential can be obtained. However, such control can adversely affect steering and vibration levels, particularly in a FWD vehicle. It should be borne in mind that when the driver is faced with treacherous surface conditions, he must be free to concentrate on steering control and therefore stress due to other factors must be minimized. In this context, both noise and vibration are important considerations.

Throttle control is rather slow in response (see Figure 3.58), but has the advantage that noise and vibration are suppressed. Consequently, the system operates smoothly and, when the TRC is active, the driver is not distracted.

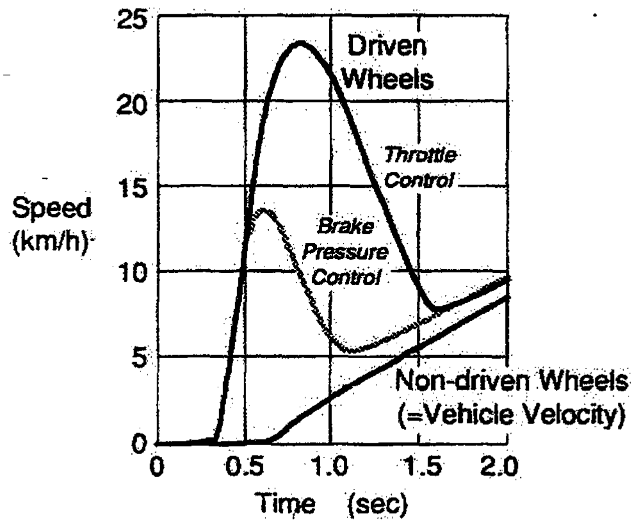


Figure 3.58 Slip reduction effect

3.20.2 System Configuration And Components

Figure 3.59 shows the configuration that was adopted for the throttle type TRC system. Basically, the system utilizes a speed sensor at each wheel, a special throttle body assembly and an ECU (Electronic Control Unit).

The TRC ECU is based on an 8-bit, single chip, CMOS micro-computer containing 1 2kbyte-ROM, 16-bit programmable timer, Hi-speed I/O, interrupt controller, and clock generator. Minimum instruction execution time is 0.5 micro seconds. Special intertaces and drive circuits were developed for this ECU. Speed sensor signals are input to the TRC ECU via the ABS ECU. Throttle position sensor and engine speed signals are input to the TRC ECU via the engine and transmission ECU.

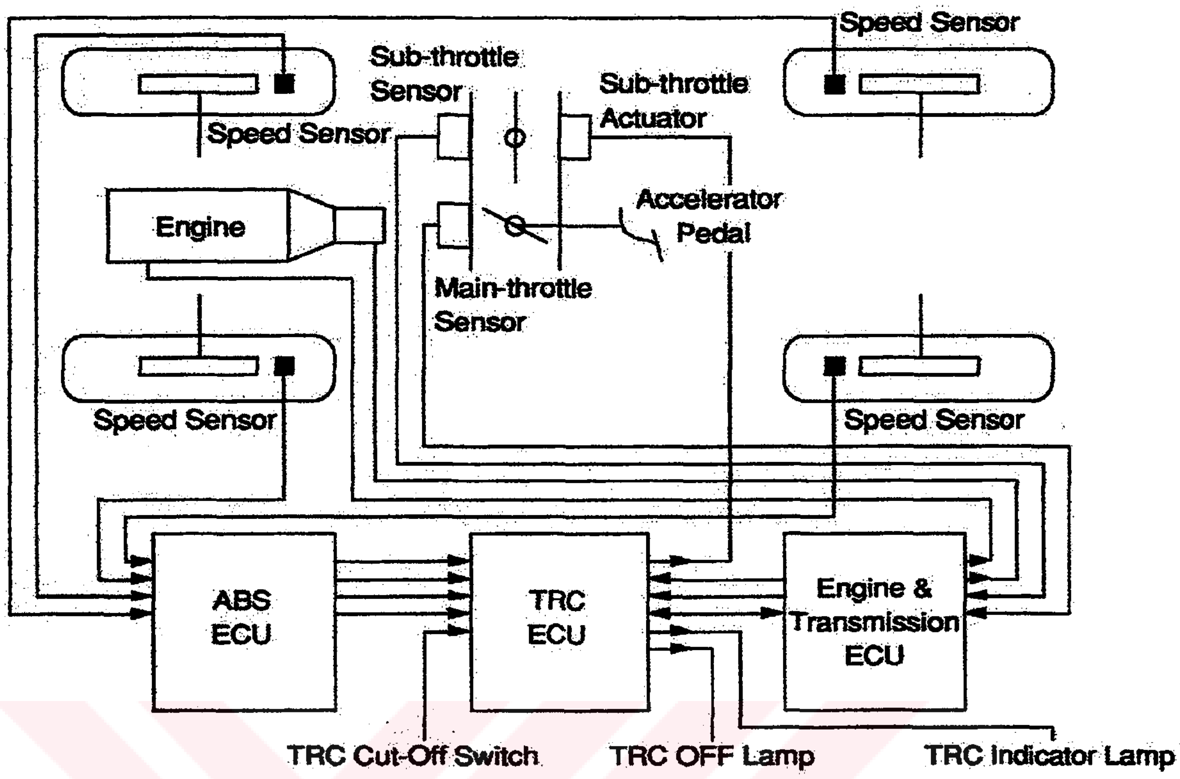


Figure 3.59 System Diagram of TRC

Fig.3.59 shows the throttle body assembly, which is comprised of a main-throttle and a sub-throttle. The main throttle is controlled by the driver through the accelerator pedal. The sub-throttle, which is upstream of the main-throttle, is usually maintained in a fully opened position by a mechanical return spring. When the TRC is activated, a step motor causes the sub-throttle to close, thereby regulating the engine torque. It takes about 200msec for the sub-throttle to move from fully opened to fully closed position. The accuracy is within 0.3deg.

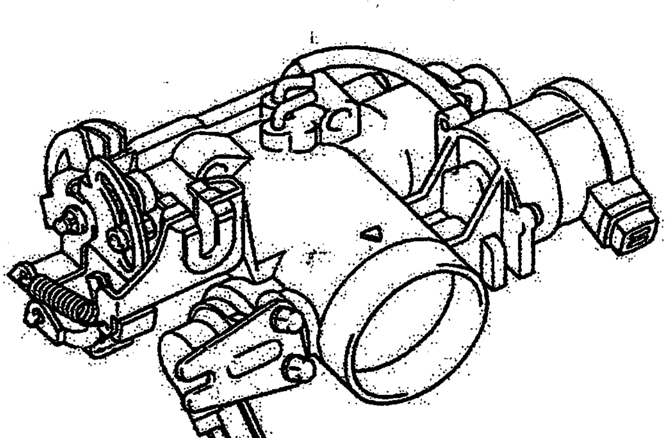


Figure 3.60 Throttle Body Assembly

3.20.3 Development Of Adaptive Logic To Improve Response

The control algorithm for throttle feedback was determined as follows:

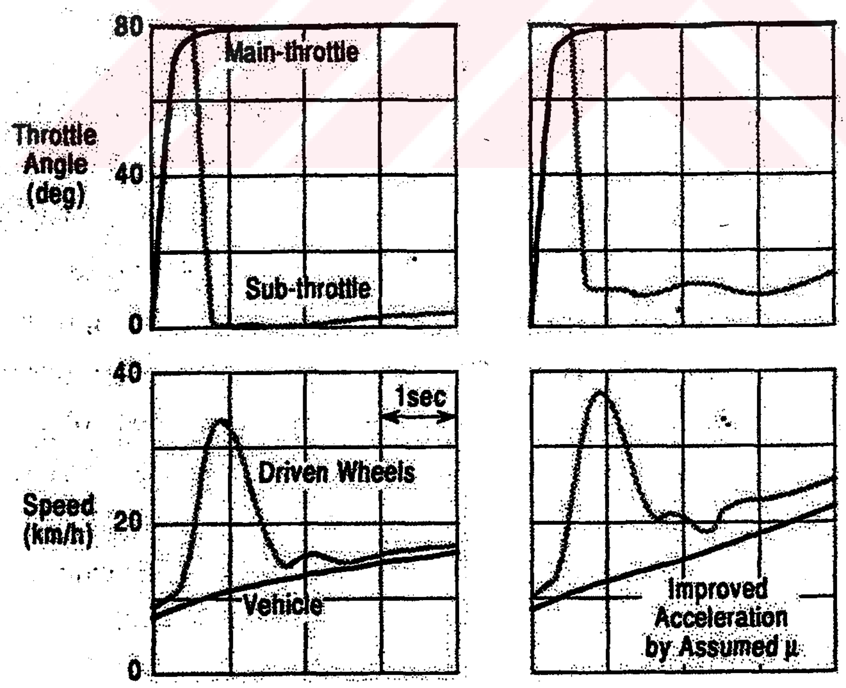
$$TA\,s(t) = K.A.\int (Vts - Vf)dt + KB.(Vts - Vf) + Ci \qquad (3.1)$$

$$Vts = (1 + S).Vb \qquad (3.2)$$

Where

Tas	: sub-throttle target angle
Vts	:driven wheels target speed
Vt	:driven wheels speed
S	:target slip ratio
Vb	:vehicle velocity
KA,KB	:feedback control gain
Ci	:initial value of TAs

The possibility of improving response by adding a differential term was considered but rejected because of the difficulty of providing compensating for the effects of disturbance and noise on the wheel speed sensor signal.



3.61a Normal gain 3.61b Doubled Gain

Figure 3.61 Effect of Adaptive Gain

A second possibility was to maximize the feedback gains KA, KB. Figure3.61 shows data obtained on a road with a low adhesion coefficient (μ). When KA and KB are properly tuned (Figure 3.61a), response is slow.If the gains are doubled (Figure 3.61b), response is marginally improved but throttle hunting occurs. In view of these findings, it was concluded that any improvement obtained within the narrow limits imposed by this approach would be negligible.

Accordingly, the authors decided that to improve response, it would be necessary to make use of additional engine management controls (i.e. fuel injection cut-off and ignition retard) and to develop adaptive logic.

3.20.4 Adaptive Control Of Ci

After TRC is activated (i.e. the step motor starts to close the sub-throttle), there is inevitably a delay before the engine output torque is reduced. This delay is dependent on the time required to adjust the sub-throttle to the initial target angle Ci and the volume of the surge tank. To compensate for this delay, fuel injection cut-off is executed from the instant TRC is activated until the sub-throttle reaches Ci. If Ci is too large, stability will be impaired, for now that the fuel injection cut-off is no longer limiting the driven wheels' slip ratio, it will increase rapidly. On the other hand, if Ci is too small, vehicle acceleration will be insufficient. To prevent these errors, Ci should be a function of μ and of engine speed. For this purpose, the u value can be obtained by reference to stored data, i.e. a table correlating driven wheel slip rate to μ. Figure 3.62 shows the effect of this logic.

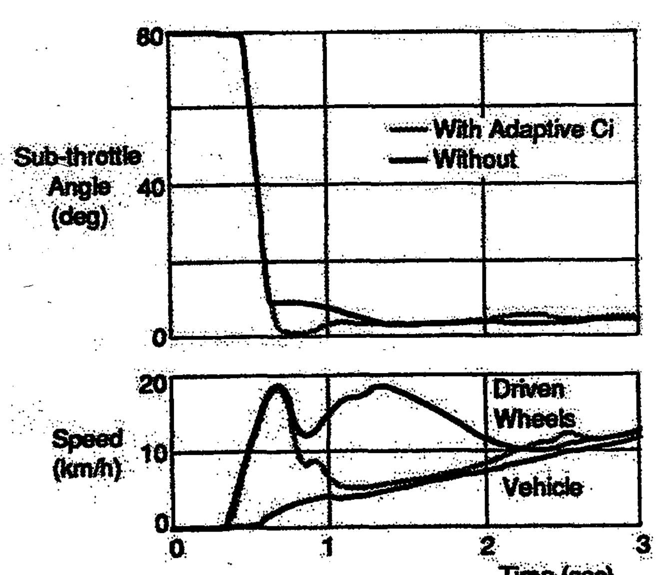


Figure 3.62 Effect of Adaptive Ci

When TRC is not active, μ can be assumed to be at least equal to the acceleration of the vehicle, as measured in terms of G. Thus, if the vehicle acceleration exceeds a set value, μ can be assigned a particular value.

3.20.5 Adaptive Throttle Angle Step-Down

There is a strong possibility that μ may diminish while TRC is operating, for example the vehicle may pass from snow to ice. In such a case, fuel injection cut-off is used to immediately increase the effect of TRC. Since slip is reduced by this means, the feedback function will result in an overestimation of the sub-throttle target angle TAs. Thus, when the fuel injection cut-off command is terminated because actual sub-throttle opening equals TAs, the slip ratio will increase, necessitating a further period of fuel injection cut-off. To prevent this continual repetition, which would exacerbate noise and vibration, the sub-throttle angle is stepped down by a predetermined amount in accordance with stored data as soon as the fuel injection cut off command is executed. The effects of this logic are shown in Figure 3.63.

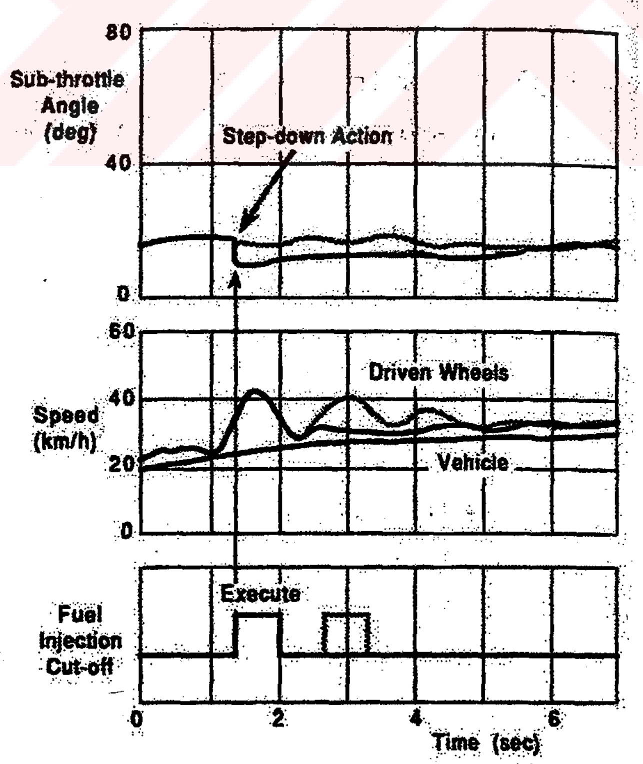


Figure 3.63 Effect of Throttle Step-down

3.20.6 TRC At Creep Torque

Even when the sub-throttle is fully closed and engine torque is reduced to a minimum, the creep torque may still be too high for the prevailing μ. In this case, fuel injection cutoff is employed to minimize slip (see Figure 3.64). A further benefit is that since slip is reduced, tire slip noise is also reduced.

3.20.7 Adaptive Feedback Gain

Assuming that the slip ratio of the driven wheels is properly regulated while TRC is active, μ can be calculated from the acceleration of the non-driven wheels. If μ is sufficiently high, feedback gain KA can be increased without the occurrence of throttle hunting. Optimum feedback gain should therefore be μ . Figure 3.65 shows how this logic helps improve acceleration determined according to the calculated.

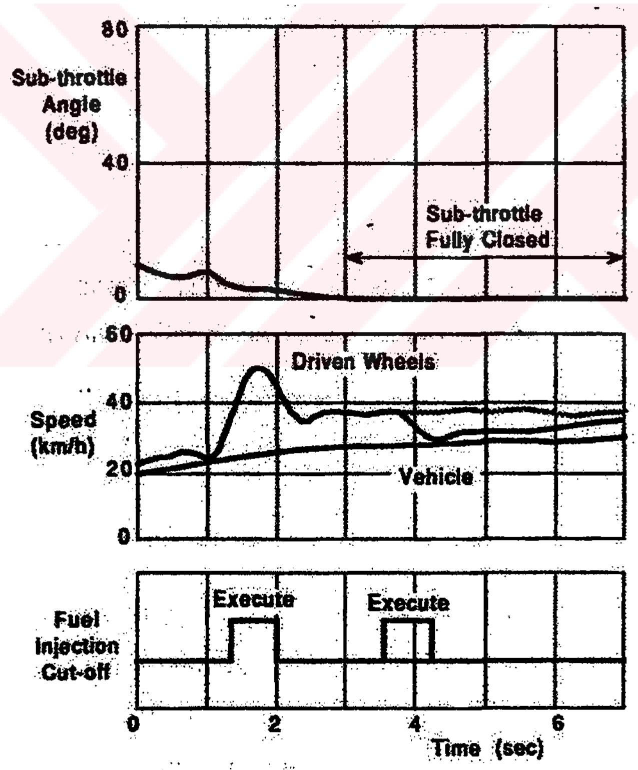


Figure 3.64 TRC at Creep Torque

However, because an external disturbance such as a change in gradient or an uneven road surface may cause an underestimation of μ, this logic could cause the feedback gain to be set below optimum. Hence, when updating the calculated value of μ, some sort of guard logic is required. For example, calculated μ should not be revised to a lower value unless wheel slip exceeds a predetermined level.

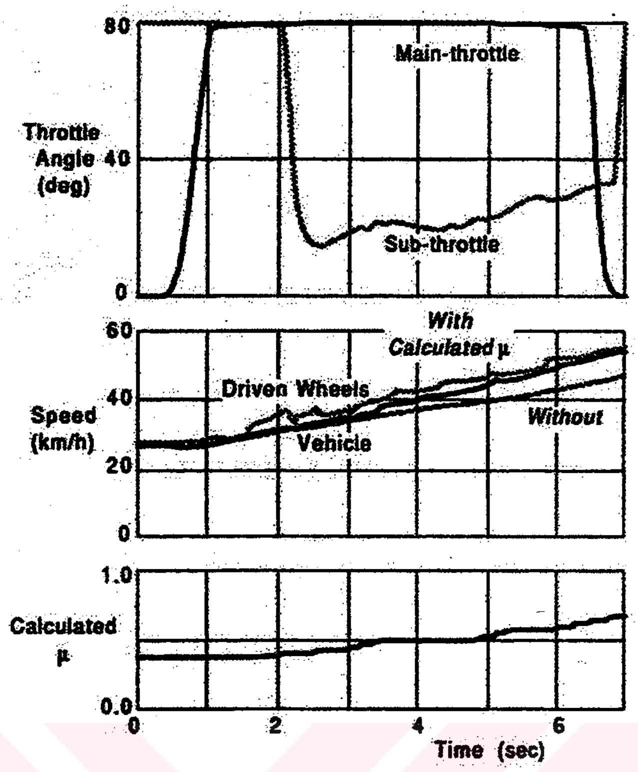


Figure 3.65 Effect of Calculated μ

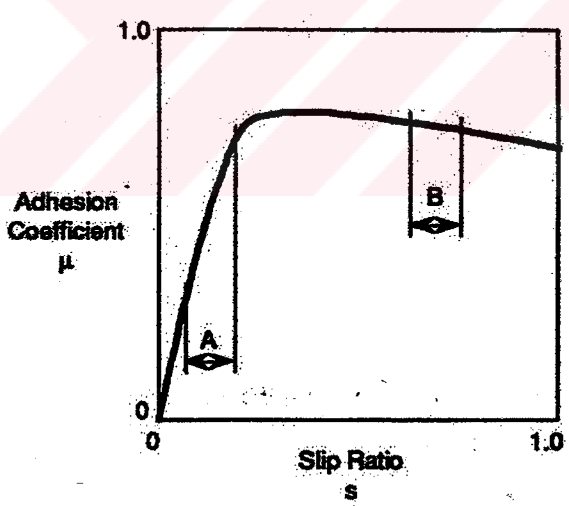


Figure 3.66 μ-s Diagram

Occasionally, the speed of the driven wheels may decrease and coincide with vehicle speed while TRC is active. Figure 3.66 shows an example of a μ-s diagram. The gradient in the region marked A, where the slip ratio is near zero, is greater than that of region B. A higher feedback gain is therefore required. For optimum acceleration, the target driven wheel speed is usually set at 104-110 percent of vehicle velocity. As Figure 3.67 shows, the difference between actual and target driven wheel speed (i.e. the proportional term of the feedback expression) has a much larger range when driven wheel speed is greater than the target value than when it is lower. This means that if driven wheel speed is close to or coincides with vehicle velocity, the feedback gain should be increased, but in a stepped rather than a linear progression.

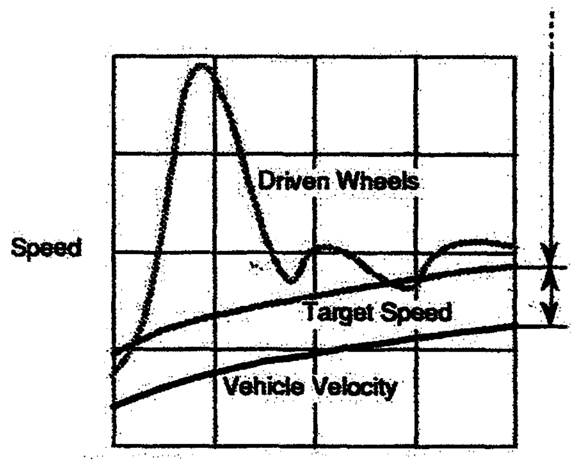


Figure 3.67 Difference between Actual and Target Wheel Speed

3.20.8 Application Of Adaptive Logic

Figure 3.68 is a control diagram of the system showing how the adaptive controls described above are applied to regulate throttle control and/or engine management. For purpose of simplicity, the logic descriptions have only referred to fuel injection cut-off, but under certain conditions, such as low coolant temperature or when engine speed falls below a threshold level determined by the engine ECU, fuel injection cut-off can not be executed. At such times, ignition retard is used instead.

3.20.9 Efficiency Of The System

The improvement realized by the new system can be seen from Figure 3.69 .It is clear that response is very nearly the same as that with brake pressure control.

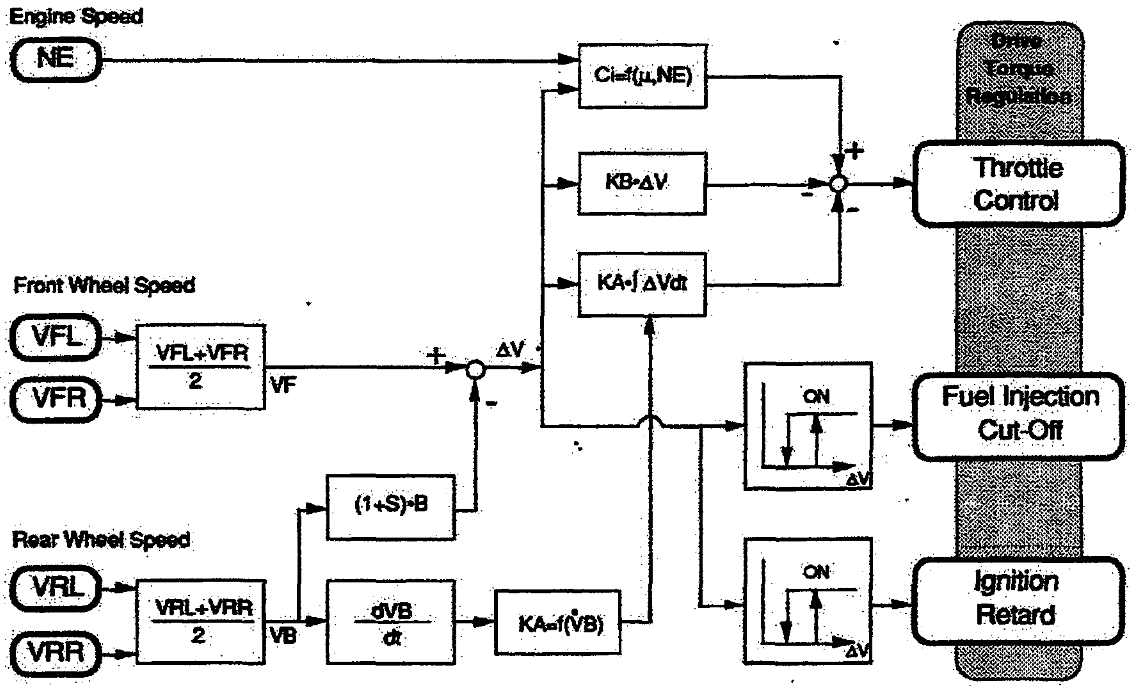


Figure 3.68 Block Diagram of TRC

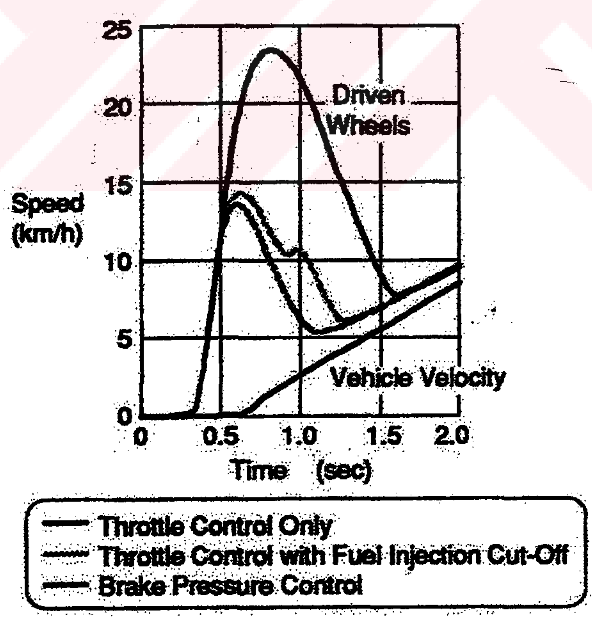


Figure 3.69 Improved Response of TRC

3.20.10 Acceleration Performance

Figure 3.70 shows 0-l00m acceleration time on snow. The vehicle with TRC is taster regardless of tire type. And the acceleration time data are more stable than they are without TRC.

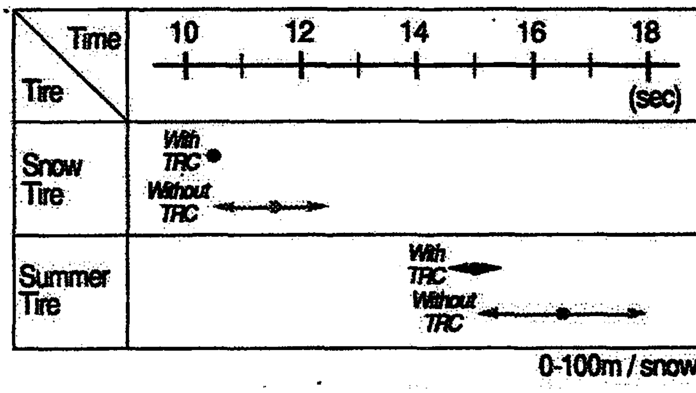


Figure 3.70 Acceleration Performance

3.21 The "Lexus" Traction Control (TRAC) System

One of the innovations for the Lexus L5400 is the development of a traction control system (TRAC system). The TRAC system suppresses the spinning of the driven wheels, which occurs easily on slippery roads during excessive acceleration, and it improves the acceleration performance and the stability of the car.

The TRAC system controls the engine sub-throttle angle and the brake hydraulic pressure for the driven wheels in the same way as the traction control system for the 1987 Toyota Crown. But, acceleration performance and stability of Lexus L5400 is better than Crown as a result of good wheel spinning control by additional improvements of the throttle and brake control methods. Especially as the TRAC system controls the brake hydraulic pressure individually for left and right wheel, the car acceleration performance on split-μ surfaces is improved notably.

In regard to the system composition, low costs and simplicity have been targeted by using components of the ABS, while the TRAC system is designed according to redundancy concept using two-valve type throttle body which gives satisfactory result in the Crown TRAC system.

The TRAC system has been evaluated in the northern part of the USA, in Alaska, Canada,Sweden, Hokkaido (Japan), etc., and excel lent car operation performance and high reliability have been confirmed.

3.21.1 As A Device For Improved Car Performance

During braking on slippery surfaces like ice and snow, the ABS presently is standard equipment for nearly all luxury cars.

On the other hand, in the case of front engine rear drive (FR) cars equipped with high-power engines, car instability like fish-tailing (swaying of the rear) etc. may occur on slippery surfaces during acceleration, and various improvement devices also have come into existence. These instabilities are caused by a reduction of the tire lateral force due to wheel spin shown in Figure 3.71 when the wheel slides sideways because of camber, tracks, irregularities, or other road surface disturbances. Especially for FR cars, the rolling front wheels have a large lateral force and there is no wheel side slip, but when the driven rear wheels spin, the wheels slide sideways.

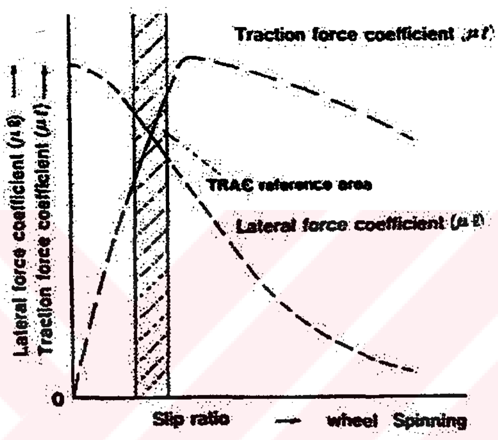


Figure 3.71 Traction and lateral force coefficients

The best improvement method for this is to use four wheel drive (4WD) system, where spinning of the driven wheels does not occur so easily, but 4WD has the disadvantage of added weight because of the more complex drive system, added costs, vibrations, noise, etc.

Installation of the traction control systems for increased car stability and improved performance during acceleration has started for some luxury cars,and it was available as an option for the 1987 Toyota Crown. The TRAC system for the Crown already has been on the market for 2 years, with good results.

For the development of the Lexuls LS400, the necessity of the TRAC system as an innovation in addition to the ABS was stressed, and development was advanced aiming for the best TRAC system becoming a car of the top class.

The basic development concepts for the TRAC system are

1.Ensuring vehicle stability and

2.Effective transmission of the traction force to the road surface.

When the driven wheel slip ratio is controlled in order to obtain maximum traction force, lateral force reduces and FR cars easily lost the stability. However, in the case of the Crown, there is only one rear speed sensor and a single channel for rear brake control, so that individual spinning control for each driven wheel is not possible, which is disadvantageous for stability , and as the traction force on the high reach the maximum stability and acceleration performance.

-μ side of split-μ surfaces is not transmitted sufficiently, it was not possible to The above points have been taken into consideration for the Lexus LS400 TRAC system, and a system improved from the Crown system has been used. The proven highly reliable 2-valve throttle body of the Crown and the indicator light, TRAC OFF switch mechanism, etc. have been used as they are.

Here, individual control was selected for the brake hydraulic pressure to control the traction force transmission mechanism on split-μ surfaces. Generally, an LSD (Limited Slip Differential) is used, but in the case of an LSD, there is a residence to turning on normal asphalt surfaces, and it also is disadvantageous in regard to ABS control. Therefore, it is not being used for the Lexus LS400.

Individual brake control obtains the same result as an LSD by braking only the wheel on the low-μ side of split-μ road surfaces, while the traction force is being transmitted effectively on the high-μ side, and there are no problems on asphalt roads because the TRAC system dosen't operate. Fig.3 shows the traction force transmission mechanism comparing individual brake control with simultaneous brake control.

On the other hand, improvement of the software also is extremely important for improvement of the TRAC performance. For the Lexus LS400 TRAC system, an ECU composed of 3 CPU's has been developed for a more substantial software.

3.21.2 ABS & TRAC ECU

A big difference between the Crown TRAC system and the Lexus LS400 TRAC system is the fact that the Lexus LS400 TRAC system uses a single ECU for control of both the ABS and TRAC system. The ECU is composed of three 8-bit single chip CMOS microcomputers developed for car use, and the individual CPU's execute data communication via a serial communication buffer.

1.ABS and TRAC system can drive the same solenoid valves. -Low cost performance-

2.ABS and TRAC system can have enough capacity of ROM (Read Only Memory) and RAM (Random Access Memory).

3.Program calculation cycle cari be short.

4.High reliability can be obtained.

- The V-CPU receives input from four speed sensors, it executes mainly four wheel speed and acceleration calculations, and it transmits information to the TCPU and the A-CPU.

- The T-CPU is responsible mainly for TRAC control, it receives input from the sensor for the degree of throttle opening etc., and it drives the step motor. The solenoid valve drive pattern is transmitted to the A-CPU.

- The A-CPU executes ABS control and brake drive control for the TRAC system. The solenoid valves are operted according to the ABS drive output signals.

In order to increase the ECU reliability, 'the CPU's mutually check their operation conditions, and when abnormalities are found, the output relays are switched off.

3.21.3 Software

The basic control philosophy follows that of the Crown TRAC system, but for further improvement of the wheel spinning control for the Lexus LS400, brake control and throttle control have been Imiproved.

Here, the control target speed calculation for the slip ratio of the driven wheels, the brake control method and the throttle control method will be treated.

3.21.4 Control Target Speed Calculation

The control target speed "Vrt" of the driven wheels, used for throttle control and brake control, is decided by the car speed "Vb", determined by the speed of the front wheels, and th& control target slip ratio "S". The slip ratio "S" has been decided by evaluation of the car acceleration performance and the stability with various low friction road surfaces and various tires.

For the Crown TRAC system, the slip ratio "S" was divided into the two values "S1" and "S2" in order to prevent interference between throttle control and brake control, but it is not desirable for accurate wheel spinning control. Therefore, with the Lexus TRAC system, interference between brake control and throttle control is prevented by the following method without dividing the slip ratio. As the result, the wheel spinning controllability has been highly improved.

3.21.5 Brake Control Method

Brake control is executed individually for left and right driven wheels according to driven wheel speed and acceleration value in the five modes of rapid pressure increase, gradual pressure increase, holding, gradual pressure decrease, and rapid pressure decrease. Basically, the brake hydraulic pressure is increased when the driven wheel speed exceeds Vrt and it is decreased when the driven wheel spead does not reach Vrt. However, when left and right driven wheel are controlled completely independent of each other, the spinning phase for left and right driven wheel may be reversed and brake control hunting may occur, and for this reason, limits were set for the relation between left and right driven wheel control mode. For example, when rapid pressure increase is executed for the right wheel, rapid pressure decrease will not be executed for the left wheel.

In order to eliminate brake control interference between ABS and TRAC system, TRAC system brake control is prohibited during ABS control.

Various performance evaluations with TRAC and without TRAC have been made on actual low-friction road surfaces, including ice and snow, and the effectiveness of the TRAC system and the superiority against Crown TRAC system have been confirmed.

3.21.6 Acceleration Performance And Directional Stability

The acceleration performance on split-μ road surfaces is extremely good. It is even good in comparison to the Crown TRAC system with simultaneous brake control for left and right driven wheel. In regard to the data, large scatter can be seen for without TRAC data at the time of start-off, which clearly illustrates the difficulty of acceleration pedal adjustment at the timle of start-off on road surfaces with low friction. And acceleration feel becomes very smooth as wheel spinning controlability advanced.

The next point is the stability of the car, and on bad road surfaces with camber, wire tracks, etc. occurring together, the difference between with TRAC and without TRAC appears notably.

3.21.7 Start-Off Ability On A Slope

Start-off test on a slope is a major performanse about the TRAC system. Lexus LS400 can climb the 15% slope of split-μ surfaces (dry asphalt and ice), but it is impossible to climb for the car without TRAC.

3.21.8 Stability In Cornering

In order to obtain an even clearer car behavior for stability evalution, the data from two contact-free ground speed meters installed with an inclination of 45' at the front of the car and from one gyrometer installed at the center of gravity of the car were analyzed by a computer, and the plane track of the car was obtained. Without TRAC, the rear of the car swings clearly. The data are for 9 sec for with TRAC as well as for without TRAC.

Lexus LS400 with TRAC has higher stability than Crown with TRAC as the yaw rate for Lexus is not increasing more than that for Crown. Actually, Lexus LS400 with TRAC can naturally accelerate in cornering on snow road.

3.21.9 Passing Acceleration Stability

Figure 3.72 shows the results of lane change testing during acceleration. The measuring time was 10 sec. Without TRAC, the rear of the car swings, but with TRAC, there is only small deviations, and the results are good, in the same way as for the acceleration performance. In this case, Figure 3.73 shows a comparison of Lexus LS400 with Crown. Lexus LS400 with TRAC has much higher stability than Crown with TRAC as the variation in yaw rate for Lexus is smaller than that for Crown.

There is one more important point for stability evalution, which does not show up in the data, and this is the problem of the burden for the driver. Without TRAC, the driver must pay attention to acceleration pedal operation and steering wheel handling, and he must balance these two skillfully, but in the case of a TRAC car, the driver can concentrate on steering, so that the psychological burden for the driver is reduced.

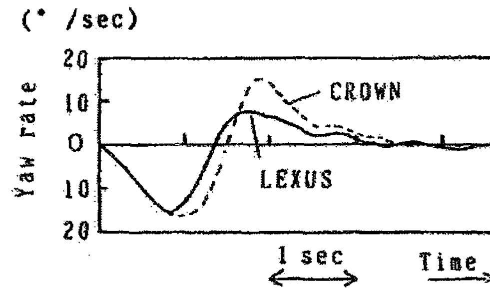


Figure 3.72 Stability on lane change

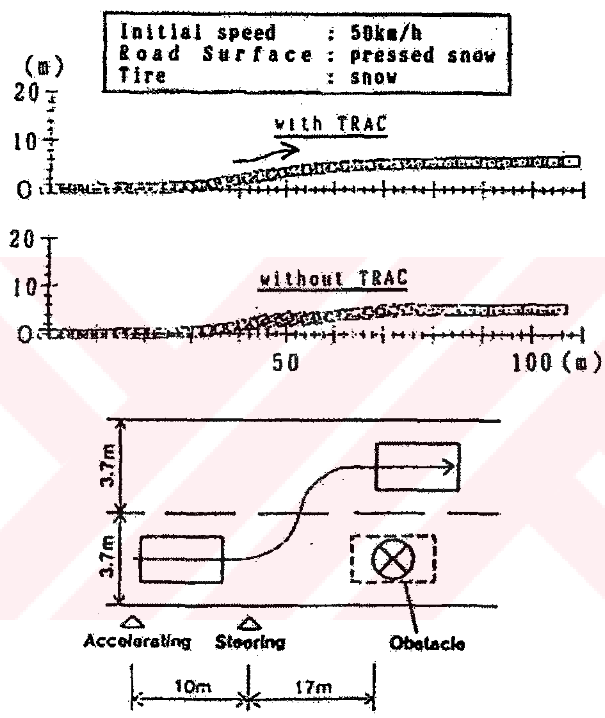


Figure 3.73 Comparison of lane change

3.22 Teves MK IV Anti-Lock and Traction Control System

After successfully introducing the Mk II ABS system a new cost reduced system named ABS Mk IV went into series production in 1989. Basic principle, performance, safety aspects and comfort are similar to the Mk II system but for cost reduction reasons it has become an add-on system with vacuum boosted actuation. The system is adaptable to all base brake system lay outs and can also easily be extended to traction control function.

High performance ABS brake systems have been successfully introduced in the market because car manufacturers and drivers have recognized the important safety function of these systems. In the beginning of ABS introduction only luxury vehicles where equipped with ABS because of the high additional cost. Today there is a requirement to install such systems also down to the medium and even compact vehicle class. Therefore it became a necessity to develop an ABS-system which meets the requirements of car manufacturers and drivers concerning performance, comfort and especially cost. Based on the extensive experience with the integrated ABS Mk II system, the new ABS Mk IV system was developed and series production started in 1989.

The current Mk II fully integrated system consists of an actuation with integrated pressure modulation unit and power supply. In addition there are four wheel speed sensors and a seperate electronic controller installed in the passenger compartment.

The basic principle for this system is to release excess wheel brake pressure back to the reservoir when a wheel., shows locking tendency. Brake pressure is recharged by the hydraulic power supply. This system has been proven over a million times by numerous vehicle manufacturers in over 60 different vehicles.

This principle also allows the extension to traction control with a minimum of additional effort. Therefore the objective when starting the ABS Mk IV development, was to take over this well proven basic principle including the modular concept of the Mk II system. Prime objective was however to maintain optimal ABS performance, safety aspects and comfort.

The first step to achieve this aim was to evaluate what cost improvement was possible and what further design improvement could be incorporated in this new system. The average driver may not see the advantages of the hydraulic booster concerning pedal feel and high level knee point.

An important step for cost reduction was to replace the hydraulic booster with a vacuum booster. This change additionally leads to reduction of components which are necessary for hydraulic actuation.

A further step was to split the integrated unit into its components which gives the possibility to increase standardization.

The electronic controller however has been further improved by adding on-board diagnosis and allowing for engine compartment compatibility.

3.22.1 Design Objectives For The Mk IV System

Several modern high-performance ABS brake Systems have been brought into mass production by now . They have defined the state of the art to fulfill the basic functional requirements of such a system regarding

- vehicle stability
- vehicle steerability
- stopping distance

under stringent safety requirements. Teves started the development of generation of ABS systems beyond established Mk II system objectives therefore were set technical solution which gives a cost reduction and which fully meets functional requirements stated compared to its various competitors.

Further design goals were set as follows:

-Potential for upgrading to a combined ABS and Traction Control System at low incremental cost

-Same or better comfort functions than state of the art, e.g.:

·Pedal feeling during normal braking

·Pedal feeling during ABS braking

·Noise and vibrations

-High flexibility for packaging

-High versatility for application in different vehicles, e.g. suitability for cars with:

·Diagonal or Front/Rear brake circuit split

·Front- and rear wheel drive.

·Straight-bore or stepped-bore tandem master cylinder

These design objectives have been met with the new ABS MK IV system.

3.22.2 System Concept

During normal braking operations the solenoid valves are not electrically excited. The left side inlet valve is in the open position. The right side outlet valve is closed. The pump is standing still. The wheel cylinder is supplied conventionally out of the master cylinder.

During an ABS braking operation the solenoid valves are cycled by the electronic controller to generate pressure hold, decrease and increase phases at the wheel cylinder. For pressure decrease, fluid is discharged through the outlet valve out of the wheel cylinder into the reservoir. To increase pressure, fluid is taken via the inlet valve from the master cylinder side.

To avoid the bottoming out of the master cylinder during ABS braking it is necessary that the volume flow through the inlet valve is replaced by a hydraulic energy source. Therefore an electric-motor driven pump is switched on by the electronic controller during ABS braking. The pump is designed under all operating conditions to provide a volume flow which is larger than the volume flow through the inlet valve required for modulation of the wheel cylinder pressure . The volume flow from the pump exceeding the the yolume flow through the inlet valve displaces the.master cylinder piston in the direction of the release position. The pressure in front of the inlet valve is still given by the pedal effort of the driver as the equilibrium of forces at the master cylinder piston must be maintained.

If the pump is not switched off the master cylinder will travel back into the released position and the excess fluid from the pump will be released through the now opening master cylinder into the reservoir. The high pressure difference and volume flow during this condition makes the use of steel center valves mandatory. Therefore there is always an ample reserve of master cylinder stroke during ABS braking to cover against running out of displacement volume under the worst case condition that the ABS fails at the transition of the vehicle from a low friction to a high friction surface. A costly and space-consuming separate master cylinder positioning device as for the MK II system is no longer required.

As the total master cylinder stroke is not necessary to cover against this failure mode, it is feasible to limit the return stroke in order to increase the pedal comfort during ABS braking. This can be achieved by sensing the master cylinder stroke or some other variable related to it and by having the pump switched off by the electronic controller as long as a predetermined master cylinder stroke is not exceeded.

3.22.3 Extension To Traction Control

There is a significant demand by the market for Traction Control systems (TCS) *using brake intervention either alone or combined with engine* intervention. Due to its basic hydraulic concept the MK IV system requires only a minimum of additional components for extension to a Traction Control system.

If the electronic controller detects a Traction Control situation by evaluating the signals from the already existing wheel speed sensors the isolation valve is energized and the pump is started. Pressure is built-up in the wheel cylinder of the spinning wheel and modulated by actuation of the inlet and outlet solenoid valves as in ABS braking.

As the master cylinder chamber is cut off from the pump by the isolation valve and its central valve is open, there is no pressure in the master cylinder and the wheel cylinder of the non-driven wheel in the same brake circuit. The excess fluid volume displaced by the pump compared to the volume flow required to maintain Traction Control, is discharged through a pressure relief valve into the master cylinder and through its open central valve back into the reservoir. The setpoint of the pressure relief valve defines the system pressure at the inlet valve. It is adjusted specifically for the vehicle, e.g to compensate the influence of the proportioning valve in a rear-wheel driven car. As each master cylinder circuit supplies a driven wheel and an undriven wheel two isolation solenoid valves (19, 20) and two pressure relief valves (21) are required. One of each would be sufficient for a front/rear split base brake system. The brake pedal is in the released position and the pump is operating during the complete Traction Control operation and there is no influence of the pedal position switch. There is an additional pressure switch (22) which is monitored by the electronic controller. Its switch point is rather low and is reached immediately when the driver actuates the brake pedal. The switch signal is used by the system software to terminate the Traction Control mode immediately in this case and to return to standby mode for an eventually pending ABS situation.

3.22.4 Function And Design Of The Electronic Controller

The electronic control unit in the MK IV system represents a high performance anti lock brake controller.

Due to the use of microprocessors as elements for the implementation of the control structures, data processing and the fail safe concept, the controller shows a large extent of flexibility.

The reliability of its failsafe function is achieved by a redundant microprocessor design. One of the demands for the development of this controller was to prevent an expansion of the PCB (printed circuit board) in comparison to the MK II controller. So it was necessary to design new customer specific integrated circuits with large scale integration. Also the use of SMD technology had been selected to fulfill this demand.

Another important requirement for the controller is the insensibility against RFI disturbances and less extent of high frequency reflections. Furthermore, it is necessary to implement in such a complex controller an intelligent diagnosis capability. The MK IV controller has the capability to provide several on board diagnosis concepts according to the customer specifications.

3.22.5 Control Concept

One of the important requirements for a high performance anti lock brake system is a comfortable brake pedal behavior during ABS control. Since pressure modulation during ABS control influences the master cylinder pistons, pedal vibration is recognized by the driver. To minimize pedal travel during ABS mode, a special pedal control algorithm was developed. The controlled system - master cylinder, wheel brake and brake pedal- consists of elements with integral and proportional transference characteristics. The pump can be described as an element with proportional dead time characteristics. The proportional transference coefficient is not constant, but is a function of parameters which can influence the pump volume capacity.(e.g. fluid viscosity, power supply, ...).

In the shown figure all four wheel brakes and the two chambers of the master cylinder are simplified as blocks.

For monitoring pedal travel a special sensor had to be developed. This pedal travel sensor, which was mentioned in the chapter on signal processing, converts the pedal travel into a digital value via an AID converter. For tile calculation of the nominal value, the control algorithm uses different input signals.

The comparison between nominal and actual value is carried out in the controller in a digital format. Out of this calculated control deviation the actuation pulses for the hydraulic pump are generated. The control algorithm has to consider the characteristics of the pump and the particularity of the pulse width modulation.

The principle ABS control concept is unaltered compared to the MK II system. The main target of the controller is to reach a high utilization of road friction coefficient, together with steerability and stability of the car. This demand has to be fulfilled with minimized brake fluid volume consumption.

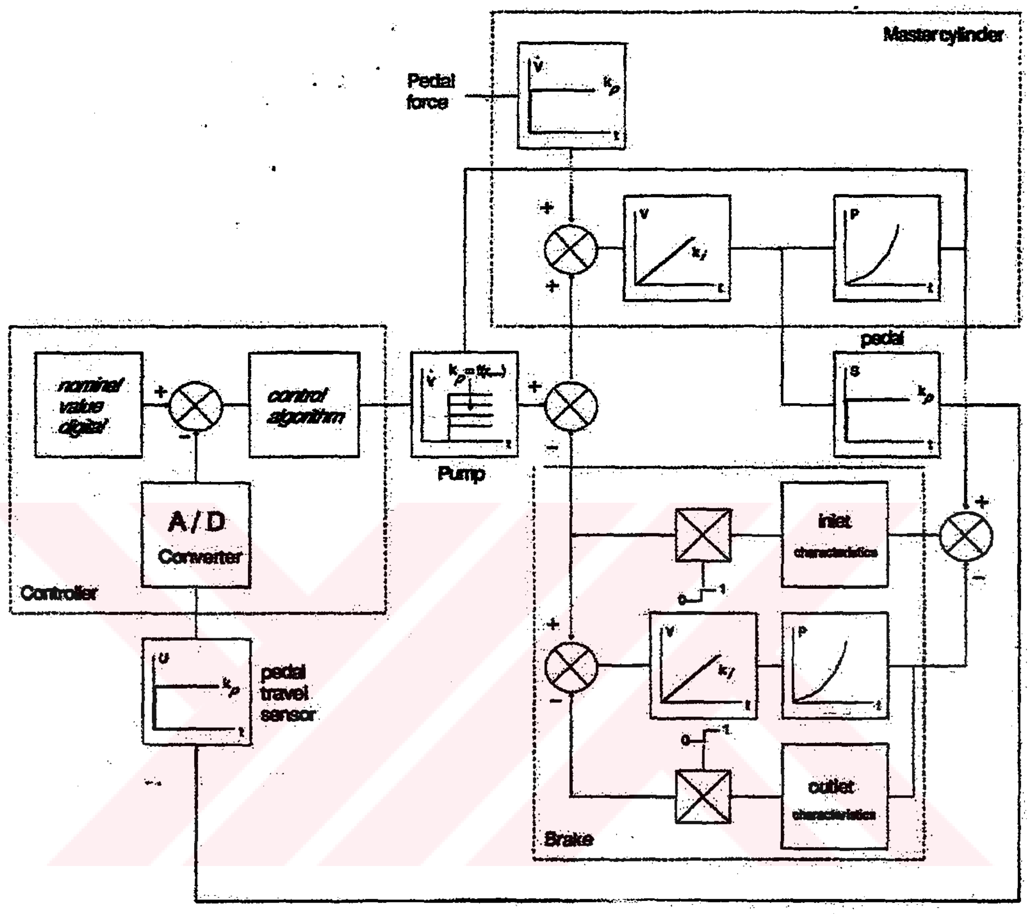


Figure 3.74 Brake Pedal Control Circuit

To solve these problems it is necessary to have a pressure modulation with low amplitude in which the control frequency should not exceed a defined value. The controller must have the capability for fast adaptation of pressure modulation according to changes influencing the control led system.

These disturbances are caused by increase or decrease of road friction coefficient or by variation of brake pedal force. The gradient for pressure increase modulation depends directly on the pressure in the master cylinder. To give the controller this dynamic capabilities this means adaptive learning algorithms had to be implemented in the controller. With these features the controller is able to adjust itself to the new conditions of the controlled system in a short time.

3.22.6 MK IV Traction Control

The MK IV system can be extended to two different traction control systems.These are:

1. Systems with brake intervention only. They operate in a limited vehicle speed range. The task of such systems is to increase traction during the starting off phase on roads with μ-split friction conditions.

2.Systems with brake- and engine intervention for the total speed range.

While cornering this system offers additional assistance to the driver or overtaking at higher vehicle speed. The simplest solution to extend the ABS Mk IV system to traction control with brake intervention, needs just one additional valve driver interface in the electronic controller. The total number of valves depends on the drive concept and the base brake layout of the vehicle. All further input signals which will be used for are already included in system. However in the area of the control concept new features have to be implemented in the existing structure.

The design of the control philosophy depends on the demands to the TC system. One solution is the realization of a differential lock function by brake intervention. In this case it is the task of the system to replace the missing road friction torque on the low-μ, side, under μ-split road conditions, by brake torque.

Due to this torque compensation the normally unlocked differential gear will be variable locked. Therefore the vehicle acceleration is increased by utilization of the tractive forces on the high-μ wheel.

But if the engine torque exceeds the value of the highest road friction torque the brake torque increase on the low-p, side will be stopped.

When using the brakes for Traction Control function it is necessary to monitor the thermal load to the brake. The part of energy which is not converted into car acceleration leads to a temperature increase at the brakes on the driven axle.

During driving the ABS/TCS controller contuniously simulates the brake temperature course and can disable the brake intervention before a critical temperature is reached. Additionally for a full speed traction control system, with minimum stress for power train and brakes, a engine intervention is required. Reduction of excess engine torque is carried out by controlling the throttle flap.

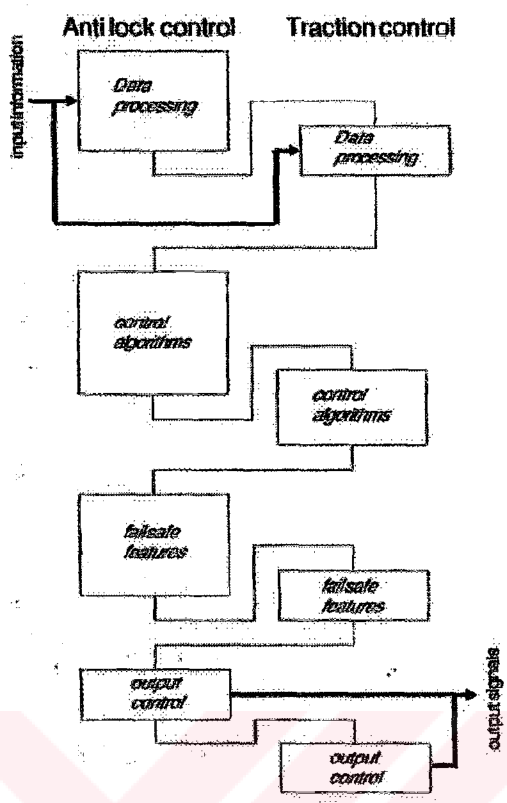


Figure 3.75 Software Structure of Electronic Controller

3.22.7 Noise Vibration And Harshness

The NVH-level during ABS control was another development objective for the Mk IV system. Damping chambers in the pump outlet circuits, fine tuning of the HCU mounting and consequently separated brake tube routing with rubber insulators led to an acceptable NVH-level. In addition, adjusting the pressure pulse sequence by software gave a further positive result. Pedal comfort during ABS control, has been developed to suit American and European vehicle manufacturers.

3.22.8 Durability And Reliability

Durability and reliability have been proven in extensive fleet test which started two years ahead of series-production. Regular drivers in more than 30 locations spread all over the USA, have been another valuable indicator for customer acceptance and system durability upfront. Successful completion of these tests led to a high confidence level for the vehicle manufacturers.

An additional fleet of vehicles had to survive two cycles of 20.000 miles failure free operation per vehicle and a daily average milage accumulation of 660 miles. The tests consisted of a mixture of Las Vegas city traffic, desert cross country driving including Death Valley hill climbing and parking in the summer months. Here ambient temperatures approaching 128°F were measured.

A similar program for winter durability tests was carried out in the environment of the Michigan Upper Peninsula during January and February. Here the Mk IV system had to prove its reliability during cold starts with temperatures down to -40°F. Stop-and-go city traffic on salt roads, driving through blizzard conditions for hours, and running through muddy back roads were part of the fixed durability cycle.

Low-cost and at the same tune high performance ABS systems are the current requirements for car manufacturers and drivers. With the introduction of the Mk IV ABS system these requirements are fulfilled.

All important performance data, safety aspects, and pedal comfort during ABS are comparable with the already known Mk II system.

The retainment of the Mk II basic ABS-principle and its carry over to a cost reduced ABS Mk IV system will lead to a further increased market penetration.

The possibility for extension to additional functions such as traction control with minimum effort, shows that this described concept will also remain in the future. Series production for ABS Mk IV combined with Traction Control is planned for the near future.

3.23 Traction Control (ASR) Using Fuel-Injection Suppression- A Cost Effective Method Of Engine-Torque Control

Traction control (ASR) is the logical ongoing development of the antilock braking system (ABS). Due to the high costs involved though, the engine power by electronic throttle control (or electronic engine power control) has up to now prevented ASR from becoming as widely proliferated as ABS. A promising method now has been developed in which fuel-injection suppression at individual cylinders is used as a low-price actuator for a budget-priced ASR.

First of all, an overview of the possibilities for influencing wheel-torque by means of reducing driven wheel slip is presented. Then, the system, the control strategy, and the demands on the electronic engine-management system with sequential fuel injection are discussed.The system's possibilities and its limitations are indicated,and fears of damaging effects on the catalytic converter are eliminated.

More than 10 years ago, the demand for safety in road traffic led to the introduction of ABS. Today this system is already standard equipment on many models in the upper and middle price classes of all automakers, and is an important accessory on most of the remaining models. The next step after ABS was to provide the driver with technical support on the drive side as well.

The continually increasing engine-outputs in the automobile sector mean that the physical limits for transmitting torque to the road are often reached and the driven wheels can spin. Particularly when the road surface has a low coefficient of friction, the driver's input to the engine can produce so much power output that the driven wheels have excessive slip.

3.23.1 Various Types Of Torque Control

The control of wheel slip requires that the torque delivered by the engine is distributed optimally to the driven wheels and that excess torque is dissipated. These interventions in the torque flow can be carried out by various actuators.

3.23.2 Distribution And Reduction Of Wheel Torque

The differential lock is the most familiar method for torque distribution, and is independent of ASR. It can be designed as a fixed-value lock or with variable degrees of lock. In addition to the principal limitations with FWD vehicles, the compatibility with ABS, the service life, and the cost are the determining factors for use with ASR.The method most commonly used for ASR torque distribution is that of actively braking the driven wheels. To do so, the ABS hydraulics are expanded accordingly. By means of additional valves, pressure can be applied to the wheel brakes independent of the actuation of the master cylinder. The pump already present in the ABS is used for pressure generation. A pressure accumulator can be fitted as an option in order to increase the pressure buildup rate. The brake actuation mentioned above is also suitable for reducing the torque at the wheels. There are ASR systems on the market which rely solely on this form of intervention, practice though it is mainly used in combination with some form of engine override. In addition to torque distribution, it then serves to reduce excess drive torque and wheel-slip peaks .

3.23.3 Reduction Of Engine Torque

he obvious method for reducing the engine torque is to close the throttle valve, the same way as the driver does. A disadvantage of this method though lies in the technical outlay involved. Either the throttle valve is actuated solely by an electronic engine-power control (drive –by-wire), or the throttle valve must be modified and a servomotor together with control electronics fitted . Both solutions have the disadvantage of the delay time required the throttle-valve for actuating.

Intervention in fuel-injection and ignition is another possibility to reduce the engine torque. The extremely coarse, but very rapid suppression of the ignition was used up to now above all to assist with the throttle-valve intervention. With the infinitely variable ignition timing, only a relatively narrow adjustment range is permissible on account of thermal engine overload. On the other hand, being as is not switched off completely but is only suppressed at selected cylinders, fuel-injection suppression or "cylinder cut-out" provides a good compromise between rapid reaction and fine control. This method of engine-torque reduction builds the heart of the new ASR system presented in this paper.

3.23.4 Close-Loop Control

The ASR is a wheel-slip control system. That is, the wheel speeds are determined through the wheel-speed sensors and no further sensors are required. Depending upon the vehicle type, the type of drive concept and the driving situation, a variety of desired slip levels apply and the instantaneous slip at the driven wheels is controlled to these levels.

In order to intervene selectively in case of deviations in the torque acting at the driven wheel, the wheel torque is taken as the manipulated variable for the control algorithm.

Using the engine speed and load parameters, the engine torque at a given instant is determined from a stored map. Appropriate time-delay elements are utilized to account for engine dynamics, and in accordance with the torque reduction using fuel-injection suppression, a separate map is stored for each torque-reduction stage.

When determining the wheel torque, the most important influencing variables taken into account are engine's and the wheels' rotating masses as well as the engaged gear calculated from the ratio of engine speed to driven-wheel speed.

Even when the driven-wheels spin, the wheel torques calculated as above are an approximation of the torque actually transferred to the road.

Basically, the control algorithm corresponds so that of a PID controller. At the start of control, using the information on the transferable torque, the controller can be quickly set to the correct working point.

3.24 ASR Built in an Add-On ABS

Presently, most hydraulic ABS/ASR systems consist of separate ABS and ASR units connected by hydraulic pressure lines, or of an integrated.unit with a booster and a master cylinder.

They are, in general, expensive and complicated to install. Akebono Brake Industry Co., Ltd. has developed a hydraulic ABS/ASR unit which is an "Add-on" type, compatible with a regular brake line, having two additional solenoid valves, a low-pressure accumulator, a pressure transfer piston, and a pump plunger for the ASR. This has produced a lighter, less expensive system that is easy to install. The following is a discussion of the system's function and performance.

Anti-lock Brake Systems (ABS) and Traction Control Systems (ASR), have been widely recognized as effective devices in promoting vehicle safety and driving comfort. However, the actual ASR installation rate has been very limited compared with that of ABS, although both systems should be used together to secure vehicle stability with the highest performancein all phases of vehicle running, cornering, and braking. One reason for the low ASR installation rate has been partly due to the prohibitive cost of the ASR hydraulic modulator. In order to prevent excessive wheel spin while accelerating, a quick hydraulic brake application is required of the ASR system, which usually necessitates the adoption of an accumulated high pressure hydraulic power source, thus making the system more complex and expensive.

In response, Akebono Brake Industry Co., Ltd. has developed an ABS/ASR hydraulic unit for ABS/ASR systems having an engine throttle control mode and a brake control mode, solving the problems of cost and installation difficulties.

3.24.1 ASR Control Logic

There are two ASR control modes, engine throttle control to reduce engine power, and brake control to lessen uneven driving rotation between left-side and right-side wheels. In the former, the system reduces excessive slippage between the driven wheels and the road surface to ensure vehicle stability and effective traction transfer through throttle position changes. In the latter, the system applies the brakes when one of the driven wheels is slipping excessively to ensure the intended acceleration, aiming at the same function of a limited slip differential.

3.24.2 Comparison Of ABS & ASR Hydraulic Systems

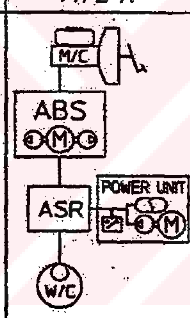
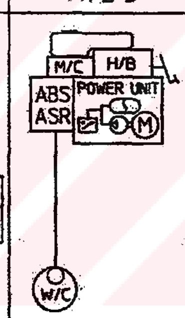
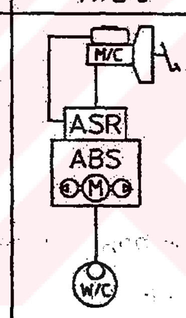
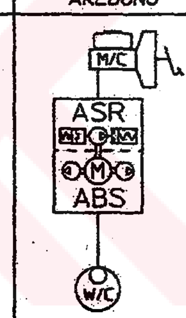
Comparisons of the proposed Akebono hydraulic system and the other existing hydraulic systems in the market are shown in the following Table 3.1.

Type A: ABS and ASR units are separate, and the ASR unit consists of a valve unit and a power unit with a high pressure accumulator.

Type B: ABS, ASR and a hydraulic booster are in an integrated system.

Type C: Add-on ABS/ASR unit with an extra brake hose from the master cylinder reservoir for initial ASR suction.

Type D: Proposed Akebono system.

	TYPE A	TYPE B	TYPE C	AKEBONO
SYSTEM BLOCK DIAGRAM				
INSTALLATION SPACE	X	△	○	◎
RESPONSE OF ASR ACTUATION	◎	◎	△	○
TOTAL COST	X	△	◎	○

X (POOR) △ (FAIR) ○ (GOOD) ◎ (EXCELLENT)

Table 3.1 hydraulic system configuration

System Components and Vehicle Installation - Type A requires more hydraulic lines between units and more installation space because of the bulky separate units.

Type B is integrated intoone unit, but it is still bulky. Type C and the Akebono system are both packed into a single compact unit additional hose to the master cylinder reservoir, while the Akebono type is a complete "Add-on" type.

ASR Brake Control Performance - Type A and Type B have high pressure accumulators for power sources and thus offer better pressure build up performance. The Akebono type also provides good performance by utilizing a low pressure accumulator.

Total Cost (Components, Installation, etc.) - Type A has two power sources, one for the ABS and the other for the ASR, having two costly elements such as a high pressure switch, etc. Thus, connecting the separate units and hydraulic lines requires more installation time.

Type B is less expensive due to the integration of the high pressure accumulator and the pressure switch. But the total system cost, however, would still be high due to the complexity of the system, although the installation time would still be rather low.

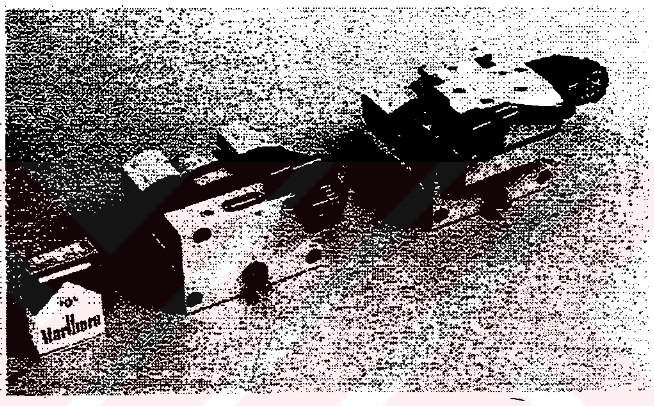


Figure 3.76 Akebono ABS Modulator And ABS/ASR Modulator

Type C consists of relatively simple elements compared with Type A and Type B, and even though a hydraulic line from the master cylinder reservoir is required, the installation time is still rather low. Thus it seems to offer the overall lowest cost.

Since the Akebono system is a complete "Add-on" system, the installation time is remarkably low. And even though the cost is effected by additional components such as the gate valve, low pressure accumulator, ASR pump, and so on, these extra elements are not prohibitively expensive.

Considering the other comparisons discussed previously, we believe that the Akebono system is a well-balanced total system.

4. Vehicle Traction Control: Variable-Structure Control Approach

Vehicle traction control, which is composed of anti-lock braking and anti-spin acceleration, can enhance vehicle performance and handling. The objective of such control is to maximize tire traction by preventing the wheels from being locked during braking and from spinning during acceleration, while helping to maintain adequate vehicle stability and steerability.

This vehicle traction system is highly nonlinear with uncertain time-varying parameters and load, attributed to the powertrain/ brake interactions and the traction characteristics at the tire/road contacts.

Current control developments for both anti-lock braking and anti-spin acceleration are mostly table-driven and calibrated through various experiments and tests. Here, an optimal traction control formulation is used. The bang-bang nature of this optimal control is similar to that of the zeroth order of the sliding mode control.

Variable-structure control systems consists of a set of continuous subsystems together with suitable switching logic. That is, the control is allowed to change its structure at any instant from one member to another member of a set of continuous functions of the system's states. The keys to the design of the variable-structure control systems are to select the parameters of each structure and to define the switching logic. If the switching logic and the control are designed such that the system's trajectory slides along a manifold. Under the assumption that the control has ample power, sliding-mode control provides advantageous properties, such as insensitivity to parameter variations and to bounded disturbances. Using this theory, it is possible to systematically design a nonlinear controller to help achieve consistent traction performance under varying operating conditions.

To achieve variable-structure traction control by regulating the wheel slip at each wheel is highly desirable to have the knowledge of the characteristics of the tire/road adhesion. One means to online identify the tire/road adhesion characteristics is to use weighted least squares estimation with forgetting factor.

R_w	wheel radius of free-rolling tire (m)
B_v	road surface/tire adhesion coefficient
μ_p	peak μ value for μ-λ curve in the acceleration region
μ_v	peak μ value for μ-λ curve in the braking region

B_r	tire rolling resistance friction coefficient
J_w	moment of inertia of rotating parts referred at the wheel ($kg.m^2$)
ω_w	wheel angular speed (rad/s)
ω_v	angular speed of free-spinning wheel (rad/s)
V	vehicle linear speed (m/s)
M_v	vehicle mass (kg)
B_v	aerodynamic drag coefficient ($=0.5\rho.C_D A_f$) ($N/m^2/s^2$)
N_v	normal force at tire-surface contact (N)
λ	wheel slip
λ_p	wheel slip corresponding to μ_p on the μ-λ curve
λ_n	wheel slip corresponding to μ_v on the μ-λ curve
T_e	engine torque at the wheel (N.m)
T_b	brake torque at the wheel (N.m)
F_t	tire tractive (friction) force (N)
F_w	wheel friction function (N.m) ($=R_w B_r N_v$)
F_v	vehicle friction function (N) ($=B_v V^2 + B_r N_v$)

Table 4.1

4.1 Vehicle Traction System

The simplified longitudinal vehicle model contains one-wheel rotational dynamics, linear vehicle dynamics, and the interactions between these two dynamics. Dynamics, such as actuators, suspension, steering, etc., are not considered. A list of variables and parameters is given in Table 4.1.

Figure 4.1 shows a simplified vehicle model which includes one-wheel rotational dynamics, linear vehicle dynamics, and interactions between them. One-wheel vehicle traction system can be presented in the state-variable form as in Equation (4.1)

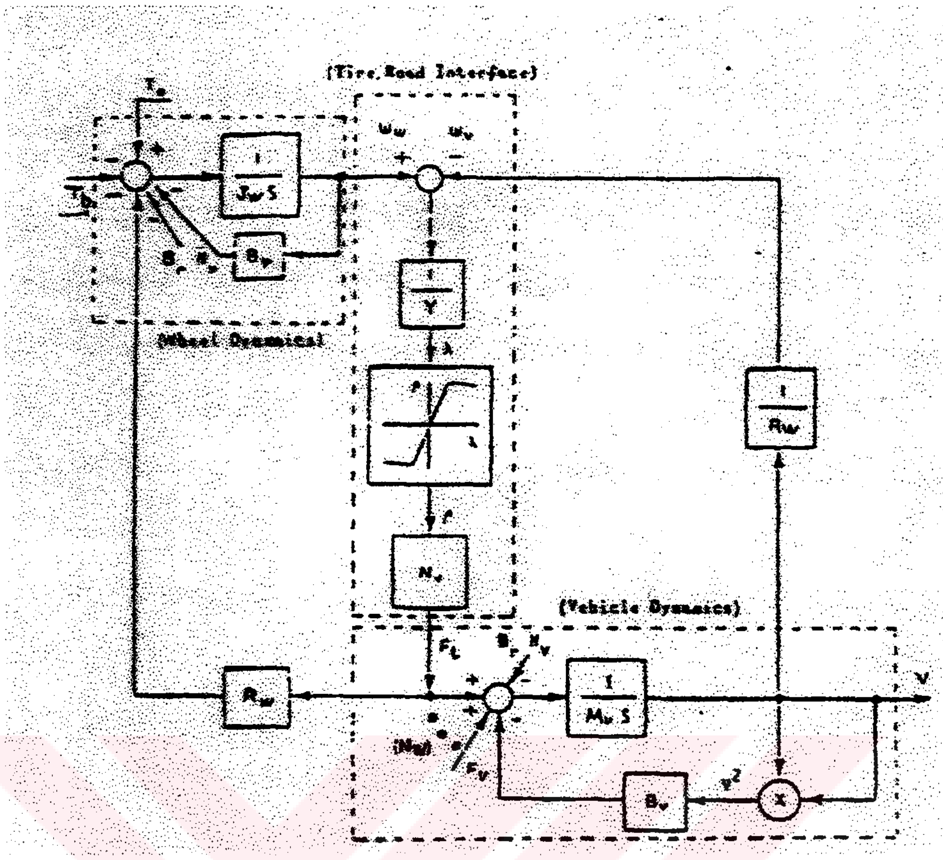


Figure 4.1 Vehicle/tire/road dynamics

$$\dot{x}_1 = -f_1(x_1) + b_{1n}\mu$$
$$\dot{x}_2 = -f_2(x_2) - b_{2n}\mu + b_3 T,$$
$$T = T_e - T_b$$
$$\mu = f(\lambda)$$
$$\lambda = \frac{x_2 - x_1}{y}$$

(4.1)

Where

x_1 = vehicle speed (rad/s) = V/R_w

x_2 = wheel speed (rad/s) ,

$y = x_2$ when $x_2 > x_1$,

$y = x_2$ when $x_2 < x_1$

a_1, a_2, b_{1n} and b_3 are:

$$f_1(x_1) = \frac{F_v(R_w x_1)}{M_v R_w}, \qquad b_{1n} = \frac{N_w N_v}{M_v R_w}$$

$$f_2(x_2) = \frac{F_w(x_2)}{J_w}, \qquad b_{2n} = \frac{R_w N_v}{J_w}, \qquad b_3 = \frac{1}{J_w} \tag{4.2}$$

$\delta f_1/\delta f_2$ and $\delta f_2/\delta f_2$ are assumed to be positive for all $x_1 > 0$ and $x_2 > 0$.

The tractive force developed by a tire during both acceleration and deceleration depends on wheel slip, road surface, and tire contsruction and condition, as well as other parameters such as vehicle speed, tire normal load, etc. The tractive adhesion coefficient, μ, which is the ratio between tractive force and normal load, can be plotted as a function of wheel slip for a given tire, road surface and vehicle speed, and is depicted in Figure 4.2. This traction system is unstable in the pure sliding region to the right of the peak of the μ-λ curve.

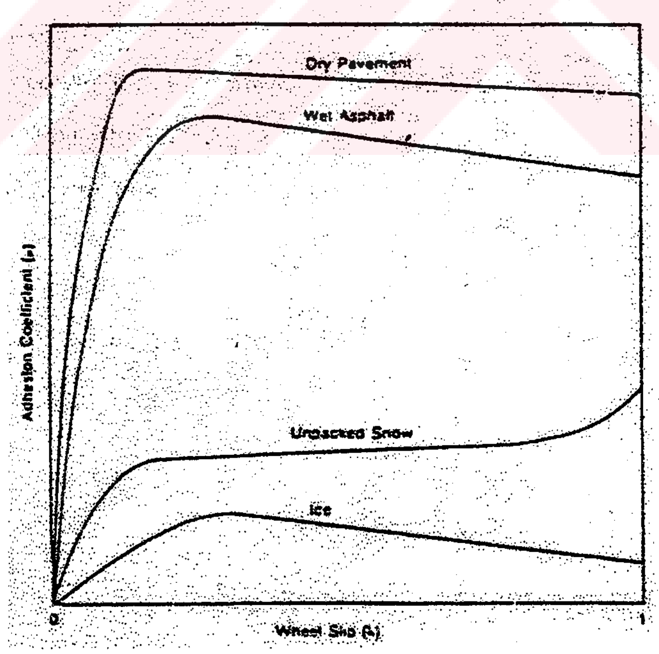


Figure 4.2 Typical Adhesion coefficients versus slip

4.2 Sliding – Mode Control Applicability Analysis

4.2.1 Variable – Structure System and Sliding-Mode Control

Consider a system described by the following state ewuation of error dynamics:

$$\dot{z} = f\,(t, z, v),$$

with the control v switching between a suitable pair of functions, $v^+ (t,z)$ and $v^- (t,z)$:

$$v = v^+ (t,z) \quad \text{for } S\,(z) > 0,$$
$$v = v^- (t,z) \quad \text{for } S\,(z) < 0.$$

where S(z) is a linear manifold defined by

$$S(z)=z_n \sum_{i=1}^{n-1} c_i\, z_i = 0. \tag{4.3}$$

It is critical to determine the parameters of v and S such that the system rate will be brought to the switching surface $S(z) = 0$ from any initial point in the phase plane. Then the state trajectory is to slide along the switching surface toward a regulated position. The switching surface $S(z) = 0$ is known as the sliding mode. It is well known that, if the plant is described in the controllable canonical form, the system will behave like an automous linear system of reduced order with poles defined by $S(z) = 0$ once the sliding mode is reached. Furthermore, the control system is insensitive to plant parameter changes and to unknown disturbances.The trajectory will chatter around the sliding surface as a result of changing the control structures , but when changed at a very high rate, the trajectory will stay in close proximity to $S(z) = 0$.

4.3 Sliding-Mode Control and Vehicle Traction

The preferable operating region for the time-optimal longitudinal vehicle traction control based on the above vehicle model is determined. This preferable region can be explained by considering the first quadrant of state space spanned by x_1 and x_2 in Figure 4.3. The first quadrant is divided into three sectors by two straight lines with the wheel slips at λ_p and λ_n. Note that $d\mu/d\lambda < 0$ in Sectors I and III, and $d\mu/d\lambda > 0$ in Section II. The optimal solution suggests that, for the best longitudinal vehicle performance, the wheel slip should be maintained within Sector II which is bounded by the optimal wheel slips, λ_p and λ_n as possible.

The subspace spanned by x_1 and x_2 can be transdormed into λ/λ phase plane as shown in Figure 4.4. Note that Regions I, II, and III in Figure 4.4 correspond to Regions I, II, and III in Figure 4.3. They represent the regions for nti-spin acceleration, and anti-lock braking, respectively.The strategy is to operate the vehicle in the normal operating zone (Region II), with anti-spin acceleration if the trajectory enters Region I .

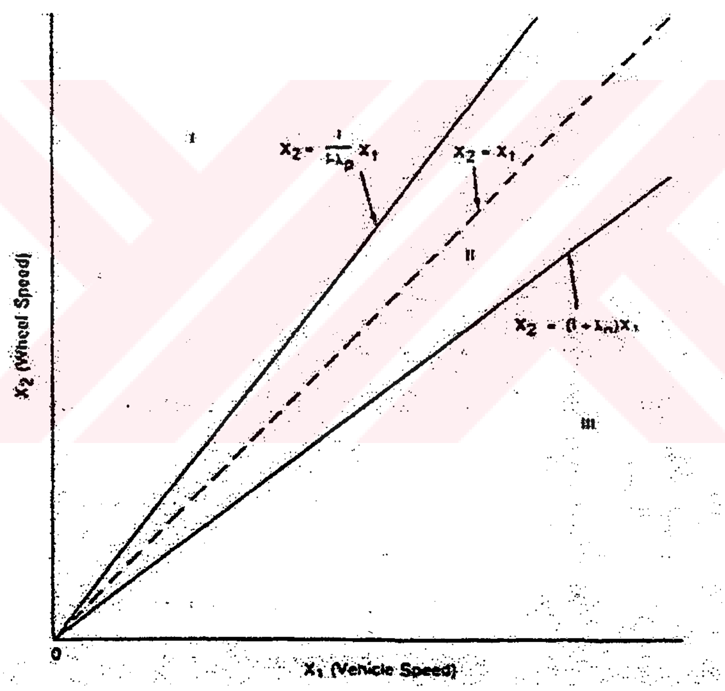


Figure 4.3. vehicle velocity / wheel velocity phase plane

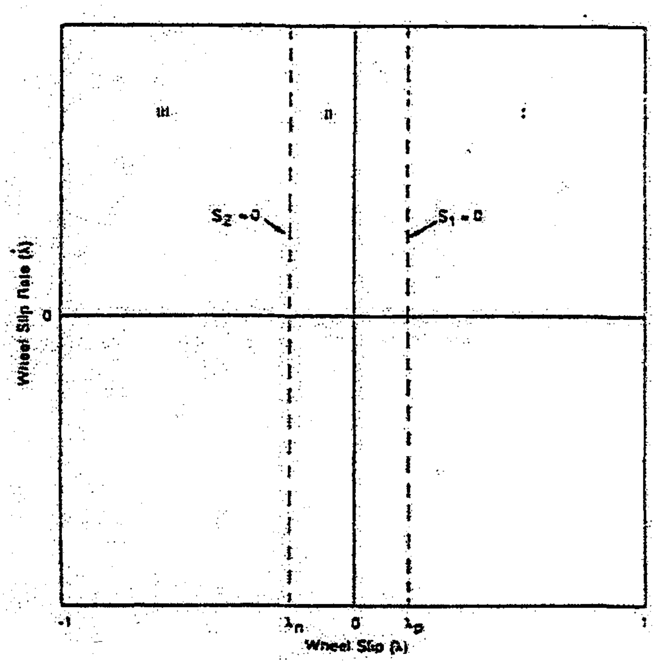


Figure 4.4 Slip/slip-rate phase plane

Let's first consider the following zeroth order switching indices which corresponds to the bang-bang control:

$$S_1(\lambda, \dot{\lambda}) = \lambda - \lambda_p \qquad (4.4)$$

with the corresponding sliding surfaces, i.e., $S_1(\lambda,\lambda) = 0$ as shown in Figure 4.4. Then, design the control such that

$$\frac{dS_1}{dt} \prec 0 \text{, when } S_1(\lambda, \dot{\lambda}) > 0. \qquad (4.5)$$

However, with a zero-order sliding mode, the switching control is nonanticipative and too oscillatory. Hence, an alternative set of first-order switching indices is chosen:

$$S_1(\lambda, \dot{\lambda}) = \dot{\lambda} + c_1(\lambda - \lambda_1) \qquad (4.6)$$

Where λ_1 can be selected to be λ_p. The anticipative nature of the first ordersliding mode control will partially compensate the lags due to the actuator and system dynamics. And therefore the feedback control with these 1st order sliding-mode indices will be less oscillatory. The coeefficient c_1 is chosen to be positive.

Otherwise, when the trajectory is to slide along the switching surface, the wheel slip will increase toward 1 (spin). The unstable sliding mode can be explained by the eigenvalue of Eq. (4.6) when c_1 is negative:

$$\dot{\lambda} = -c_1 (\lambda - \lambda_1). \tag{4.7}$$

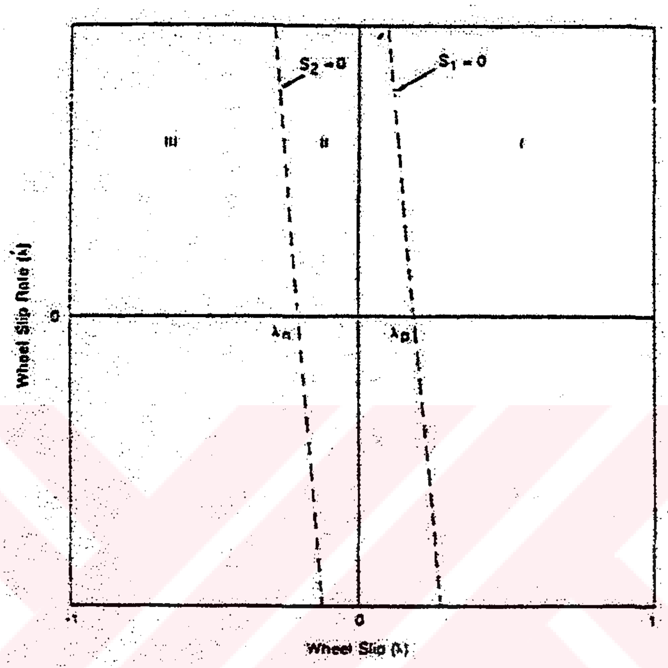


Figure 4.5 Sliding surface in slip/slip rate phase plane

Sliding surface representing $S_1(\lambda, \dot{\lambda}) = 0$ for Eq.(4.6) is shown in Figure 4.5.

4.3.1 Sufficient Conditions for Sliding Mode

The sufficient condition which guarantee the existance of the sliding mode, $\{S_1 = 0\}$ is described in the following theorem.

Theorem: For the vehicle system during acceleration as described by Eq. (4.1), which satisfies the assumptions:

(1) $c_1 >> 1 >> \partial f_1 / \partial x_1$, and $1 >> \partial f_2 / \partial x_2$ and

(2) $c_1 \mu > -\dot{\mu}$ for $S_1 > 0$,

the surface $\{S_1 = 0\}$ can be reached from any initial state in the region $\{S_1 > 0, \lambda > 0\}$

if

$$e_1 + \frac{\dot{x}_1^2}{2x_1} + c_1[f_1 - (1-\lambda)f_2] + (1-\lambda)b_3(\dot{T} + c_1 T) \prec 0, \qquad (4.8)$$

where:

$$e_1 = [(\partial f_1/\partial x_1)b_{1n}\mu] + (\partial f_2/\partial x_2)[f_2 + b_{2n}\mu - b_3 T], \text{ and } (1-\lambda) = \frac{x_1}{x_2} \qquad (4.9)$$

c_1 is normally much greater than 1. $\partial f_1/\partial x_1$ and $\partial f_2/\partial x_2$ are several orders less than 1 for passenger cars. Hence, assumption **(1)** is a reasonable assumption for practical purposes, and assumption **(2)** becames the only restriction for the theorem.

For the time-invariant case, μ can be written as:

$$\dot{\mu} = \frac{\partial \mu}{\partial \lambda}\dot{\lambda}. \qquad (4.10)$$

Therefore, assumption **(2)** can be transformed into the restrictions on λ:

$$\dot{\lambda} \prec \frac{c_1\mu}{-\frac{\partial \mu}{\partial \lambda}} = \frac{c_1\mu}{\left|\frac{\partial \mu}{\partial \lambda}\right|} \quad \text{for } \lambda > \lambda_p \text{, and} \qquad (4.11)$$

$$\dot{\lambda} \prec \frac{c_1\mu}{-\frac{\partial \mu}{\partial \lambda}} = \frac{-c_1\mu}{\left|\frac{\partial \mu}{\partial \lambda}\right|} \quad \text{for } \lambda < \lambda_p. \qquad (4.12)$$

Typical values of these bounds would be about 50 percent of c_1, and these bounds yield a reasonable region for $\dot{\lambda}$ since c_1 is sufficiently large. Even if μ is a function of time as well as wheel slip, the theorem can be applied if assumption **(2)** is satisfied. Note that μ can be written as in equation (4.13) when μ depends on both time and wheel slip:

$$\dot{\mu} = \frac{\partial \mu(\lambda,t)}{\partial t}\dot{\lambda} + \frac{\partial \mu(\lambda,t)}{\partial t}. \qquad (4.13)$$

4.4Computer Simulation

In the simulation setup; vehicle parameters used in the simulation are listed below:

Vehicle mass

$M_v = 1400$ Kg

Tire rolling resistance friction coefficient

$B_r = 0.01$

Aerodynamic drag coefficient

$B_v = 0.595\ N/(m.s)^2$

Normal force at tire-surface contact

$N_v = 3560$ N

Wheel radius of free rolling tire

$R_w = 0.31$

Overall gear ratio

$r = 9.5285$

Wheel inertia

$I_w = 0.65\ kg.m^2$

Engine inertia

$I_e = 0.429\ kg.m^2$

Acceleration:

It is assumed that the transmission is in the first gear with an overall gear ratio r. The equivalent wheel inertia J_w is then calculated as follows:

$$J_w = I_w + I_e * r^2 /2 \qquad (4.14)$$

The engine torque is assumed to remain constant at 120 N.m. Thus, the engine torque at the wheel is:

$$T_e = (120 / 2) * r \text{ (N.m)} \tag{4.15}$$

The maximum brake torque is set at 2000 N.m, and the maximum rate of change for the brake torque is 50000 N.m /s. The state equations are in the form of equation (4.1) with $N_w = 2$. The sliding mode is defined by equation (4.6) with c_1=60 and $\lambda_1=\lambda_p$.

Let the control law for $S_1 > 0$, as suggested by equation (4.8), be:

$$\dot{T} = -c_1 T - P_1 \quad , \tag{4.16}$$

where:

$$P_1 = \frac{x_2}{x_1}\frac{1}{b_3}\left[e_1 + \frac{\dot{x}_1^2}{2x_1} + c_1\left[f_1 - (1-\lambda)f_2\right]\right] \tag{4.17}$$

The controlled will tend to regulate T around $-P_1/c_1$. Although Theorem 3.1 guarantees the convergence of the trajectory to the sliding mode if assumption (A.4) is satisfied, the convergence may only be asymptotic and may take a very long time.

Thus, the control law for $\dot{T}$ (rate of change of applied torque) is modified as follows:

$$\dot{T} = -H(T)\, c_1\, T - [P_1 + E_c] \text{, when } S_1 > 0 \tag{4.18}$$

$$\dot{T} = 30000 \qquad \text{when } S_1 < 0,$$

where:

$$E_c = 100\frac{S_1}{1 + H(T)T} \text{ and} \tag{4.19}$$

$$H(T) = 1 \text{ for } T \geq 0, \tag{4.20}$$

$H(T)=0$ for $T < 0$, (4.21)

and e_1 is as defined in equation (4.8). By keeping the engine output constant, we have:

$$\dot{T}_b = -\dot{T} \tag{4.22}$$

The control law for $\dot{T}$ is chosen in such a way that $dS_1/dt < 0$ whenever $S_1 > 0$ in accordance with Theorem 4.1. To not restrict T to a value near zero, $H(T)$ is included in the control law. Ec is designed such that it speeds up the convergence of the trajectory to the sliding surface when T is small and S_1 is large. 100 (one hundred) is a scaling factor which makes E_c compatible with other terms in equation (4.18).

4.5 .SLIDING CONTROL

Model imprecision may come from actual uncertainty about the plant *(e.g.,* unknown plant parameters), or from the purposeful choice of a simplified representation of the system's dynamics (e.g., modeling friction as linear, or neglecting structural modes in a reasonably rigid mechanical system). From a control point of view, modeling inaccuracies can be classified into two major kinds:

– *structured* (or *parametric)* uncertainties

– *unstructured* uncertainties (or *unmodeled dynamics)*

The first kind corresponds to inaccuracies on the terms actually included in the model, while the second kind corresponds to inaccuracies on *(i.e.,* underestimation of) the system order.

Modeling inaccuracies can have strong adverse effects on nonlinear control systems. Therefore, any practical design must address them explicitly. Two major and conplementary approaches to dealing with model uncertainty are robust *control* and *adaptive control.* The typical structure of a robust controller is composed of a nominal part, similar to a feedback linearizing or inverse control law, and of additional terms aimed at dealing with model uncertainty. The structure of an adaptive controller is similar. but in addition the model is actually updated during operation, based on the measured performance.

A simple approach to robust control, is the so-called sliding control methodology. Intuitively, it is based on the remark that it is much easier to control 1st-order systems (i.e., systems described by 1st-order differential equations), be they non nth-order systems (i.e., systems described by nth-order differential equations). Accordingly, a notational simplification is introduced by equivalent 1st-order problems. It is then easy to show that, for the transformed problems "perfect" performance can in principle be a achieved in the presence of arbitrary parameter inaccuracies. Such performance, however, is obtained at the price of extremely high control activity. This is typically at odds with the other source of modeling uncertainty, namely the presence of neglected dynamics, which the high control activity may excite. This leads us to a modification of the control laws which, given the admissible control activity, is aimed at achieving an effective trade-off between tracking performance and parametric uncertainty.

For the class of systems to which applies, sliding controller design provides a systematic approach to the problem of maintaining stability and consistent performance in the face of modeling imprecisions. Furthermore, by allowing the trade-offs between modeling and performance to be quantified in the simple fashion, it can illuminate the whole design process.

4.5.1 Sliding Surfaces

Consider the single-input dynamic system

$$x^{(n)} = f(\mathbf{x}) + b(\mathbf{x})\,u \qquad (4.23)$$

where the scalar x is the output of interest (for instance, the position of a mechanical system), the scalar ii is the control input (for instance, a motor torque), and **x** $\mathbf{x} = [x\ \dot{x}\ \ldots x^{(n-1)}]^T$ is the state vector. In equation (4.23) the function f(**x**) (in general nonlinear) is not exactly known, but the extent of the imprecision on f(**x**) is in general nonlinear) is not exactly known, but the extent of the imprecision on f(**x**) is upper bounded by a known continuous function of **x** ; similarly, the control gain b(**x**) is not exactly known, but is of known sign and is bounded by known, continuous functions of **x**. For instance, typically, the inertia of a mechanical system is only known to a certain accuracy, and friction models only describe part of the actual friction forces. The control problem is to get the state **x** to track a specific time-varying state $x_d = [x_d\ \dot{x}_d \ldots x_d^{(n-1)}]^T$ in the presence of model imprecision on f(**x**) and b(**x**).

For the tracking task to be achievable using a finite control u, the initial desired state $\mathbf{x}_d(0)$ must be such that

$$\mathbf{x}_d(0)=\mathbf{x}(0) \tag{4.24}$$

In a second-order system, for instance, position or velocity cannot "jump", so that any desired trajectory feasible from time t=0 necessarily starts with the same position and velocity as those of the plant. Otherwisw, tracking can only be achieved after a transient.

4.5.2 A Notational Simplification

Let $\tilde{\mathbf{x}}=\mathbf{x}-\mathbf{x}_d$ be the tracking error in the variable x, and let

$$\tilde{x}=x-x_d=\left[\tilde{x}\ \dot{\tilde{x}}\ldots\tilde{x}^{(n-1)}\right]^T \tag{4.25}$$

be the tracking error vector. Furthermore, let us define a time-varying surface S(t) in the state-space $R^{(n)}$ by the scalar equation s(x;t)=0, where

$$s(x;t)=\left(\frac{d}{dt}+\lambda\right)^{n-1}\tilde{x} \tag{4.26}$$

and λ is a strictly positive positive constant. For instance, if n=2,

$$s=\dot{\tilde{x}}+\lambda\,\tilde{x} \tag{4.27}$$

i.e., s simply a weighted sum of the position error and the the velocity error; if n=3,

$$s=\ddot{\tilde{x}}+2\lambda\,\dot{\tilde{x}}+\lambda^2\tilde{x} \tag{4.28}$$

Given initial conditions (4.24), the problem of tacking $\mathbf{x}\equiv\mathbf{x}_d$ is equivalent to that of remaining on the surface S(t) for all t > 0; indeed s≡0 represents a linear differential equation whose unique solution is $\tilde{x} \equiv 0$, given initial conditions (7.24). Thus, the problem of tracking the n-dimensional vector x_d can be reduced to that of keeping the scalar quantity s at zero.

More precisely, the problem of tracking the n-dimensional vector x_d (i.e., the original n^{th}-order tracking problem in x) can in effect be replaced by a 1^{st}-order stabilization problem in s. Indeed, since from (7.26) the expression of s contains $\tilde{x}^{(n-1)}$, we only need to differntiate s once for the input u to appear.

Furthermore, bounds on s can be directly translated into bounds on the tracking error vector $\tilde{\mathbf{x}}$, and therefore the scalar s represents a true measure of tracking performance. Specifically, assuming that $\tilde{\mathbf{x}}(0) = \mathbf{0}$ (the effect of non-zero initial conditions in $\tilde{\mathbf{x}}$ can be added seperately), we have

$$\forall t \geq 0, \quad |s(t)| \leq \Phi \qquad \Rightarrow \forall t \geq 0, \geq \left| \tilde{x}^{(i)}(t) \right| \leq (2\lambda)^i \varepsilon \tag{4.29}$$

i=0,...,n-1

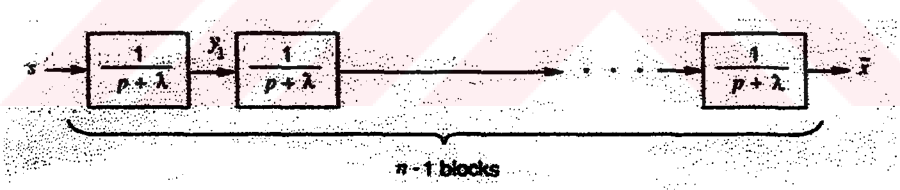


Figure 4.6 a Block diagram

Where $\varepsilon = \Phi / \lambda^{n-1}$.Indeed, by definition (4.26) , the tracking error $\tilde{\mathbf{x}}$ is obtained from s through a sequence of first-order lowpass filters (figure4.6 a , where p=(d/dt) is the Laplace operator). Let y_1 be the output of the first filter. We have

$$y_1(t) = \int_0^t e^{-\lambda(t-T)} s(T) dT \tag{4.30}$$

From $|s| \leq \Phi$ we thus get

$$|y_1(t)| \le \Phi \int_0^t e^{-\lambda(t-T)} dT = (\Phi / \lambda)(1 - e^{-\lambda t}) \le \Phi / \lambda \tag{4.31}$$

We can apply the same reasoning to the second filter, and so on, all the way to $y_{n-1} = \tilde{x}$. We then get

$$|\tilde{x}| \le \Phi / \lambda^{n-1} = \varepsilon \tag{4.32}$$

Similarly, $x^{(i)}$ can be thought of as obtained through the sequence of Figure 4.6 b. From the previous result, one has $|z_1| \le \Phi/\lambda^{n-1-i}$, where z_1 is the output of the $(n-i-1)^{th}$ filter. Furthermore, noting that $p/(p+\lambda)=(p+\lambda-\lambda)/(p+\lambda)=1-\lambda/(p+\lambda)$

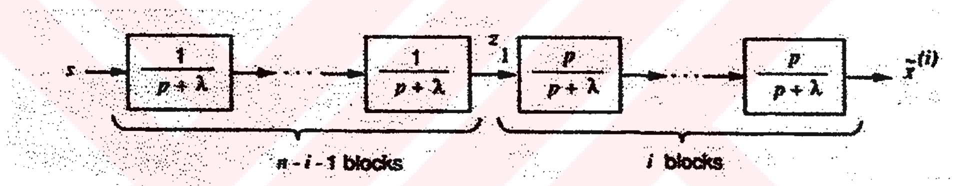


Figure 4.6 b Block diagram

one sees that the sequence of Figure 4.6 b implies that

$$\left|\tilde{x}^{(i)}\right| \le \left(\frac{\Phi}{\lambda^{n-1-i}}\right)\left(1+\frac{\lambda}{\lambda}\right)^i = (2\lambda)^i \varepsilon \tag{4.33}$$

i.e., bounds (4.29) Finally, in the case that $\tilde{\mathbf{x}}(0) \ne \mathbf{0}$, bounds (4.29) are obtained asymptotically, i.e., within a short time-constant $(n-1)/\lambda$.

Thus, we have in effect replaced an n^{th}-order tracking problem by a 1^{st}-order stabilization problem, and have quantified with (4.29) the corresponding transfonnations of performance measures.

The simplified, 1^{st}-order problem of keeping the scalar s at zero can now be achieved by choosing the control law u of (4.23) such that outside of S(t)

$$\frac{1}{2}\frac{d}{dt}s^2 \leq -\eta|s| \tag{4.34}$$

where η is a strictly positive constant. Essentially, (4.34) states that the squared "distance" to the surface, as measured by s^2, decreases along all system trajectories. Thus, it constrains trajectories to point towards the surface S(t), as illustrated in Figure 4.7 In particular, once on the surface, the system trajectories remain on the surface. In other words, satisfying condition (4.34), or sliding condition makes the surface an invariant set. Furthermore, as we shall see, (4.34) also implies that some disturbances or dynamic uncertainties can be tolerated while still keeping the surface an invariant set. Graphically, this corresponds to the fact that in figure 4.7 the trajectories off the surface can "move" while still pointing towards the surface. S(t) (4.34) is referred to as a sliding surface,and the system's behaviour once on the surface is called sliding regime or sliding mode.

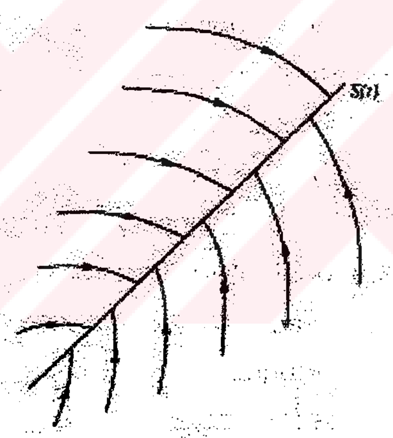


Figure 4.7 the sliding condition

The other interesting aspect of the invariant set S(t) is that once on it, the system trajectories are defined by the equation of the set itself, namely

$$\left(\frac{d}{dt}+\lambda\right)^{n-1}\tilde{x}=0 \tag{4.35}$$

In other words, the surface S(t) is both a place and a dynamics. This fact is simply the geometric interpretation of our earlier remark that definition (4.26) allows us, in effect, to replace an n^{th}-order problem by a 1^{st}-order one.

Finally, satisfying (4.34) guarantees that if condition (4.24) is not exactly verified, *i.e.,* if x(t=0) is actually off $x_d(t=0)$, the surface S(t) will nonetheless be reached in a finite time smaller than $|s(t=0)|/\eta$. Indeed, assume for instance that $s(t=0) > 0$, and let t_{reach} be the time required to hit the surface s=0. Integrating (4.34) between t = 0 and t = t_{reach} leads to

$$0 - s(t=0) = s(t=t_{reach}) - s(t=0) \leq \eta(t=t_{reach} - 0) \tag{4.36}$$

which implies that

$$t_{reach} \leq s(t=0)/\eta \tag{4.37}$$

one would obtain a similar result starting with $s(t=0) < 0$, and thus

$$t_{reach} \leq |s(t=0)|/\eta \tag{4.38}$$

Furthermore, definition (4.26)) implies that once on the surface, the tracking error tends exponentially to zero, with a time constant $(n-1)/\eta$(from the sequence of (n - 1) filters of time constants equal to $1/\lambda$).

The typical system behavior implied by satisfying sliding condition (4.34) is illustrated in Figure 4.8 for n = 2. The sliding surface is a line in the phase plane, of slope $-\lambda$ and containing the (time-varying) point $\mathbf{x}_d = [x_d \; \dot{x}_d]^T$. Starting from any initial condition, the state trajectory reaches the time-varying surface in a finite time smaller than $|s(t=0)|/\eta$, and then slides along the surface towards X_d exponentially, with a time-constant equal to $1/\lambda$.

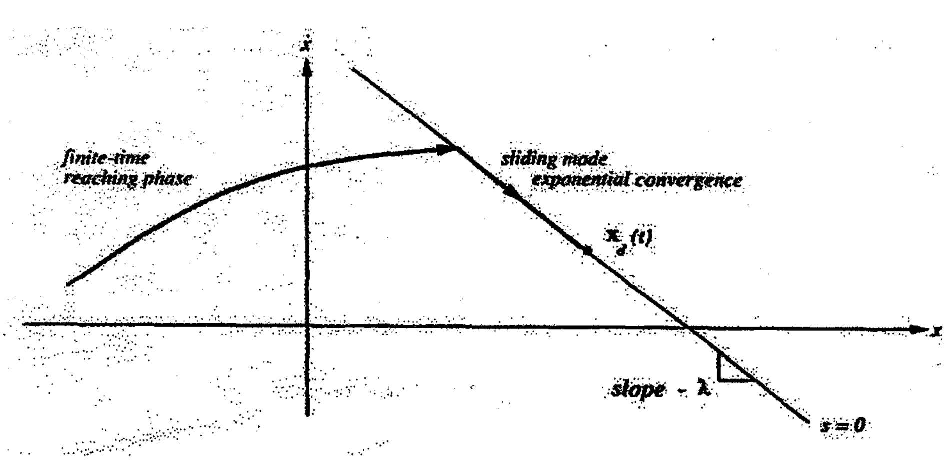


Figure 4.8 Graphical interpretation of equations (4.26) and (4.34) (n=2)

In summary, the idea behind equations (4.26) and (4.34) is to pick-up a well-behaved function of the tracting error, s, according to (4.26), and then select the feedback control law u in (4.34) such that s2 remains a Lyapunov-like function of the closed-loop system, despite the presence of model imprecision and of disturbances. The controller design procedure then consists of two steps. First, a feedback control law u is selected so as to verify sliding condition . However, in order to account for the presence of modeling imprecision and of disturbances, the control law has to be discontinuous across S(t). Since the implementation of the associated control switchings is necessarily imperfect (for instance, in practice switching is not instantaneous, and the value of s is not known with infinite precision), this leads to chattering(Figure 4.9).Now, chattering is undesirable in practice, since it involves high control activity and further may excite hi-frequency dynamics neglected in the course of modeling. Thus, the discontinuous control law u is suitably smoothed to achieve an optimal trade-off between control bandwidth and tracking precision :while the first step accounts for parametric uncertainty, the second step achieves robustness to high-frequency unmodeled dynamics.

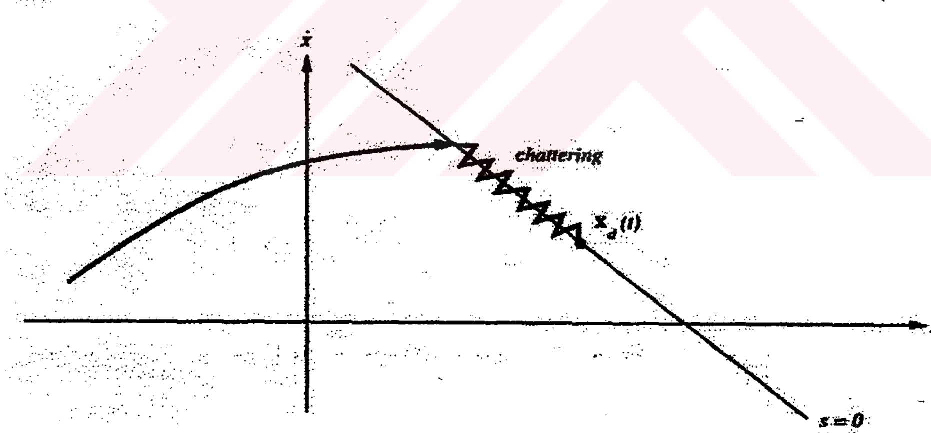


Figure 4.9 Chattering as a result of imperfect control switchings

4.5.3 Direct Implementations of Switching Control Laws

The main direct applications of the above switching controllers include the control of electric motors, and the use of artificial dither to reduce stiction effects.

Switching Control In Place Of Pulse-Width Modulation: In pulse-width modulated electric motors, the control input u is an electrical voltage rather than a mechanical force or acceleration. Control chattering may then be acceptable provided it is beyond the frequency range of the relevant unmodeled dynamics. Provided that the necessary computations (including both control law and state estimation) can be handled on-line at a high enough rate, or implemented using analog circuitry, pure sliding mode control using switched coutrol laws can be a viable and extremely high-performance option.

Switching Control With Linear Observer: The difficulty in obtaining meaningful state measurements at very high sampling rates can be turned around by using state observers. For linear systems, the design of such observers is well known and systematic. The principle of the approach to designing a switching controller using an observer is then very simple. Instead of tracking the surfaces s=0, the system is made to track the surface s_e =0, where s_e is obtained by replacing the state **x** by its estimate $\mathbf{x}_e$ in the expression of s. This can be achieved by computing a dynamic compensation term $\hat{u}_e$ based on the available state estimates, and using switching terms of the form - $k(\mathbf{x}_e)$ sgn(s_e), where $k(\mathbf{x}_e)$ is chosen large enough to compensate both for parametric inaccuracies and for observer inaccuracies. This yields $s_e \to 0$ (as $t \to \infty$). Then, if the observer has been properly designed so that it converges despite modeling uncertainties (which, again, is easy to achieve in the linear case), we also have $s \to s_e$. Therefore, $s \to 0$, and the actual state converges towards the desired state. Furthermore, sliding mode and its robust properties are maintained on the surface s_e=0, which tends towards the desired sliding surface as the observer converges.

Switching Control In Place Of Dither: When uncertainty consists of effects small in magnitude but difficult to model, such as stiction or actuator ripple, switching in s may be advantageously used in place of a more standard "dither" signal. Ideally, the frequency of the switching should be chosen well beyond that of significant structural vibration modes (in mechanical systems), while remaining below the actuators' bandwidth. This assumes again that meaningful state estimates can be provided at the selected switching frequency. Such an approach can particularly improve the quality of low-speed behavior, which otherwise is extremely sensitive to friction.

4.5.4 Continuous Approximations of Switching Control Laws

In general, chattering must be eliminated for the controller to perform properly. This can be achieved by smoothing out the control discontinuity in a thin boundary layer neighboring the switching surface

$$B(t) = \{x, |s(\mathbf{x};t)| \le \Phi\} \qquad \Phi \succ 0 \tag{4.39}$$

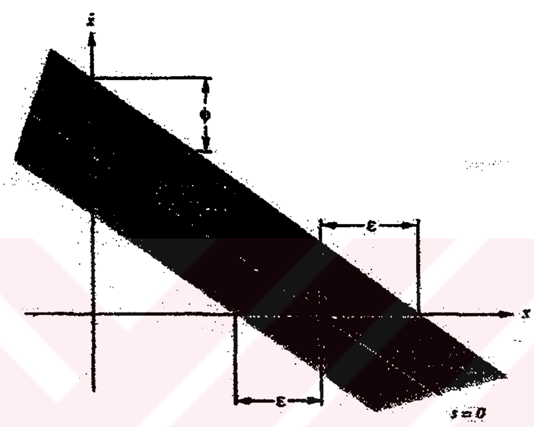


Figure 4.10a The boundary layer

where Φ is the boundary layer thickness, and $\varepsilon=\phi/\lambda^{n-1}$ is the boundary layer width, as Figure 4.10a illustrates for the case n = 2. In other words, outside of B(t), we choose control law u as before (i.e., satisfying sliding condition (7.5), which guarantees th:tf the boundary layer is attractive, hence invariant: all trajectories starting inside B(t=0) remain inside B(t) for all $t \ge 0$ and we then interpolate it inside B(t) - for instance, replacing in the expression of u the term sgn(s) by s/φ,inside B(t), as illustrated in Figure 4.10b.

This leads to tracking to within a guaranteed precision ε (rather than "perfect" tracking), and more generally guarantees that for all trajectories starting inside B(t=0)

$$\forall t \ge 0, \left|\tilde{x}^{(i)}(t)\right| \le (2\lambda)^i \varepsilon \qquad i = 0, \ldots, n-1 \tag{4.40}$$

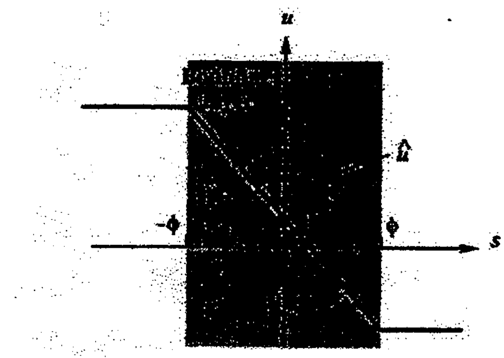


Figure 4.10b: Control interpolation in the boundary level

The intuitive understanding of the effect of control interpolation in a boundary layer can be carried on further, and guide the selection of the design parameters λ and ϕ. As we now show, the smoothing of control discontinuity inside B(t) essentiallv assigns a lowpass filter structure to the local dynamics of the variable s, thus eliminating chattering. Recognizing this filter-like structure then allows us, in essence, to tune up the control law so as to achieve a trade-off between tracking precision and robustness to unmodeled dynamics. Boundary layer thickness ϕ can he made time-varying, and can be monitored so as to well exploit the control "bandwidth" available. The development is first detailed for the case β=1 (no gain margin), and then generalized.

Consider again the system (4.23) with $b = \hat{b} = 1$. In order to maintain attractiveness of the boundary layer now that ϕ is allowed to vary with time, we must actually modify condition (4.34). Indeed, we now need to guarantee that the distance to the boundary layer always decreases

$$s \geq \Phi \qquad \Rightarrow \frac{d}{dt}[s-\Phi] \leq -\eta \tag{4.41}$$

$$s \leq -\Phi \qquad \Rightarrow \frac{d}{dt}[s-(-\Phi)] \geq \eta \tag{4.42}$$

Thus, instead of simply requiring that (4.34) be satisfied outside the boundary layer, we now require that (combining the above equations)

$$|s| \geq \Phi \qquad \Rightarrow \frac{1}{2}\frac{d}{dt}s^2 \leq (\dot{\Phi}-\eta)|s| \tag{4.43}$$

The additional term $\dot{\Phi}|s|$ is in (4.43) reflects the fact that the boundary layer attraction condition is more stringent during boundary layer contraction ($\dot{\Phi} \prec 0$) and less stringent during boundary layer expansion ($\dot{\Phi} \succ 0$). [12]

5. RESULTS AND DISCUSSIONS

The parameters which are effective on wheel and vehicle velocities, applied brake and net torques and wheel-road releationship are listed below:

T_{eng} (Engine Torque), I_e (Engine Moment Of Inertia), B_r (Rolling Friction Coefficient), N_w (Number Of Active Wheels), R_w (Wheel Radius), M_v (Vehicle Mass), I_w (Wheel Moment Of Inertia), r (Gear Ratio) and B_v (Aerodynamic Drag Coefficient).

T_{eng} (Engine Torque)

Engine torque has a big effect on wheel slip. When the engine torque is increased, the wheel velocity also increases but it has no effect on vehicle velocity. Parallel to this, the ratio between wheel velocity and vehicle velocity increases. Thus, strong engines cause much more spin during acceleration. The increment of engine torque, increases the applied brake torque.

I_e (Engine Moment Of Inertia)

Engine moment of inertia is effective at the beginning of the vehicle movement. By decreasing the moment of inertia, spin of the wheels can occur more effectively. After 600 seconds, slip ratio decreases and stays constant. Engine moment of inertia does not affect vehicle velocity. Engine moment of inertia is effective on brake and net torques till 400 th second of the movement. After 400th second the brake torque decreases and net torque increases.And both torques stay constant.

B_r (Rolling Friction Coefficient)

Rolling Friction Coefficient is a function of wheel-road relationship. When the friction between road and wheel increases slip ratio will decrease and better acceleration results are get.

N_w (Number Of Active Wheels)

A comparison between two-wheel drive and four-wheel drive is done. In four-wheel drive, the wheel slip is a little bit reduced. Number of active wheels has no great effect on the torques. The 4WD increases the brake torque and decreases the net torque.

R_w (Wheel Radius)

Bigger wheels reduce the wheel slip. The change in the radius of the wheel has a big effect on velocity and on slip ratio. A small increment in wheel radius causes better acceleration. Wheel radius is also effective on torques. Bigger wheels decrease brake torque and increase the net torque.

M_v (Vehicle Mass)

When the mass of the vehicle is increased, the slip ratio will reduce. Because the vehicle mass is effective on the normal force on the wheel. When the vehicle becomes heavier the applied brake torque decreases and net torque increases.

I_w (Wheel Moment Of Inertia)

Wheel moment of inertia is not a very effective parameter. When bigger I_w's are used the slip ratio can be decreased a little bit. The effect of wheel moment of inertia is negligible on the torques. The increament of the inertia causes small decrements on the brake torque and increment on the net torque.

r (Gear Ratio)

Use of smaller gear ratios will reduce the slip ratio. But it has no effect on vehicle acceleration. Greater gear ratios decrease the applied brake torque and increase the net torque.

B_v (Aerodynamic Drag Coefficient)

The effect of this parameter is negligible on both velocities and torques.

C_1 (Convergence constant)

Convergence constant is a very effective parameter. It is important to chose an optimum value. For smaller values it takes longer time to make the system stable. For this system c_1 is chosen as 60 for an optimum solution. Small values of c_1 causes big slip ratios. It is also very effective on the torques. When c_1 is 20 very big changes occurs on torques until the stable area. When c_1=40 and c_1=60, convergence constant causes less changes on the torques. For c_1=60 , better results are get.

6. CONCLUSION

Current control developments for anti-spin acceleration are mostly table-driven and calibrated through various experiments and tests. It is the atttemp to investigate vehicle traction control from a theoretical view point to gain more in-depth understanding of the vehicle traction system, which lead to the improvement of the control design for vehicle traction control.

Because of the similarity between the optimal traction control and zeroth order sliding mode, the application of sliding model control and variable structure control to vehicle traction is explored. Sufficient conditions for applying sliding-mode control to vehicle traction during anti-spin acceleration in the preferable operating region are obtained. Based on these sufficient conditions, control laws are derived. The sufficient conditions and the control laws are then verified via computer simulations. These sufficirnt conditions can be used to guide the selection of the actuators and control schemes during hardware implementation.

For real time implementation of the equations λ can be computed with the measurement of the vehicle. For anti-spin acceleration vehicle speed can be obtained fron the speeds of non-driven wheels.

It is important to know the tire/road contact conditions in order to achieve optimal anti-spin control performance. In particular, the knowledge of thepeak of the μ-λ curve is crucial to the controller. A surface estimation process is therefore proposed to identify the tire/road contact characteristics. Adaptive vehicle traction control, incorporating the variable structure control and the surface estimation process is simulated.

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8. BIOGRAPHY

Meltem Öksüzoğlu was born in Ankara in 1975. She graduated from İzmir 60. Year Anatolian High School in 1993 and İstanbul Technical University Mechanical Engineering in 1997.

She is still attending Mechanical Engineering Master Program in İ.T.U. Also she has been working as a Vehicle Engineer in Ford-Otosan since 1997.

APPENDIX A:

MATLAB PROGRAM

```
% Vehicle traction control: Variable-structure control
% approach by Tan and Chin.
% Load mudata.mat (or any mat-file which supplies the
% lambda and muval vectors as muval=f(lambda), to be
% used for interpolation) before running this script.


Mv=1400; % Vehicle mass (Kg).
Br=0.01; % Rolling friction coefficient.
Bv=0.595; % Air friction (drag) coefficient (N/m2/s2).
Nv=3560; % Normal force, one wheel (vehicle_weight/4) (N).
Rw=0.31; % Wheel radius (m).
r=9.5285; % Gear ratio (first gear).
Iw=0.65; % Wheel moment of inertia (Kg.m2).
Ie=0.429; % Engine moment of inertia (Kg.m2).
Jw=Iw+Ie*r*r/2; % Total moment of inertia at wheel (Kg.m2).
Teng=120; % Constant engine torque (N.m).
Te=(Teng/2)*r; % Engine torque at wheel (N.m).
clear T Tb
Tb(1)=0; % Initial brake torque (N.m).
T(1)=Te-Tb(1); % Net wheel torque (Tb will be varied.  Tb_dot = - T_dot).
Nw=2; % Number of active wheels.
b1n=Nw*Nv/Mv/Rw;
b2n=Rw*Nv/Jw;
b3=1/Jw;
f2=Rw*Br*Nv/Jw;

c1=60; % Convergence constant.
if exist('lambda')~=1 load mudata, end %mu=f(lambda).
%Lp=0.15; % Lambda where the maximum of mu occurs.
% Find Lp (the lambda where the maximum of mu is):
x=0:.005:1;
y=interp1(lambda,muval,x,'spline');
iy=find(y==max(y));
Lp=x(iy);

% x1 is Omega_vehicle (corresponding to its velocity), x2 is Omega_wheel.
% Their initial values:
clear x1 x2 x1_dot x2_dot
x1(1)=0.5; x2(1)=0.5;
x1_dot(1)=0; x2_dot(1)=0;
v=x1(1)*Rw; % Vehicle velocity.

% Initial lambda and derivative:
```

```
clear L L_dot
L(1)=0; L_dot(1)=0;

ts=0.0002; % Integration time step.


% --------------loop------------------------------------

          for k=1:1000

% Slip (lambda):
L(k)=(x2(k)-x1(k))/x2(k);
L_dot(k) = -x1_dot(k)/x2(k) + x1(k)*x2_dot(k)/x2(k)/x2(k);
% Adhesion coefficient:
mu=interp1(lambda,muval,L(k),'spline');
% partial f1 / partial x1 :
df1_dx1=(2*Bv*Rw/Mv)*x1(k);
e1=df1_dx1*b1n*mu;
f1 = Bv*Rw*x1(k)*x1(k)/Mv + Br*Nv/Mv/Rw;
P1=(x2(k)/x1(k))*(1/b3)*(e1 + x1_dot(k)*x1_dot(k)/x1(k)/2 + c1*(f1-(1-L(k))*f2));
S1=L_dot(k)+c1*(L(k)-Lp);
if T(k)>=0  H=1; else  H=0; end
Ec=100*S1/(1+H*T(k));

if S1>=0
  Tb_dot=H*c1*T(k)+(P1+Ec);
else
  Tb_dot=-30000;
end
% Integrate and apply the limits:
Tb(k+1) = Tb(k) + Tb_dot*ts;
if Tb(k+1)>2000  Tb(k+1)=2000; end,  if Tb(k+1)<0  Tb(k+1)=0; end
T(k+1)=Te-Tb(k+1);

% Integrate the wheel equation:
x2_dot(k+1)=(T(k+1)-(Br+mu)*Nv*Rw)/Jw;
x2(k+1)=x2(k)+x2_dot(k)*ts;

% Integrate the vehicle equation:
v_dot=(mu*Nv-Br*Nv-Bv*v*v)/Mv;
v=v+v_dot*ts;
x1(k+1)=v/Rw;
x1_dot(k+1)=v_dot/Rw;

          end

% -----------------------------------------------------


          figure(1)
          % Phase plane plot (L_dot versus L):
          plot(L,L_dot)
          % Desired axis limits:
          ax=[-1 1 -20 20]; axis(ax)
          % Now, add the switching line, whose equation is  L_dot=-c1*(L-Lp).
```

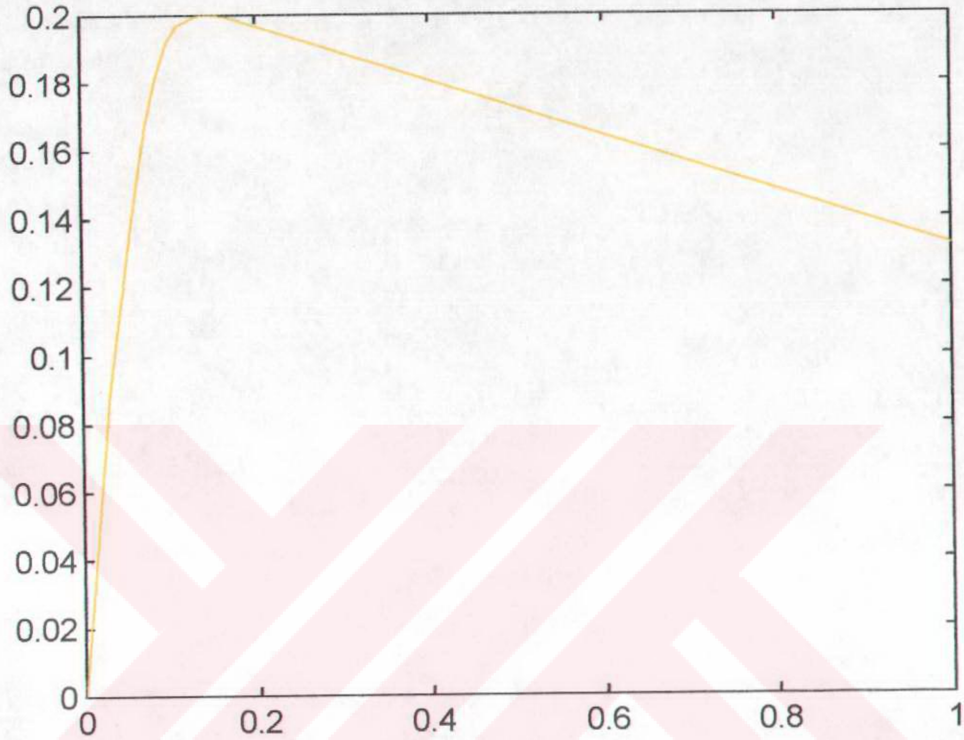
```
% First, find the lambda values L1 and L2 which correspond to the top
% and bottom of the switching line in the graph:
L1=-ax(4)/c1+Lp; L2=-ax(3)/c1+Lp;
hold on, plot([L1 L2],[ax(4) ax(3)],'--')
% Draw a vertical line, showing the target L (=Lp):
plot(Lp*[1 1],[ax(3) 0],':'), %hold off
% Place the labels, the title, and text that displays Lp:
xlabel('Lambda'), ylabel('Lambda_dot')
title('Lambda  -  Lambda_dot    Phase plane')
text(Lp+.02,ax(3)+1.5,num2str(Lp)), text((Lp+L2)/2+.03,ax(3)/2,'Switching
 Line')


figure(2)
plot(x1,col), hold on, plot(x2,col), plot(L,col), %hold off       xlabel('Time
 steps')
ylabel('Velocity (m/s) or Lambda')
title(' Vehicle Velocity & Wheel Velocity and Lambda')
figure(gcf)

figure(3)
plot(T,col),hold on, plot(Tb,col); %hold off%
xlabel('Time steps (sn)')
ylabel('Torque (N.m)')
title('Net Torque & Brake Torque')
```

MUDATA.MAT GRAPHICS

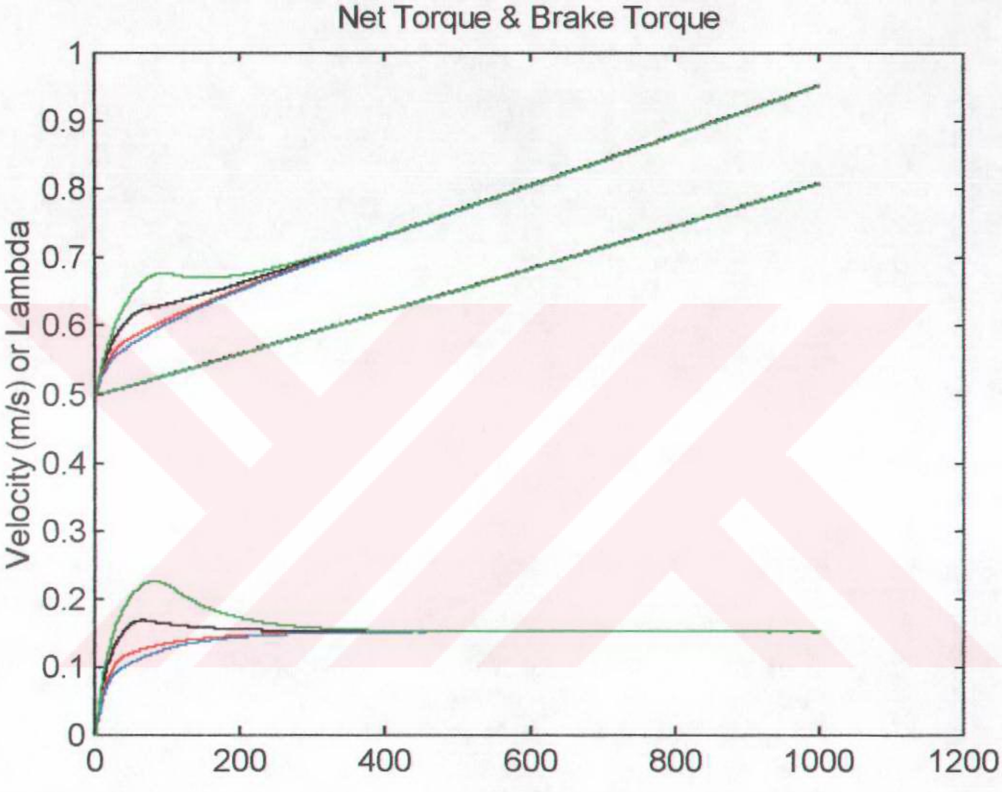
Lambda versus μ



APPENDIX B:

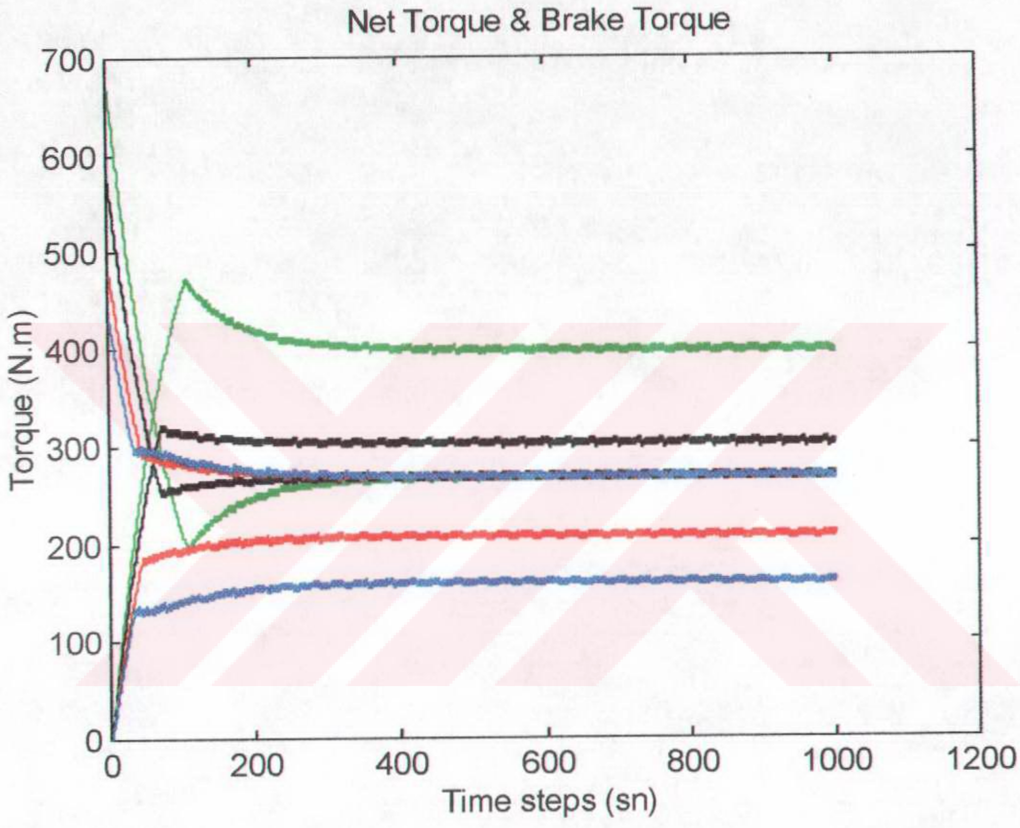
GRAPHICS

Effect Of Engine Torque (T_{eng}) On Wheel Velocity and Vehicle Velocity and Lambda



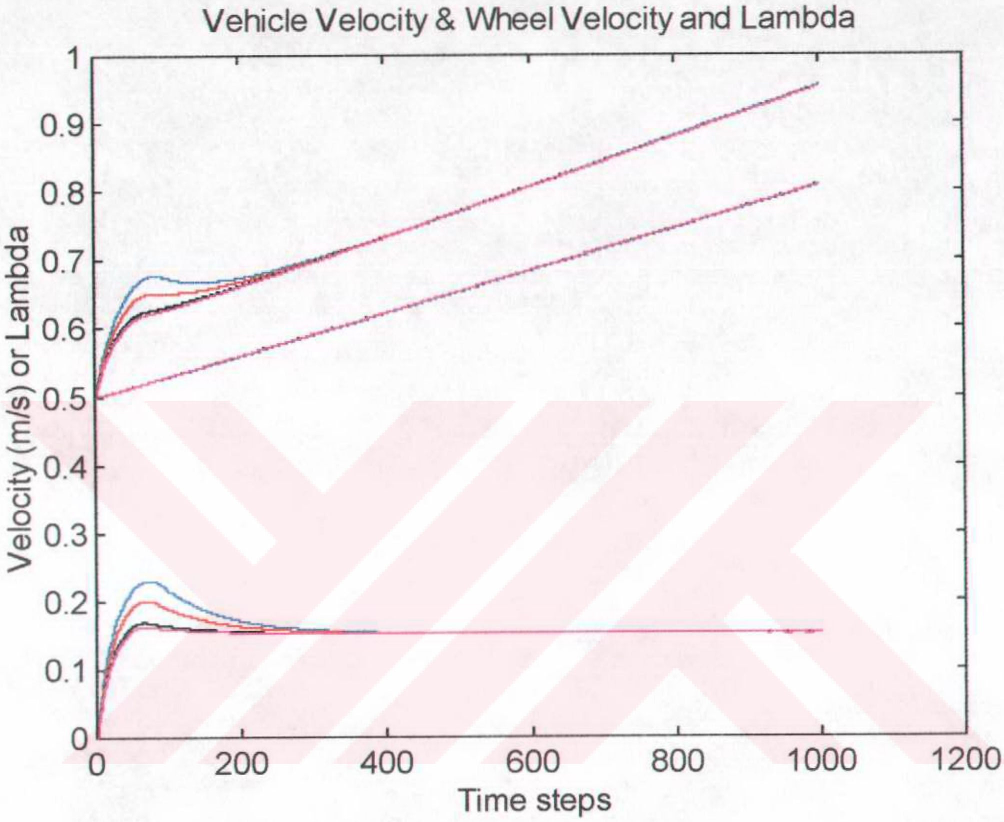
blue = 90 N.m
red = 100 N.m
black = 120 N.m
green = 140 N.m

Effect Of Engine Torque (T_{eng}) On Net Torque and Brake Torque



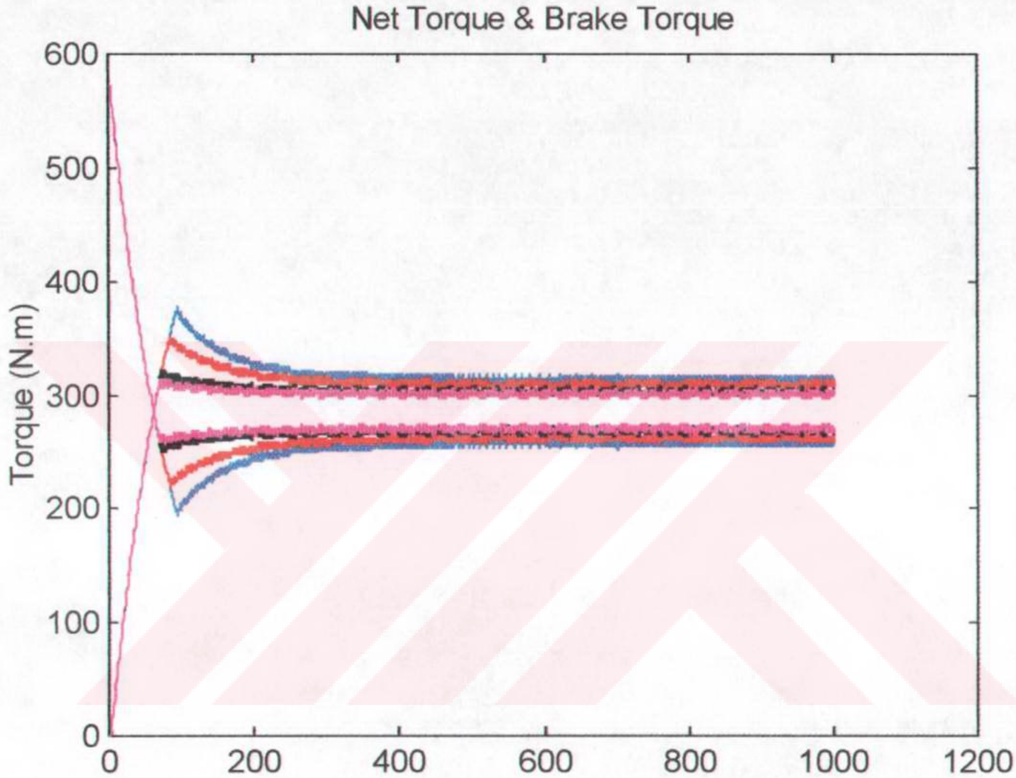
blue = 90 N.m
red = 100 N.m
black = 120 N.m
green = 140 N.m

Effect Of Engine Moment Of Inertia (I_e) On Wheel Velocity and Vehicle Velocity and Lambda



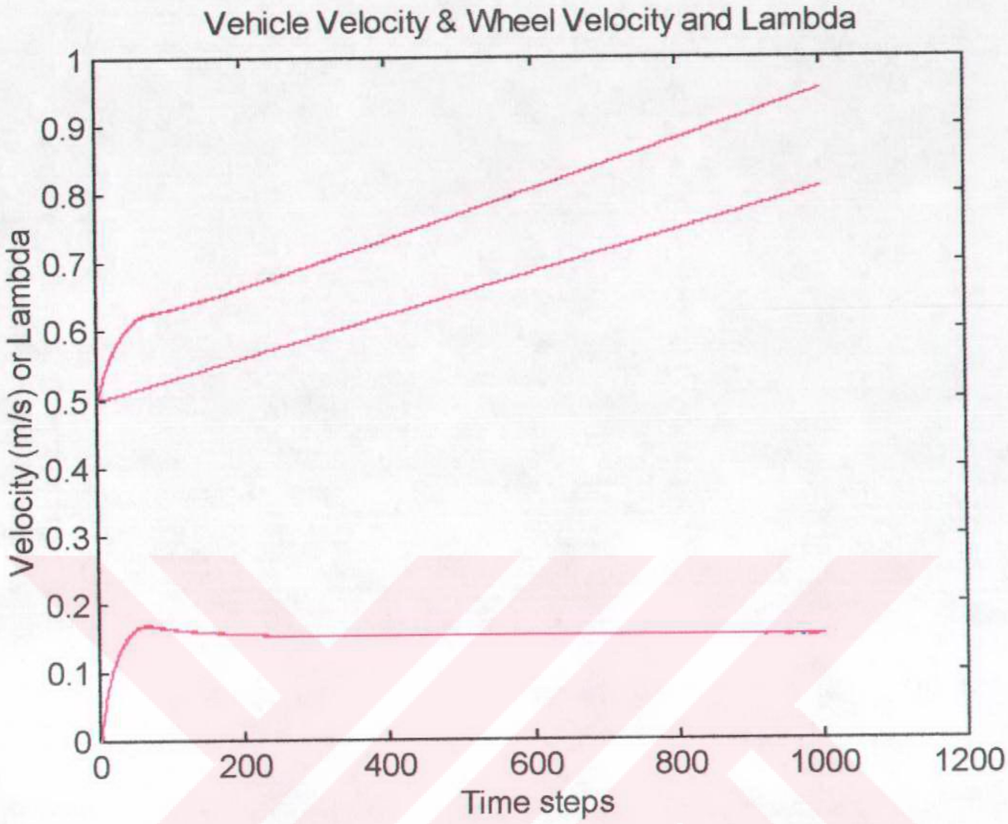
blue	**= 0.30 kg.m^2**
red	**= 0.35 kg.m^2**
black	**= 0.429 kg.m^2**
magenta	**= 0.45 kg.m^2**

Effect Of Effect Of Engine Moment Of Inertia (I_e) On Net Torque and Brake Torque

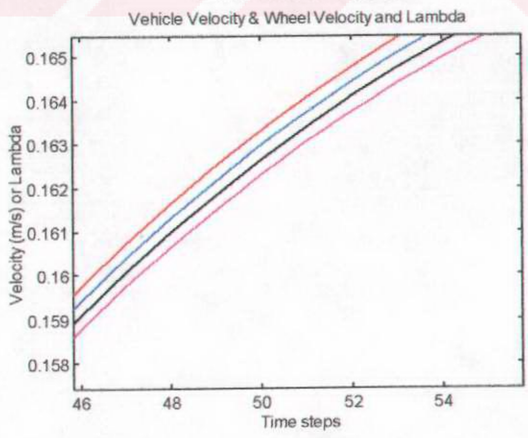


blue	**= 0.30 kg.m^2**
red	**= 0.35 kg.m^2**
black	**= 0.429 kg.m^2**
magenta	**= 0.45 kg.m^2**

Effect Of Wheel Moment Of Inertia (I_w) On Wheel Velocity and Vehicle Velocity and Lambda

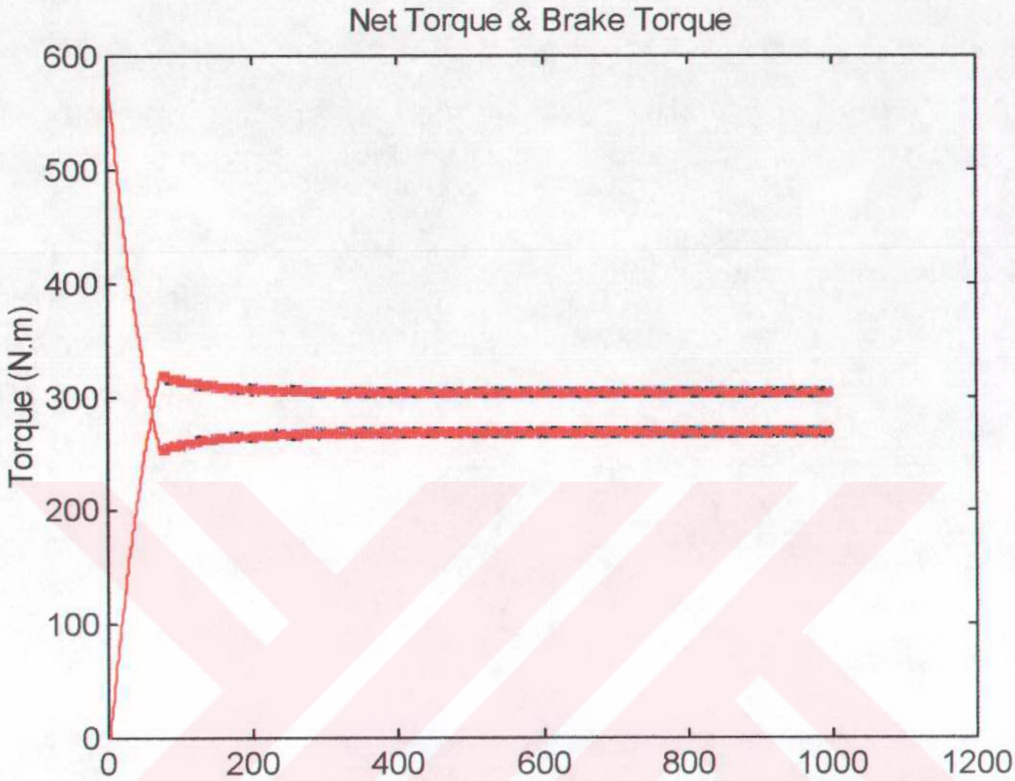


Zoomed View

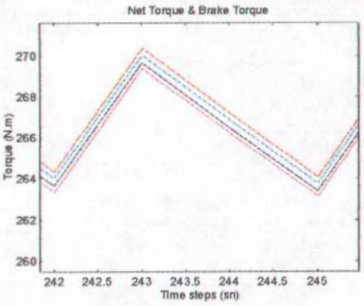


red = 0.55 kg.m^2
blue = 0.60 kg.m^2
black = 0.65 kg.m^2
magenta = 0.70 kg.m^2

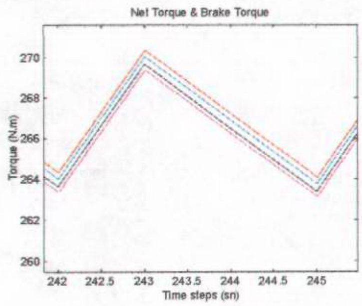
Effect Of Wheel Moment Of Inertia (I_w) On Net Torque and Brake Torque



Zoomed Views



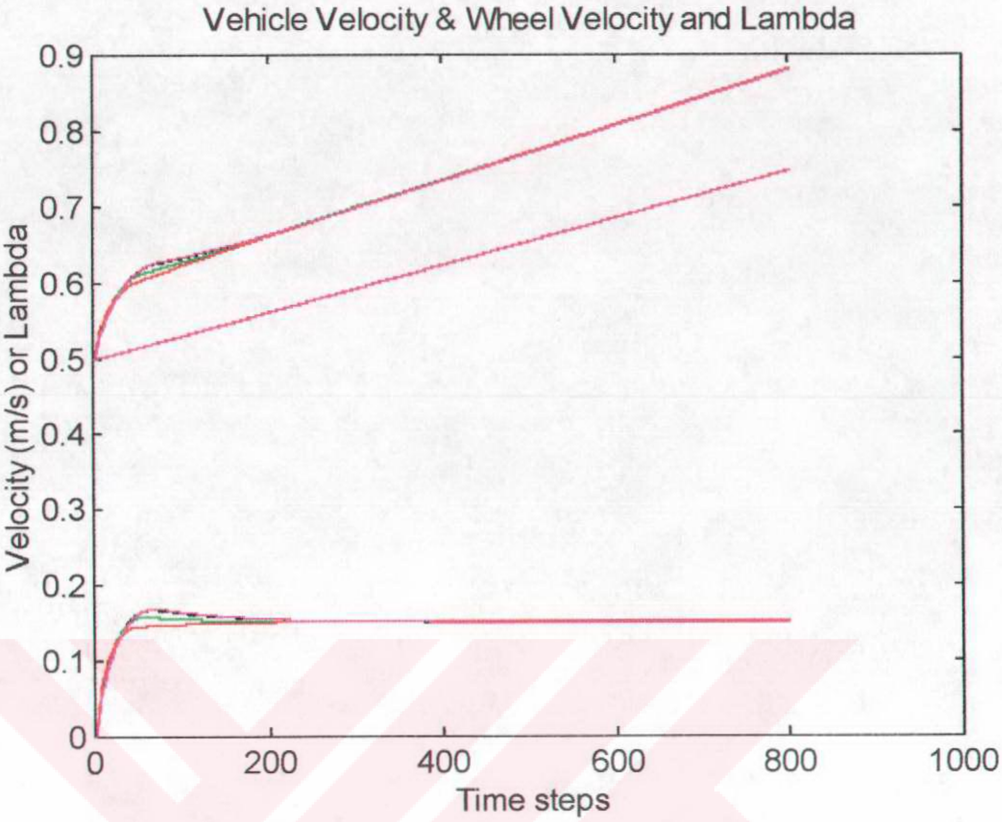
Net Torques



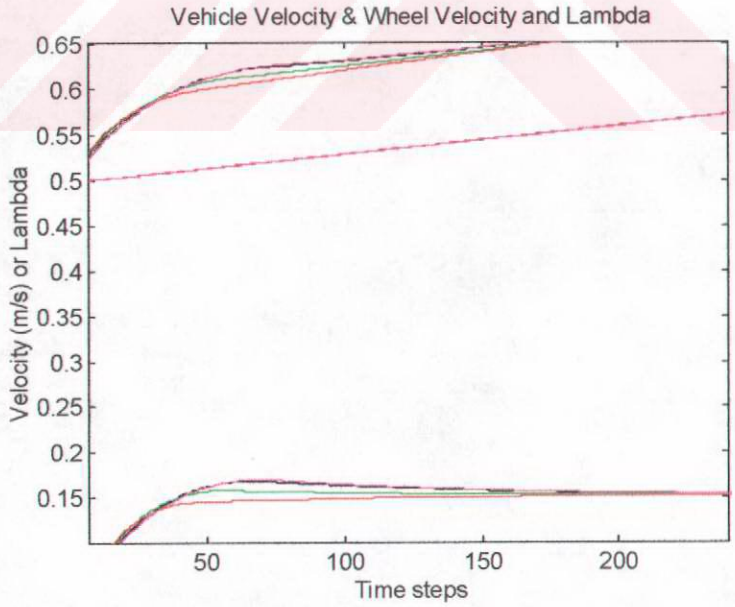
Brake Torques

Red	**= 0.55 kg.m^2**
blue	**= 0.60 kg.m^2**
black	**= 0.65 kg.m^2**
magenta	**= 0.70 kg.m^2**

Effect Of Gear Ratio (r) On Wheel Velocity and Vehicle Velocity and Lambda

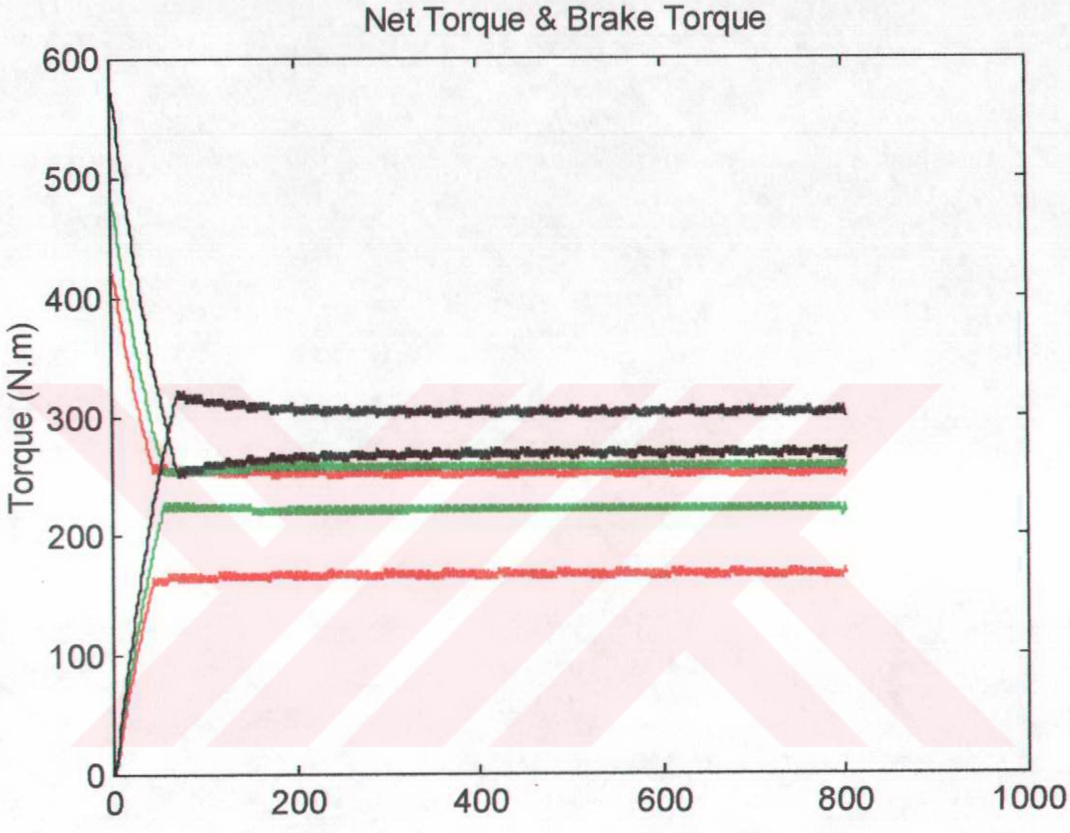


Zoomed view



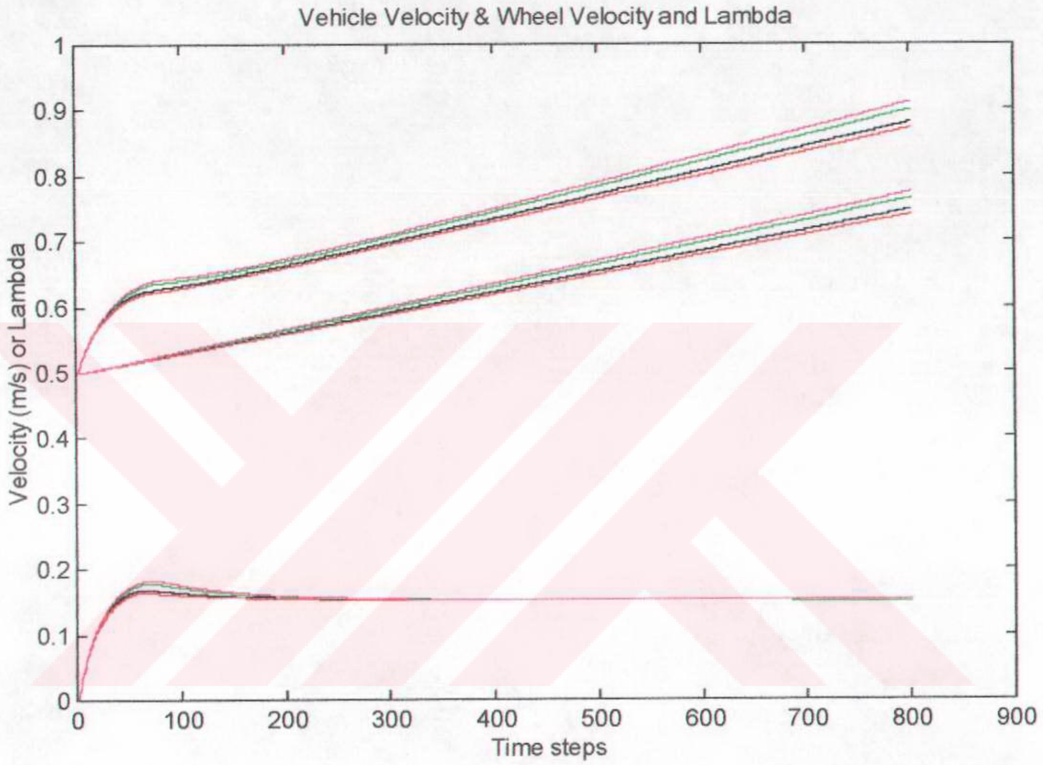
red = 7
green = 8
black = 9.5285
magenta = 10

Effect Of Gear Ratio (r) On Net Torque and Brake Torque



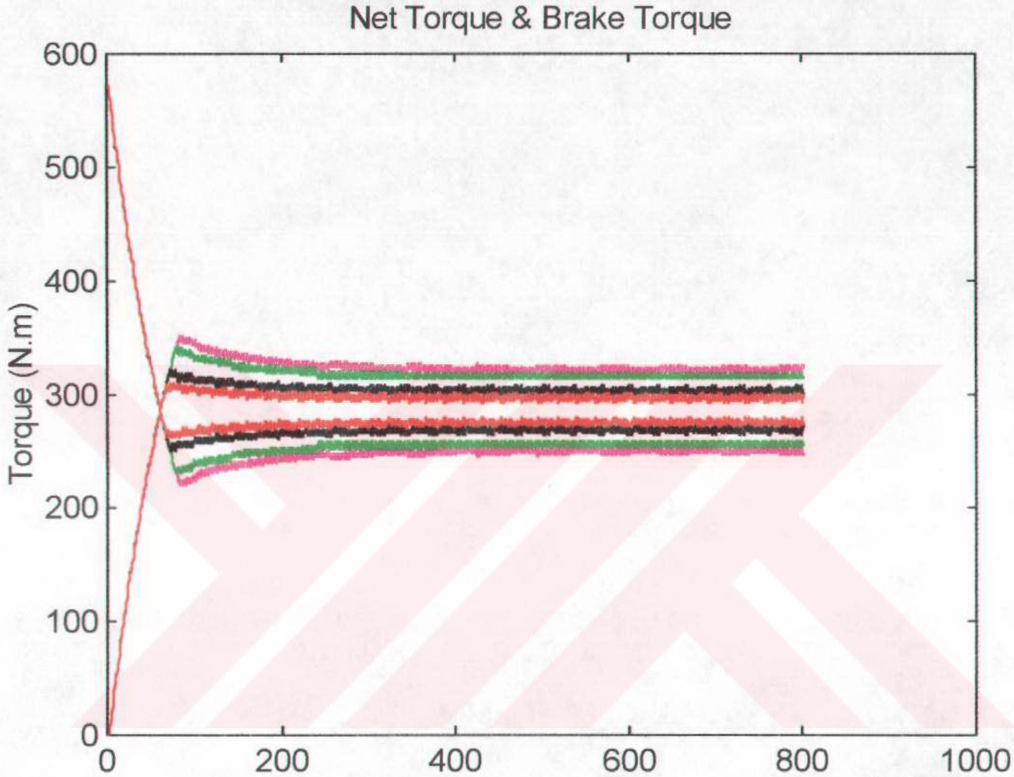
red = 7
green = 8
black = 9.5285

Effect Of Wheel Radius (R_w) On Wheel Velocity and Vehicle Velocity and Lambda



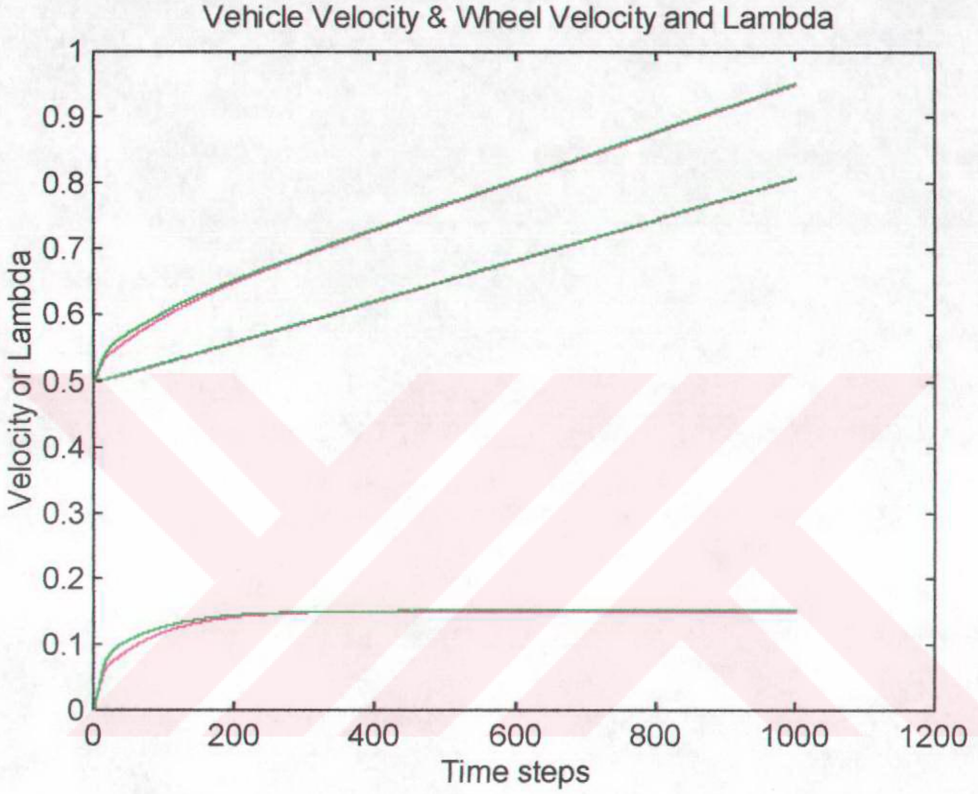
magenta = 0.28 m
green = 0.29 m
black = 0.31 m
red = 0.32 m

Effect Of Wheel Radius (R_w) On Net Torque and Brake Torque



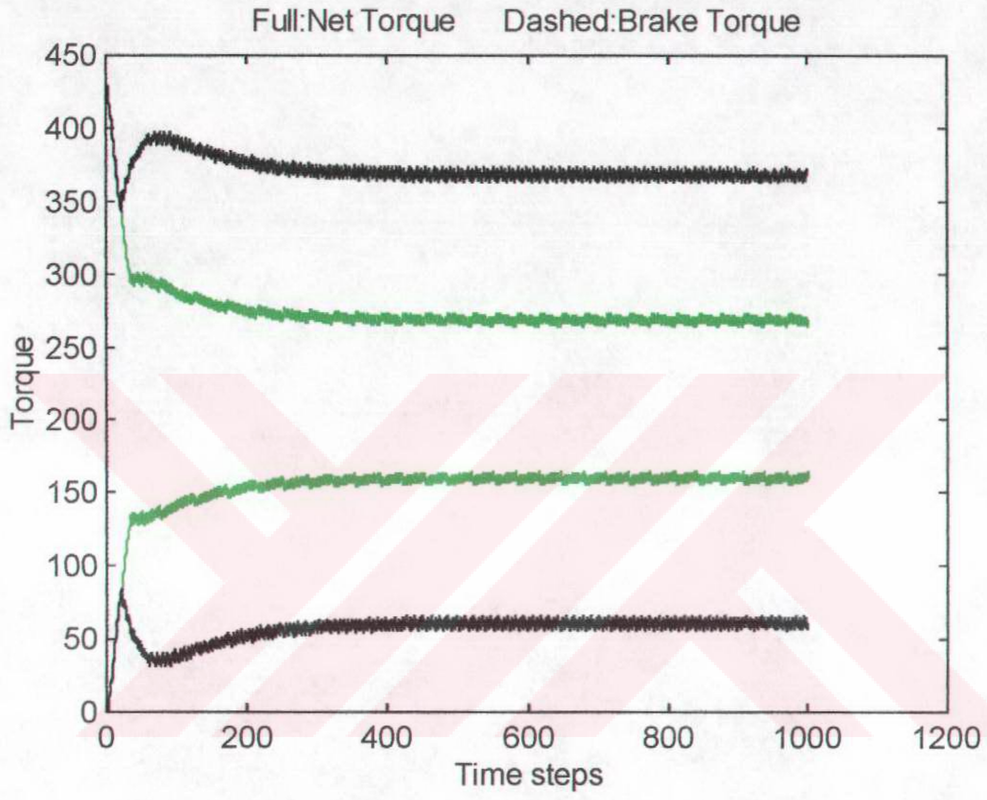
magenta	**= 0.28 m**
green	**= 0.29 m**
black	**= 0.31 m**
red	**= 0.32 m**

Effect Of Vehicle Mass (M_v) On Wheel Velocity and Vehicle Velocity and Lambda



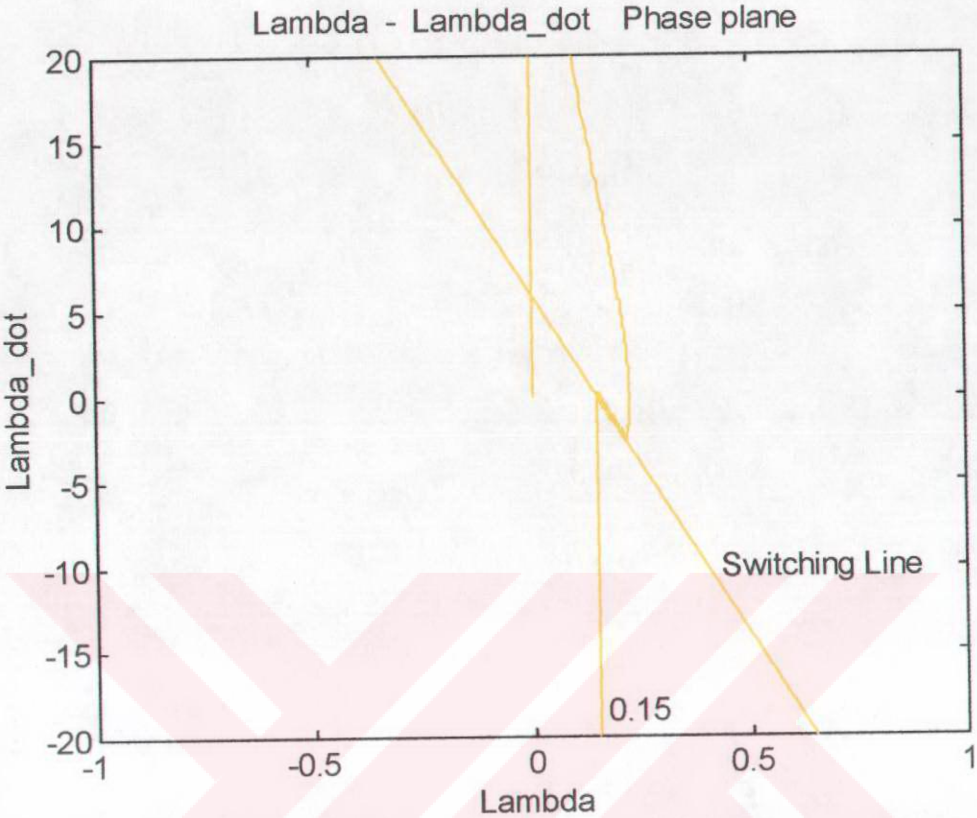
magenta = 2000 kg
green = 1400 kg

Effect Of Vehicle Mass (M_v) On Net Torque and Brake Torque

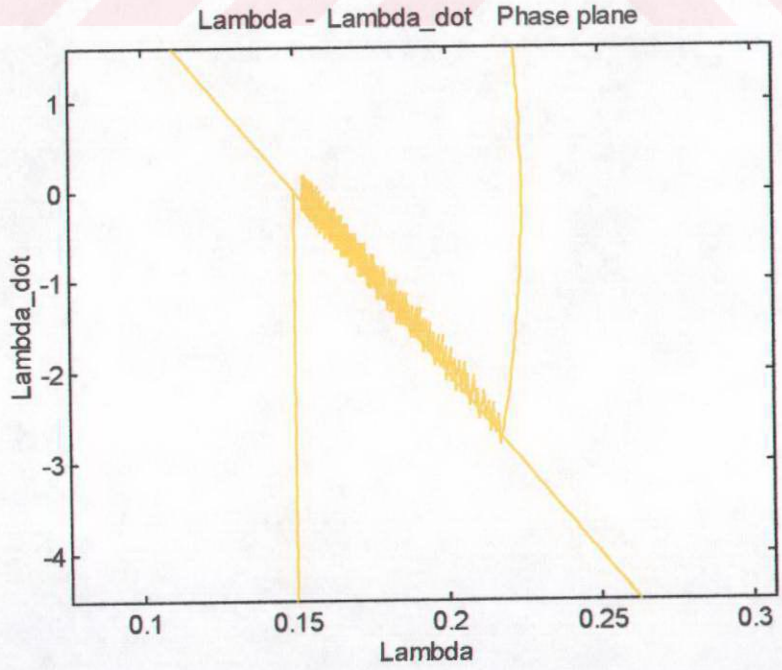


black = 2000 kg
green = 1400 kg

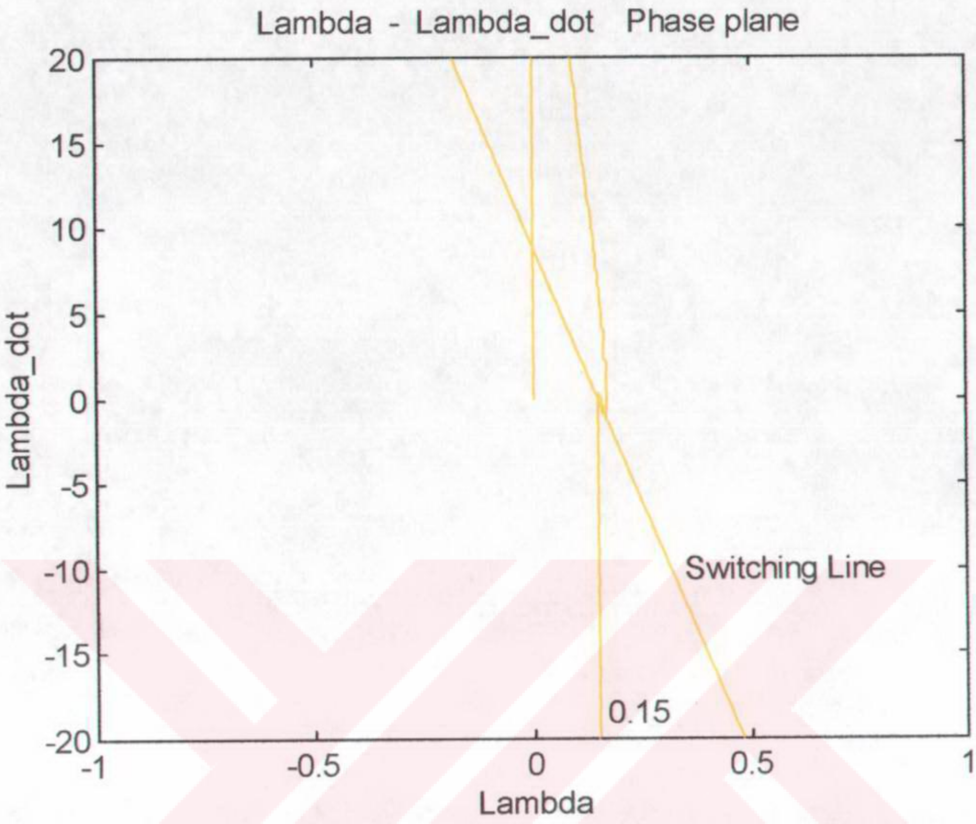
Phase plane For Convergence Constant (c_1=40)

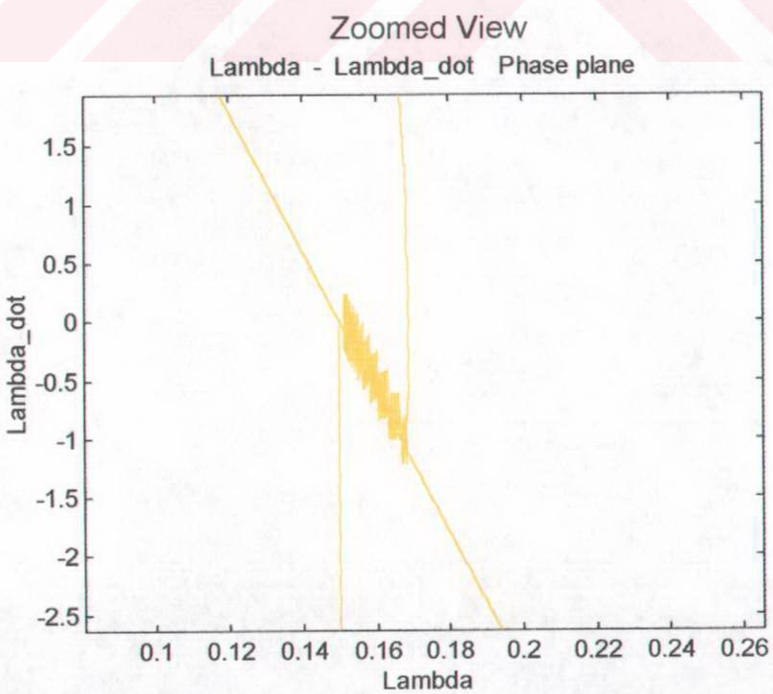


Zoomed View

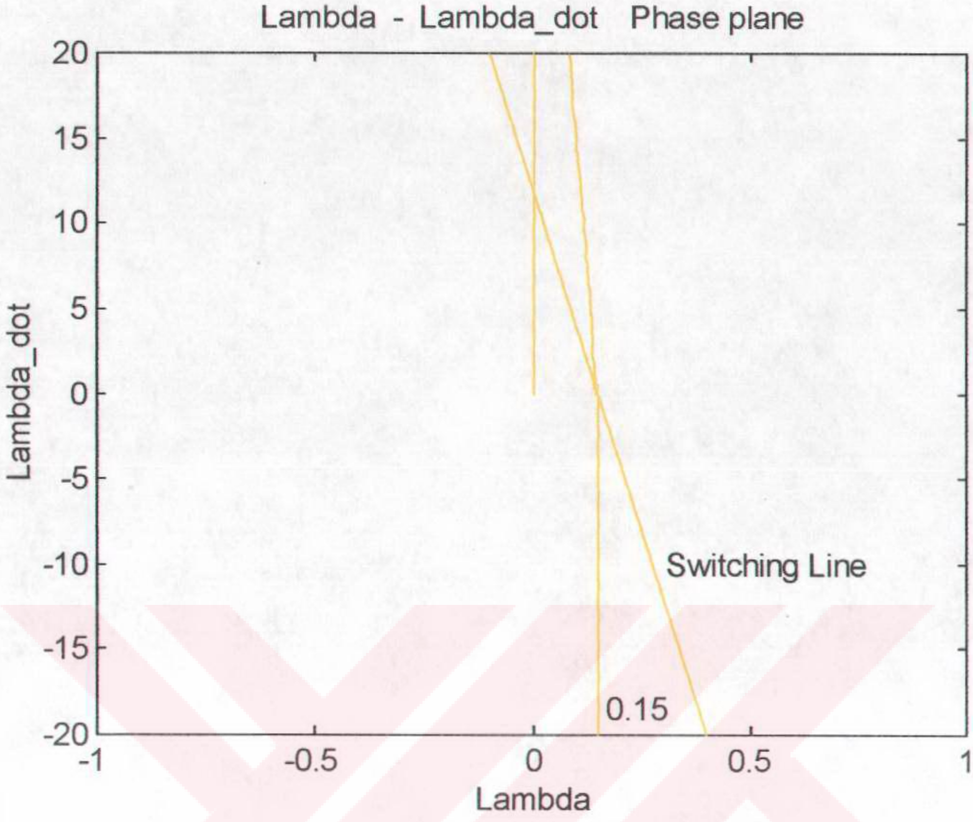


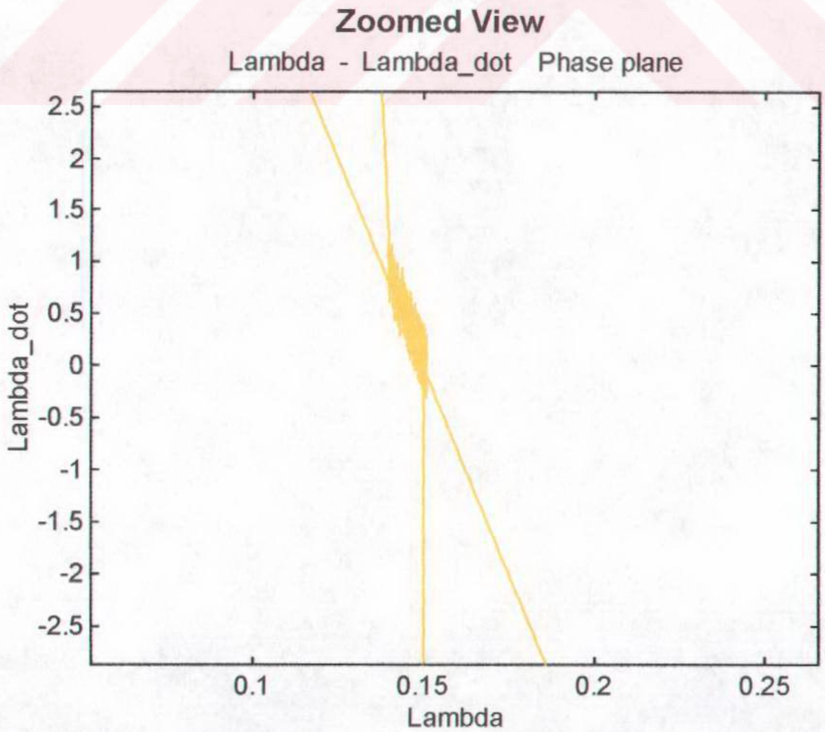
Phase plane For Convergence Constant (c_1=60)



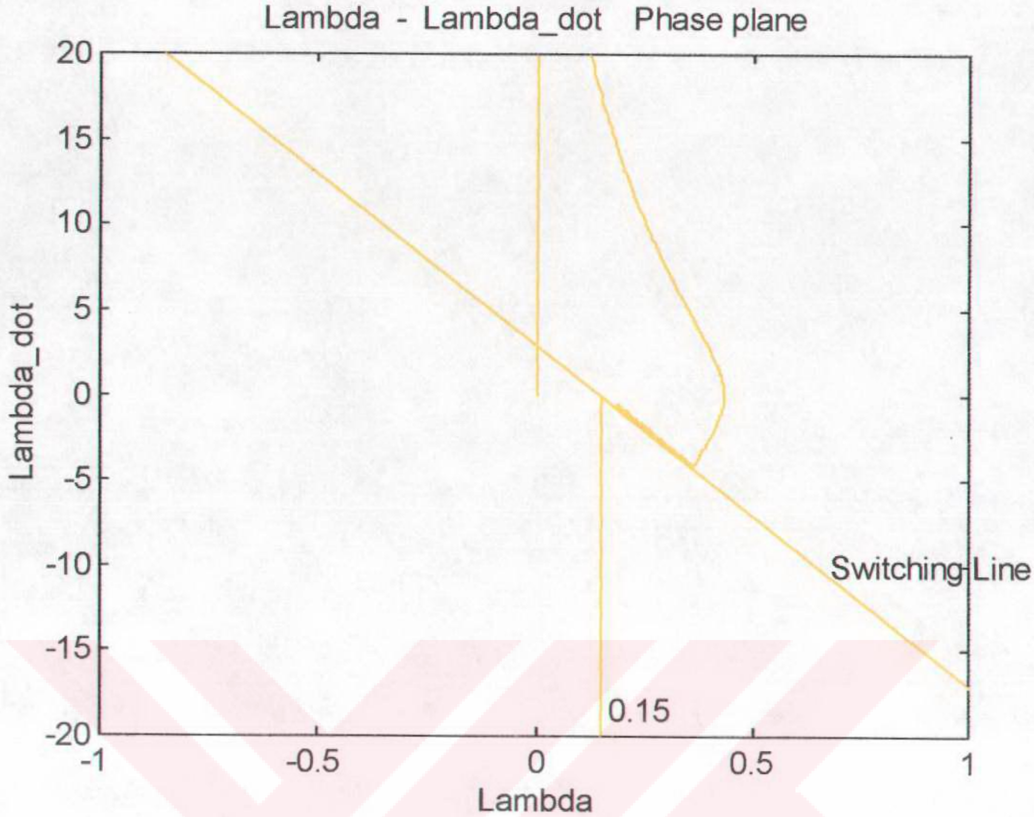


Phase plane For Convergence Constant (c_1=80)

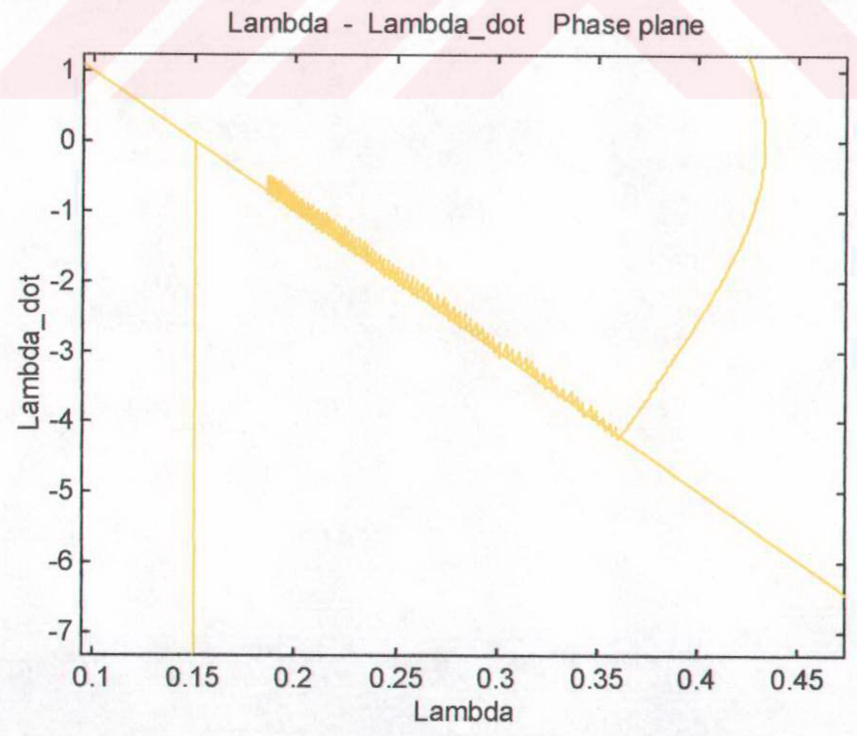




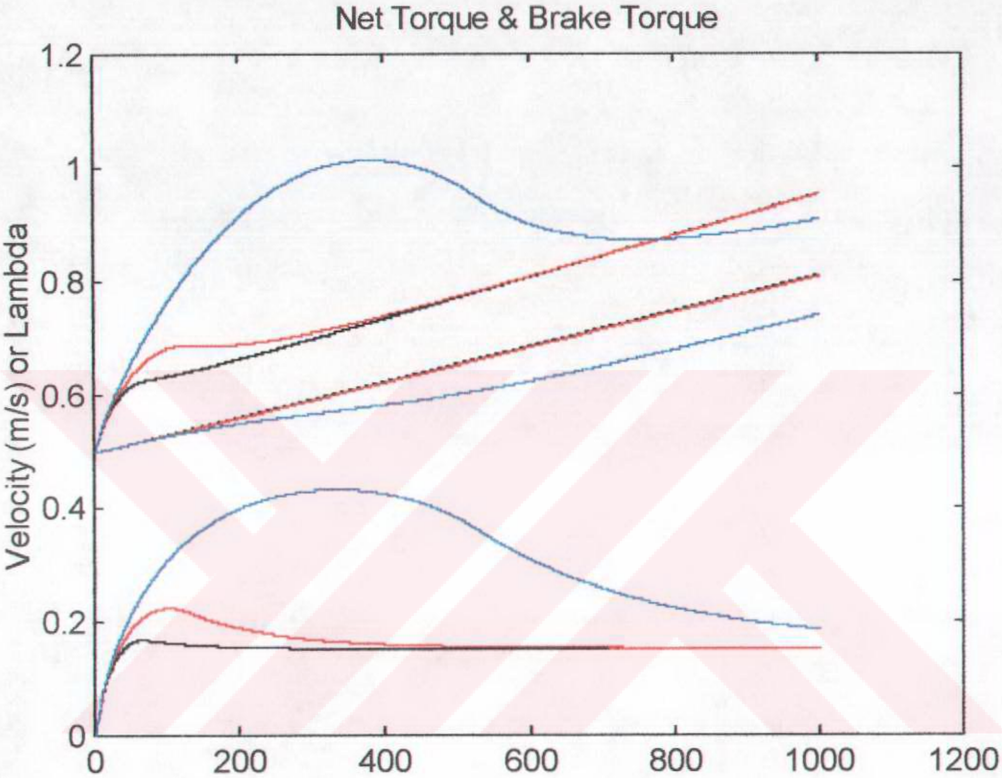
Phase plane For Convergence Constant (c_1=20)



Zoomed View

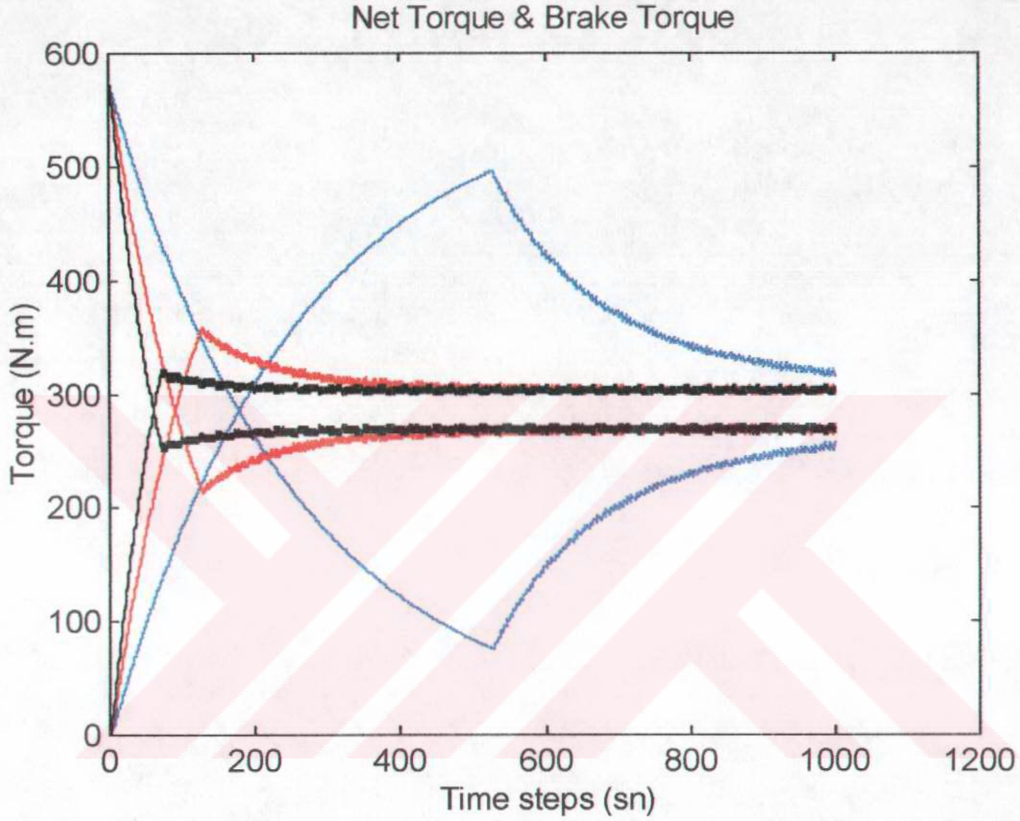


Effect Of Convergence Constant (c_1) Wheel Velocity and Vehicle Velocity and Lambda



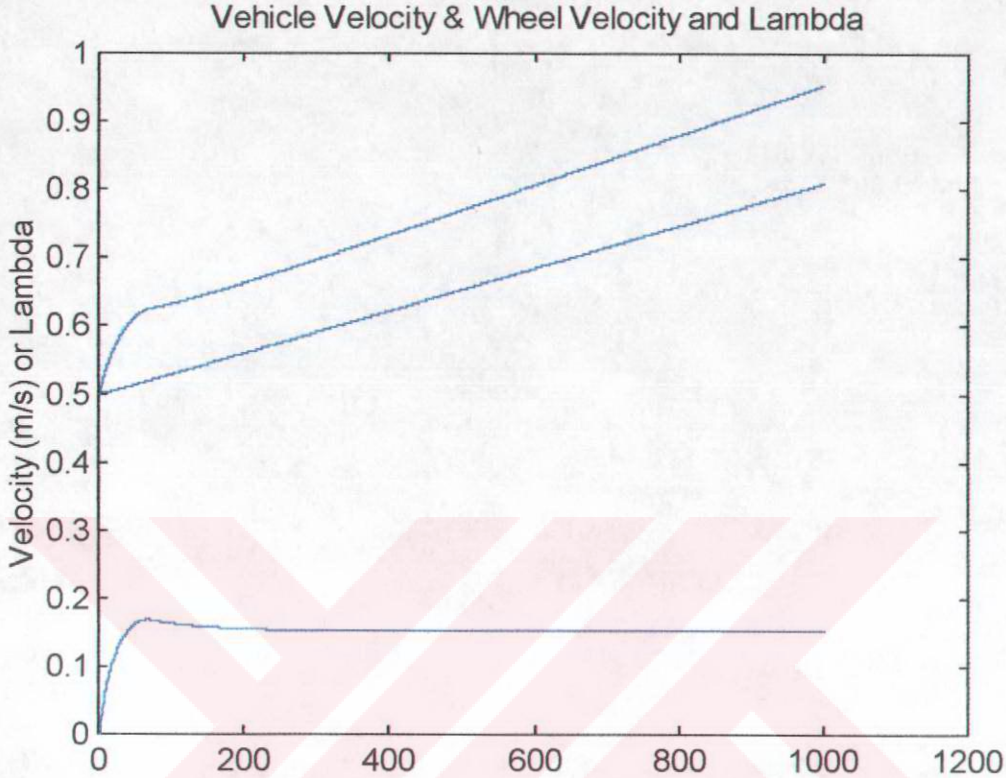
blue = 20
red = 40
black = 60

Effect Of Convergence Constant (c_1) On Net Torque and Brake Torque

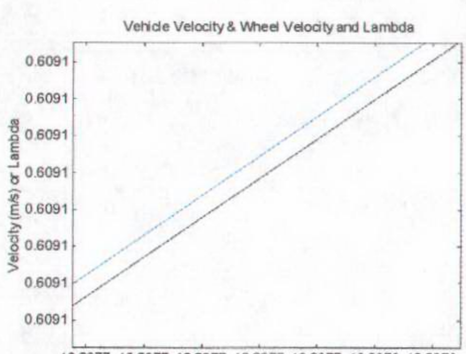


blue = 20
red = 40
black = 60

Effect Of Number Of Active Wheels (N_w) On Wheel Velocity and Vehicle Velocity and Lambda

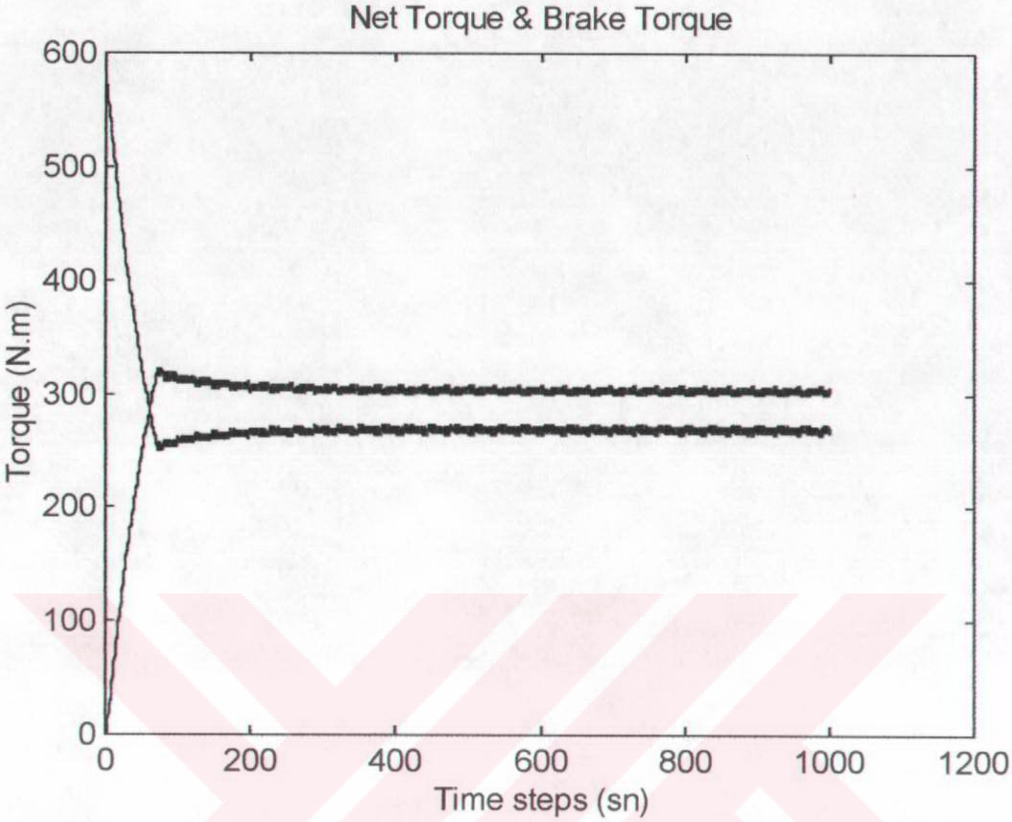


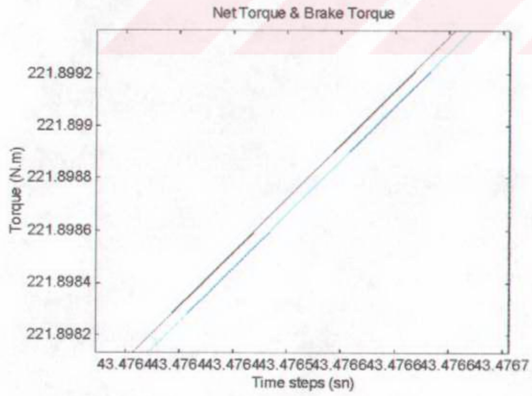
Zoomed View



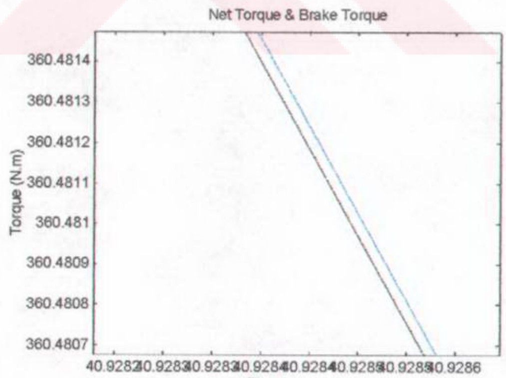
Black = 4
Blue = 2

Effect Of Number Of Active Wheels (N_w) On Net Torque and Brake Torque





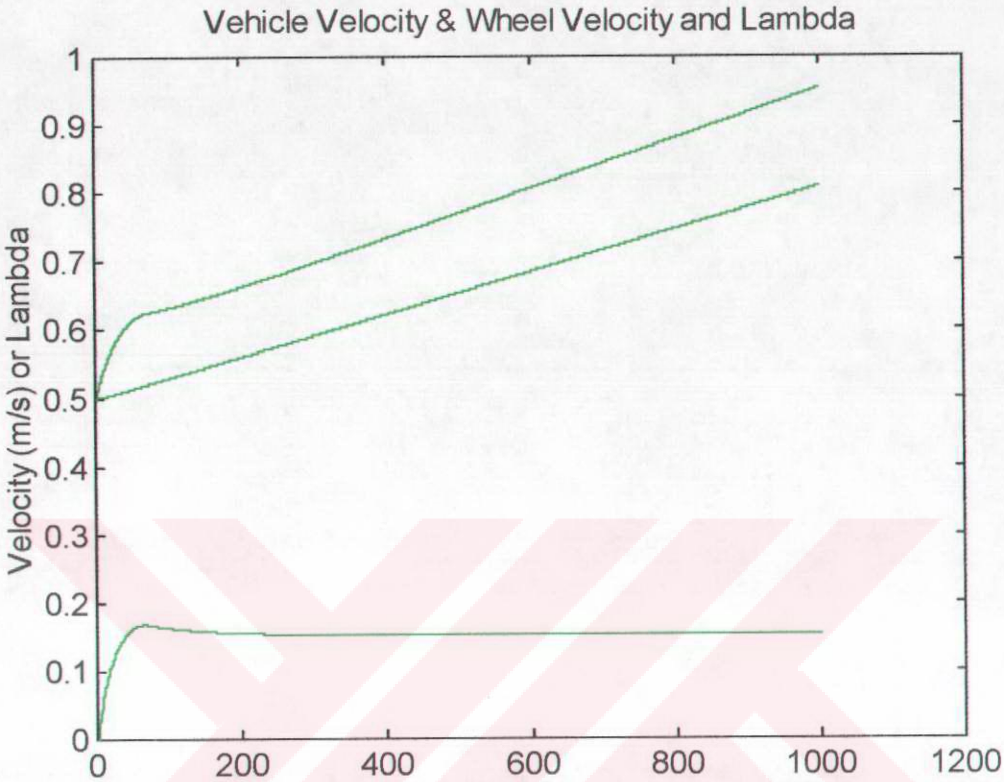
Brake Torque



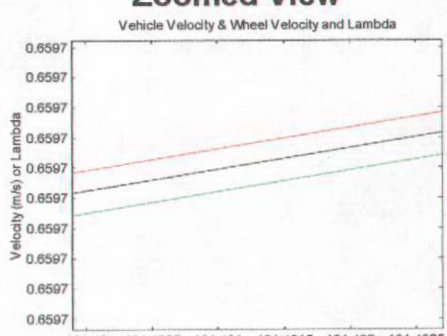
Net Torque

Black = 4
Blue = 2

Effect Of Aerodynamic Drag Coefficient (B_v) On Wheel Velocity and Vehicle Velocity and Lambda

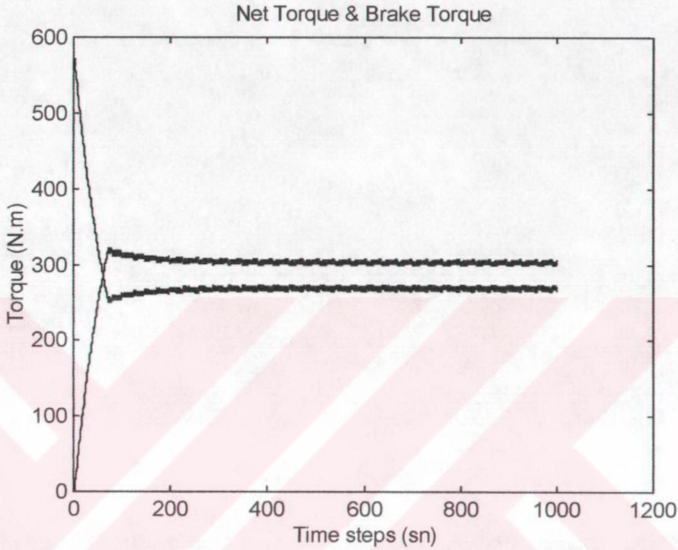


Zoomed View

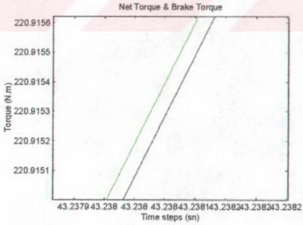


red = 0.4 $N/m^2/s^2$
black = 0.595 $N/m^2/s^2$
green = 0.8 $N/m^2/s^2$

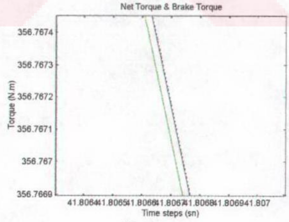
Effect Of Aerodynamic Drag Coefficient (B_v) On Net Torque and Brake Torque



Zoomed Views



Brake Torque



Net Torque

red = **0.4**
black = **0.595**
green = **0.8**