UNIVERSITY OF SOUTHAMPTON

ABSTRACT

FACULTY OF
ENGINEERING AND APPLIED SCIENCE

DEPARTMENT OF MECHANICAL ENGINEERING

Master of Philosophy

Remote Road Profile Sensing for Active Suspension System

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This theses is an account of work that had been carried out to find a mean to measure the profile of the road ahead of a moving vehicle. These work included, study of suspension system design in general, finding evident that a preview system is needed to implement an truly active suspension form the point of view of a control, a simple specification for the profiling system, study of work done in profile sensing in general with road profiling in particular, study and experimental work on ultrasonic distance measurement, evaluation on optical rangefinder available commercially and construction of a simple prototype profiling system. In conclusion, optical devices are recommended as the principle building block for a profiling system. Existing optical devices are both too expensive and bulky to use immediately. More work should be carried out in the design of the profiling system and much more powerful computer is needed.

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Table of Contents

Table of Figures

Tables

Table of Plate

1.Introduction

This thesis describes the work that has been carried out at Southampton with the aim of developing a remote road profile sensor for use as part of an active suspension system. The problem of remote profile sensing is essentially that of distance measurement or rangefinding. At least one rangefinder is fixed to the front of the vehicle and scans the road surface ahead.

This either necessitates mounting the rangefinder on a projection at the front of the vehicle, or if this is impractical, operating the sensor in such a way that it scans the road ahead at an angle as described later.

The work consists of a comparative study of several techniques which may be used to construct a rangefinder, and the evaluation of a number of commercially available sensors.

The suspension system in any wheeled vehicle is an assembly of springs and damping elements designed to isolate the passengers from shocks produced by the wheels encountering surface irregularities. Research into suspension systems has been carried out almost since the advent of wheeled vehicles, but has gathered pace in the last 50 years with the widespread use of motor transport. In addition to continual refinement of the traditional passive suspension, a number of active systems have been and are being developed. The performance of an active system may be improved if it is given prior warning of the forces it is to be called upon to eliminate. Thus, the addition of a remote road profile sensor to an active suspension system will convert it from what may be termed a "reactive" system, which applies forces to the vehicle body after the appearance of forces arising from surface unevenness, to a truly active system in which the forces are applied simultaneously.

Active suspension systems developed to date include mode switching [1,2,3,4,5] (also known as adaptive) and slow-active [13,14,16] type. So to implement an active suspension system successfully several issues need to be addressed, including sensor development, actuator development, and the formation of an appropriate control strategy.

A number of road profile sensing systems have previously been developed. Many of these are used for assessing road maintenance requirements[22,23,24,25], and rely upon sensors perpendicular to the road surface which are either mounted on brackets at the front of the vehicle[24,25] or towed behind on a trailer[22,23]. These systems generally store the data and calculate the road profile later. For this reason, as well as the awkward mounting arrangements used, such systems are unsuitable for active suspension use. However, it is valuable to study the rangefinding techniques employed since these may be applicable to this project after some modification.

In existing road profile measurement systems ultrasonic and optical methods of rangefinding are used. It was noted that RF systems such as radar had not been employed, and an investigation of the feasibility of this approach was made at the start of the project. Although radar has been used in experimental collision avoidance systems[54] and for measurement of vehicle speeds, it was felt by the project sponsor that the high frequencies involved might be a source of radio-frequency interference (RFI). In addition it appears that in the UK at least there are a number of regulatory and licensing problems associated with the automotive use of radar. Finally, it was felt that the resolution of a few centimetres available from a radar system would probably be inadequate. For these reasons the investigation has concentrated on ultrasonic and optical methods.

The specification required for a road profile sensor forming part of an automotive active suspension should be capable of meeting the following requirements. At a maximum speed of 120 km/hr (about 70 mph) the vehicle will be covering over 30 m/s. If the sensor is not to miss significant variations in the road surface the sample rate should be at least 1kHz (giving a sampling interval of about 30 mm).

The active suspension system envisaged by the project's sponsor has a reactive time of around 0.05s. Thus, it is necessary for the sensor to give at least 0.05s warning of an impending bump, and this implies profile measurements carried out at least 1.5m ahead of the vehicle. A look-ahead distance of 2m was chosen for use in this project.

Since the vehicle will pitch and roll during driving some form of attitude sensing will be required to compensate the rangefinder data. If the rangefinder look-ahead distance is 2m, the effect of pitching is to shorten or lengthen this distance. It is estimated that the minimum look-ahead will be around 1m and the maximum 3m. These figures are derived from consideration of the likely reaction time of an active suspension system. Thus the rangefinder must be capable of operating within this extent.

This intention is that the profile sensor should be mounted close to or as part of the vehicle headlamp assembly. This is at a height of about 0.5m from the road. With the look-ahead distance fixed at 2m this means the rangefinder beam will strike the road at an angle of 10-15 degrees. The sensor used must be capable of operating reliably at these shallow incident angles.

The sensor has to be rugged and reliable enough to survive the automotive environment. It should have as small a size as possible, and should ideally be maintenance free.

Since the rangefinder measures the road profile from a moving platform ie, the vehicle, as discussed earlier, therefore it will be necessary to provide information on the instantaneous attitude of the vehicle, hence information about the exact location of the rangefinder relative to the surface of the road is required before the profile data can be obtained. One or more secondary sensors will be required for this purpose. Since the vehicle has a pair of wheels on each side which can be considered as following the same path, two profile sensors will ultimately be necessary. However, it was decided for simplicity to concentrate on the design of a single profile sensor.

The project has been carried out in several parts. A study has been made of suspension designs, and a number of industrial profile sensing systems have been obtained and reviewed. The two approaches studied are ultrasound and optical rangefinders. An ultrasound rangefinding system was constructed and used as a reference system for the evaluation of a number of other ultrasonic systems. Although ultrasound was found to be capable of a high enough sample rate for successful operation at high vehicle speeds, the resolution was limited. However, ultrasound could be used as the basis of a low-cost system.

A number of commercial optical rangefinders were evaluated which promised to give the sample rates required. An IBEO laser rangefinder was ordered as a result of the study, and used to construct a prototype road profile sensing system for some elementary experiments.

2. Suspension systems design

Suspension technology began in about 1665 when springs were added to horse-drawn carriages. The technology of suspension design has progressed a long way since then. At present, the most interesting breakthrough is the introduction of active suspension systems. To date, there are five different types of suspension system designs. These are Passive, Mode switching, Semiactive, Slow active and Fully active suspension systems. Other classifications such as Adaptive, Intelligent or Reactive systems, are also used but are included in the five types listed above.

2.1 Descriptions of the different systems

2.1.1 Passive systems

Nearly all suspension systems in present vehicles are passive. A passive system consists of a spring and damper with non-variable rate. Passive systems are capable of storing, restoring and dissipating energy. They are relatively simple and cheap to build, and no control logic is involved. Such systems consume no power, since the dampers simply dissipate energy and there are no electrically operated parts. If the best passive spring and damper setting for each condition were chosen then significant performance improvements could be gained without the need for expensive actuators. Unfortunately, the running conditions, i.e. road surfaces and speeds, vary too much and an optimum setting can never be achieved. The set up of a system is usually optimised for the types of road that the vehicle is most likely to encounter. Hence, a saloon car's suspension is designed for ride comfort and a performance car's suspension is designed for good handling and road holding. Thus a passive suspension system has only limited control over the dynamic behaviour of the vehicle.

2.1.2 Mode switching

A mode switching system, also known as adaptive system, usually consists of a non-variable spring fitted in parallel with a two or three state switchable, variable rate, damper. Simple control logic is used in this type of system to determine which damping rate should be used to suit different driving conditions. In mode switching systems, sensors for detecting the road profile, speed of the vehicle, steering angle, braking and acceleration are installed to determine the driving condition of the vehicle. A large number of experimental mode switching systems have been developed in the past few years[1,2,3,4,5]. Experimental results have shown that these systems can offer worthwhile improvements over passive systems in terms of ride comfort and drive performance. A mode switching suspension, although more complicated than a passive system in terms of structure and control strategy, is still relatively simple to implement. The cost of producing a mode switching suspension is not very high since the components required to build such systems are readily available[6,7,8,9].

2.1.3 Semi-active systems

A semi-active suspension system consists of a continuously variable damper in parallel with a fixed rate spring. This system differs from a mode switching system only in that the rate of the damper is continuously variable. The continuously variable damper in such system is used to dissipate the energy of a disturbance in a controllable manner. A semi-active suspension system is much less complicated and cheaper to implement than a fully active system. Again, sensors are needed to determine the road and driving conditions together with sensors for wheel speed measurement. In a semi-active system the control logic is more complicated than that used for a mode switching type. The information required for setting the damping rate is needed continuously. A number of experimental semi-active systems had been built [10,11]. A semi-active suspension system uses no power to counteract the disturbance. In the system described in reference[11] (which uses fluid to vary the damping rate of the damper), power is consumed by the pumping system. A semi-active suspension system is capable of providing greater control over suspension characteristics than a mode switching system.

In the system described in [10] only two damping dates are provided to reduce the complexity of the control logic used. It is sometimes difficult to distinguish between mode switching and semiactive suspension systems.

2.1.4 Slow-active suspension system

A slow-active suspension consists of an actuator in series with a passive spring, and the assembly fitted in parallel to a damper. The actuator used in such system has a limited response frequency, usually up to about 3 Hz. This property distinguishes it from a fully active system. When the frequency excitation is above the response frequency of the system, the actuator will be switched off and the system will respond as a passive suspension. Displacement sensors are used to measure the wheel/body displacement, and electronic circuits are used to calculate the force required to overcome the disturbance. Other sensors for vehicle speed, steering speed and acceleration may also be used to determine the status of the vehicle. Generally a vehicle with a slow-active suspension system also has a certain degree of height control. Production vehicles using this technology are already available [12,13,14]. Since active components are used in the suspension, power is consumed by these systems. The power required for such a system, should be less than 0.5 KW[see Eg 15]. In terms of ride and handling characteristic, a slow active suspension system is almost as good as a fully active suspension system.

The provision of static load height control on a vehicle does not imply that it is fitted with a slow-active suspension. Height control or load-levelling systems do not operate in the range of body motion frequencies for bounce, pitch and roll.

2.1.5 Fully active suspension system

In a fully active suspension system the conventional damper and spring is replaced by a hydraulic actuator. The actuator is controlled by a fast response servo valve and a force feedback loop. The signal which indicates the force required to react to the disturbance is calculated by a microprocessor. The design of the control law is very important if the system is to give good performance. At present, designing an optimum control strategy represents a challenge for vehicle engineers. A number of experimental vehicles with fully active suspension have been constructed [16,17]. Both theoretical and experimental results show that a fully active suspension system gives a great improvement to the performance and ride comfort of a vehicle. However, a fully active suspension system requires more working space then its slow-active counterpart. It also uses more energy then the slow-active system. Typically a mean power consumption of 1.5 KW and a maximum power consumption of about 3 KW are required. The power consumed by the system increases as the bandwidth of the response increases. However, the high frequency response of the system is usually limited by the speed of operation of the actuator.

A fully active suspension system is much more costly to build than any other type. One of the problems with a fully active system is the finite bandwidth (typically between 50 and 100 Hz), above which no damping remains in the system. At frequencies above the system bandwidth there is a solid transmission path between body and wheels, which leads to noise, vibration and harshness.

2.1.6 Need for a preview system

Studies have shown that the performance of an active suspension system will be improved if the road profile a head of a vehicle is sensed le, with feedforward information in the control system [18,19]. It has also been shown that information about the profile of the road fits harmonically into the control theory of a fully active suspension system, as the feedforward part of the control law[18]. The study in reference[19] has also shown that a distance of 2 m is appropriate. For this reason a look-ahead distance of 2 m was used in this study.

In normal driving the displacement of the front axle may be used to derive information to control the rear axle actuator, with the assumption that the displacement input to the rear wheels is a time delayed version of that experienced by the front wheels.

3. Review of work on profile sensing

3.1.Review of previous work on road profile sensing

Road profile measurements have long been used in road maintenance work. The assessment schemes most commonly used are the MARCH [20] and CHART [21] standards. These use measurements of cracking and rutting area to determine the level of repair needed by a particular section of road.

Traditionally the cracking and rutting assessments used by CHART and MARCH have been carried out manually. An evaluation of cracking can be carried out from the verge or pavement, but measurements of rutting have to be undertaken in the roadway. This can cause traffic disruption and may be dangerous to both the road user and those doing the evaluation. For this reason a number of road profile measurement techniques have been developed which do not require the user to work on the carriageway.

Four road profile measurement systems have been identified as being particularly relevant to this project. These are:

1)The laser-based high speed profileometer, developed by the Transport and Road Research Laboratory (TRRL).

2)The ultrasonic non-contact pavement smoothness monitor, sold by Earthtech inc. in the USA.

3)The ultrasonic rutmeter, developed by Queens University, Belfast.

4)The laser road surface tester used by the Swedish Road and Traffic Research Institute. These devices and systems are discussed in detail below.

1) The TRRL high speed profileometer [22] consists of a 5 metre long measuring beam, mounted on a central pair of wheels, which is towed behind the measuring vehicle. The beam carries three optical rangefinders, each of which consists of a semiconductor laser and a photodiode receiver array. The laser illuminates the road surface, and the reflected beam is focused onto the photodiode array. Three rangefinders are necessary to compensate for till in the measuring beam. The distance to the road surface is then found using the triangulation method discussed in chapter 3. The longitudinal road profile is digitised and stored by a microcomputer in the towing vehicle for later analysis. The system can operate at vehicle speeds between 5 and 80 km/hour, and will tolerate variations in speed.

2) The noncontact pavement smoothness monitor developed by Earthtech inc. [23] is similar to the TRRL system except that the rangefinders used are ultrasonic. Pulses of ultrasound travel down to the road surface and are reflected back to a receiver. The time taken for this to happen indicates the range. Five such rangefinders are mounted on a 3 metre long trailer which is towed along the road under investigation. The resolution of the system is 1mm, and it can measure the road profile every 50mm when the towing vehicle is travelling at 3km/hr. This slow speed is due to the low repeat rate of the ultrasonic pulse generators used.

3) Queens' University, Belfast, have also developed an "ultrasonic rutmeter" [24], which consists of a number of ultrasonic rangefinders mounted across the rear of a vehicle. A signal processing unit and an APPLE computer are carried within the vehicle.

Unlike the two systems described above, this arrangement allows the cross-profile as well as the longitudinal profile to be acquired. The system can obtain a measurement every 500mm when the vehicle travels at a speed of 50km/hour. The vertical resolution is 0.33mm.

4) A system known as the road surface tester is used in Sweden [25]. This device consists of nine optical rangefinders and a microcomputer. Once again the triangulation principle is use to measure variations in the road profile. The sensors are mounted in a row across the front of a vehicle, thus enabling a complete three-dimensional profile of the road to be built up. In this respect the system resembles the Rutmeter, but since optical rather than ultrasound measurement is used the repetition rate and resolution are much higher at 2kHz and 0.22mm respectively.

3.2.Other applications of profile sensing

Profile measurements are used in many industrial applications. For example, the thickness of thin films has to be measured in materials science, and the thickness of interconnection oxide steps and contact hole profiles in semiconductor products are often checked by surface profile measurement[26]. Such measurements are usually carried out by recording the movement of a stylus which is passed across the specimen.

In the aerospace industry, the ground profile is often measured by remotely or automatically piloted vehicles. This is usually by means of an expensive and very accurate laser altimeter[27].

Profile measurement is also used in human engineering to measure skin roughness[26].

Further applications include the assessment of plating thickness on a printed circuit board [26], the measurement of photographic emulsion thickness, monitoring the texture of paper surfaces during manufacture, and the measurement of flatness in sheets of steel produced by a rolling mill.

3.3. Requirements of this project

The systems described above are not directly useful for the project discussed in this report, since they all operate perpendicularly, or in other words measure the range of a surface directly facing the sensor. In the automotive application the sensor is required to "look ahead" of the vehicle at a surface lying at a shallow angle. In addition many of the systems described calculate the profile "off-line" from stored results. In the projected application real-time processing will be needed. The laser altimeter used by some aircraft is technically feasible, but the cost (around £20,000) is unrealistic for an automotive application. Thus, a completely new system has to be developed.

4.Review of possible distance measuring techniques

4.1 Distance measurement using ultrasound

Ultrasound is widely used for distance measurement. Ultrasonic rangefinders are used in camera autofocusing systems[28], for liquid level measurement, for object detection and in applications where a simple but not highly accurate measurement is required like obstacle detection behind a vehicle[29,30].

There are two ways of measuring distance by ultrasound. One approach is to measure the time taken for pulses of ultrasound to travel to and be reflected back from an object. The second method is to repeatedly sweep across a band of ultrasonic frequencies at a fixed interval[30]. The frequency of the reflected wave is compared with that of the transmitted wave at the time the reflection is received. The distance of the object reflecting the wave will be proportional to the differential frequency of the two waves. The sweep rate in this type of system is governed by the range of the measurement, since it cannot be repeated until the wave with the initial frequency has reached the end of the measuring range.

There are several reasons why ultrasound is widely used as a low cost solution to distance measurement. Ultrasonic equipment is very simple and cheap to construct. Most of the components needed to build an ultrasonic range finder are readily available standard electronic devices. With a proper design, ultrasound equipment can be very robust, reliable and maintenance free. For example piezoelectric ultrasonic transmitters and receivers are available for under £5.

Piezoelectric devices generate ultrasound by using the piezoelectric effect which occurs in some crystal structures [31,32]. If a slice of an electrically insulated piezoelectric crystal is compressed by applying forces to the surface of the slice, the crystal will be slightly deformed. If certain conditions are satisfied by the symmetry of the internal structure of the crystal, positive and negative charges appear on opposite sides of the crystal. Materials exhibiting this phenomenon are said to be piezoelectric.

On the other hand, if an electric field is applied to such a crystal, the surface of the crystal will be deformed. If the electric field is reversed, the direction of deformation is also reversed. Therefore, if an alternating electric field is applied to a piezoelectric crystal at an ultrasonic frequency, ultrasound will be generated. The situation is reversed for ultrasound detection. Piezoelectric devices are very simple and cheap to produce.

However, there are a number of problems which prevent ultrasound from being the perfect range finding technique. Since ultrasound in air is a compression wave, the speed of propagation is governed by the speed of sound, which is relatively slow (330 m/s). In a simple system we cannot commence another measurement until the reflected wave from the first has been received, so the maximum sample rate is inversely proportional to the measuring range of the system. A possible way to increase the sample rate of the system is to multiplex the measurement and have several systems working at different frequencies which are interlaced. However, this will make the system more complex, which removes one advantage of using ultrasound as a simple means of measurement.

There is also a limitation on the accuracy of the measurement. The resolution of a pulse-echo system is given in [33] as :

$$D = (ct/2) \times N/2E \quad \ldots\ldots\ldots 1$$

Where **D**= resolution
c= speed of sound
t= duration of transmission
N/E=noise-to-signal level

For a typical system with **t** = 0.5 **ms** and **N/E** = 1/8, the resolution of the system is 1 cm.

The speed of sound is also affected by changes in temperature [34]. The speed of sound at a given temperature is governed by equation 2:

$$V = V_o \ (1 + T/273) \ldots\ldots\ldots 2$$

Where **V** = Velocity of sound
Vo= Velocity of sound at 273 K (331.46 m/s)
T= Temperature in Kelvin

Or approximately 0.7 **m/s** change per degree change in temperature.

This change in speed is not very significant compared with other sources of error, such as variation in the topology and the reflecting properties of the surface. If necessary it could be further reduced by the use of a temperature sensor. Unwanted ultrasound is emitted by many sources, for example from car, lorry and motorbike engines. It is therefore unsuitable for long distance measurements, where the magnitude of the reflected wave is of the same order as environmental background noise [35.36].

Ultrasound is well suited to measure the perpendicular distance to an object, since it is the shortest distance of the object from the source. Under these conditions the system works at its highest sample rate, and due to the strong reflected signal the effect of environmental noise is minimised.

4.2.Distance measurement using optical methods

4.2.1 Introduction to lasers

A laser is a monochromatic coherent light source. The name Laser is an acronym for Light Amplification by Stimulated Emission of Radiation. The radiation that it emits is no different than any other form of electromagnetic radiation. However, there are some unique properties of laser light which are not available from any other light source. The unique properties of laser light are [37] :

1) A high degree of both spatial and temporal coherence (strong correlation in phase).

2) High monochromaticity (small wavelength spread).

3) High brightness (primarily due to small beam divergence).

4) Capability of very low (microwatts) to very high (kilowatts) continuous power output for different types of lasers.

5) High peak power (terawatts) and large energy (hundreds of joules) per pulse in pulsed output lasers.

6) Capability of being focused to a small (diffraction limited) spot size (of the order of the wavelength of the light).

The unique properties of laser light are the reason for its wide use in precision engineering. The uses of laser light in engineering can be grouped into three basic categories, which correspond to low-power, medium-power and high-power applications. In low-power applications, lasers are used for alignment, gauging, inspection, interferometry and holography. In medium-power applications lasers are used for heat treating metals. In high-power applications lasers are used for welding and cutting processes.

There are many different types of laser. The helium-neon (HeNe) laser is the most common commercially available type. It is a gas laser, or in other words a laser which is operated by excitation of the molecules of a gas. In this case the gas in a mixture of He and Ne. The output wavelength is 0.6328μm (red) for most applications. However the HeNe laser can also emit at two infra-red wavelengths. The continuous power output of the HeNe laser ranges from a few microwatts to about 50 mW. It is a highly reliable, low cost laser. It is extensively used in applications such as alignment, surveying, ranging, displacement measurement, holography, pattern recognition, communications, surface finish analysis and flow measurement.

Ruby lasers with an output wavelength of 0.6943μm (red) operate in pulsed fashion with a low repetition rate, of the order of one pulse per second. Many joules of energy can be realized within a single pulse. This energy has been used for drilling diamonds, sending pulses to the moon, spot welding, hole piercing, and pulsed holography. A ruby laser is excited by means of capacitive discharge through flash lamps. The size of the capacitors required is a disadvantage. For this reason ruby lasers are very bulky and are not easily portable.

Nd-YAG and Nd-Glass lasers have an output wavelength of 1.06μm in the near infrared. The output is plused and the power varies from a few watts to around 1 kW. Applications of these lasers include welding, cutting, hole piercing, and laser fusion experiments.

There are several different types of CO_2 laser. The emission wavelength is 10.6μm (mid infrared). The power output of a CO_2 laser is continuous or pulsed, with the average power ranging from a few watts to tens of kilowatts. Applications of this type of laser are numerous and including cutting, hole piercing, welding, heat treatment, scribing, and marking. CO_2 lasers can work paper, plastic, wood, glass, cloth, ceramics, and most metals.

Dye lasers can emit radiation at a variety of wavelengths. Power outputs range from milliwatts to watts. Dye lasers are usually "pumped" or excited by a secondary laser. They have been used for spectroscopy, photochemical reaction studies, pollution detection, and surgery.

Semiconductor lasers are the type most likely to be used for our project. The semiconductor laser is a distant cousin of the light-emitting diode (LED). Semiconductor lasers emit radiation from about 0.9μm (near infrared) to within the visible band. Semiconductor lasers are very small in size and can be driven by a battery. However the power supply must deliver a constant voltage, since semiconductor lasers can easily be damaged by fluctuating voltages. They are used in fiber optic communications, pattern recognition, infrared illumination, and pollution detection and control.

4.2.2 Laserrangefinding

Lasers are used for very high precision distance measuring due to the short wavelength of electromagnetic radiation in the visible and infrared region. There are three different methods of measuring distance using a laser. These are the interferometry, triangulation and time of flight methods. Each is reviewed in detail in this chapter.

A further method used for displacement and vibration measurements is the Doppler technique. The Doppler method uses the Doppler frequency shift in coherent light, which occurs when light is reflected from a moving object. This approach provides displacement information about a moving object by integrating the velocity component of the object. The displacement is not measured directly, so it is not possible to determine the range of an stationary object. Since the profile of the road does not move, the relative movement that we can detect must be caused by the movement of the vehicle.

4.2.2.1 Interferometrymethod

Interferometry methods use the principle of interference. This is a process in which two or more waves of the same frequency combine to form a resultant wave. The displacement at any point on the resultant is the vector sum of the displacement of the individual waves. Interferometry can be used to obtain the velocity and distance of an object by measuring the phase difference between an outgoing and a reflected wave [38]. This is a very accurate method. The distance of the object reflecting the wave can be determined to a around quarter of the wavelength of the radiation, i.e. to about 130 nm (1/4 of 520) if a visible laser is used. See Fig 4.1. This method is widely used by surveying equipment manufacturers [39,40].

A special reflector is often required for this method. Usually, the wave is reflected using a prism which gives a known phase shift of 180 degrees. A reflector must be used since the reflecting properties of ordinary surfaces are unknown and insufficient light may be returned to the detector. In general the reflected wave can be at any phase angle with respect to the emitted wave. The phase of the reflected wave is largely determined by the nature and texture of the reflecting surface. Since road surfaces consist of many different materials with different textures, it is impossible to relate the phase of the reflected wave to range. It seems unlikely therefore that interferometry methods will be of use in our application.

4.2.2.2 **Triangulation method**

Optical triangulation is also used to determine distance. Several surface tracing and ranging systems have been developed using this principle [41,42]. This method has been used successfully in many industrial applications such as automatic welding, thickness inspection, liquid level detection, and in automatic focusing systems [43,44,45].

A triangulation system usually consists of a low-power HeNe or semiconductor laser, a lens and a detector. See Fig 4.2. The laser beam is projected onto the surface whose distance is to be determined. The light is scattered from the surface and focused by a lens system onto a detector. The detector can be a linear diode array, a charge coupled device or simply a linear position detector. If the illuminated surface has a displacement in the direction of the axis of the laser beam, the spot of light on the surface will have a component of displacement perpendicular to the axis of the detector lens. This displacement causes a corresponding displacement of the image on the detector. The displacement of the image on the detector generates an electrical signal which can be used to determine the displacement of the surface.

Optical triangulation is a very simple distance measuring method, since it only requires a laser source (an ordinary light source will be sufficient if a straight forward light detection is carried out in stead of the use of some form of noise elimination technique such as chopping and phase detection), an optical system and a detector.

Unfortunately, there are several problems associated with optical triangulation. In an optical triangulation system the source and the detector must be physically separated as shown in fig 4.1. The separation distance is determined by the displacement to be measured and its range. Since there is a physical limit to the size of the detector, and hence on the area that the scattered laser beam can illuminate, the device will only work within a restricted range. For this reason an optical triangulation system is specified in terms of a stand-off distance and an associated measuring range. The stand-off distance is the central point of the measurement, and the measuring range is the detectable displacement about that point. If the surface illuminated by the laser moves outside this range, the system will not be able to determine the distance of the surface, due to the loss of signal. Nevertheless, optical triangulation is a feasible method for developing the range finder required by this project.

4.2.2.3.**Time of flight method**

The "time of flight" approach is also used for optical rangefinding. This technique relies upon measurements of the time taken for pulses of laser light to travel to and be reflected from an object. A number of surveying systems use this technique. Such systems are usually expensive, since high speed electronics are required to measure the extremely short time intervals involved. All the commercial time-of-flight systems available use low-power semiconductor lasers, and are eye-safe. Such systems can determine the distance of an object repeatedly, up to the maximum range of the measurement. A noncontacting distance measurement system using the time of flight method is technically suitable for the range finder required for this project, although possibly rather expensive.

4.2.3 Requirement to build an optical rangefinder

No matter which measurement method is used, a laser source is always needed to build an optical range finder because of the coherence and high intensity properties of laser radiation. The same properties cannot be achieved by a conventional light source. Of the different types of laser available, the most suitable for the rangefinder is probably a semiconductor laser. These are low cost, powerful, can be driven from the vehicle electricity supply, and are compact in size.

The cost of a semiconductor laser, together with a lens to produce a collimated beam is around £130 for a one-off purchase [46]. The price will fall dramatically if large numbers are purchased. The physical size of a semiconductor laser, together with its collimating system, is very small (typically 33.7 mm in length and 11 mm in diameter)[46]. A further advantage of using a semiconductor laser is that the emitted radiation may be modulated directly by modulating the power input to the laser. This is useful for the purpose of improving the signal to noise ratio.

The only disadvantage of a semiconductor laser is that the radiation it emits is invisible. Safety precautions have to be taken to prevent inadvertent viewing of the beam for prolonged periods. All semiconductor lasers currently emit infrared radiation. However, it seems likely that visible light semiconductor lasers will soon be available.

Some form of detector is needed to build a range finder as discussed previously. If the time-of-flight method is used, a laser sensitive photo-diode is sufficient to detect the reflected signal. The cost of such detectors is very low.

In the case of the triangulation method, some form of position sensitive detector is needed. There are several such detectors available. Examples include Charge Coupled Device (CCD) sensors, photo-diode arrays, and the Optometer [47] produced by Hintze.

CCD devices are widely available and are often used in imaging systems, such as video cameras. CCDs have a very high resolution [48] up to 1 part in 10,000 over the active region), but they are relatively expensive, costing a few hundred pounds each.

A photo-diode array consists of a number of photo-diodes mounted alongside each other with individual outputs to indicate where light has impinged upon the sensitive surface. They are very cheap but suffer from poor resolution.

The Optometer [47] is a device producing a differential voltage which is a linear function of the position of a light beam 'hitting' its photo sensitive surface. The Optometer has good resolution (1 part in 4000) and is very much cheaper then the CCD. A typical one-off cost is around £100 per device. The Optometer works in both the visible and near infra-red regions of the spectrum. It is suitable for detecting the radiation emitted by a semiconductor laser. The only problem associated with the Optometer is the sensitivity of the device, which is not high enough to detect the backscatter from a surface 2m from a low intensity laser such as a class I (totally eye safe) device. For this approach to work either the power of the laser must be increased above the class I safety limit, or some form of focusing is needed. The increased power means that the device cannot be used unshielded. Focusing the beam will create a "danger zone", since there will be a region where the power density is very large.

A number of electronic circuits are required to complete the range finder. The electronic systems required for a range finder using the triangulation principle are relatively simple. All that such a system needs is circuitry to generate a modulated laser emission, usually in a form of pulses, and circuitry to convert the output of the Optometer sensor into a signal indicating the distance of the object reflecting the laser light. These circuits can be built from standard electronic components and are low cost.

If a time of flight system is built the electronics required are much more complicated. The circuits must operate within the time taken for a light pulse to travel outward and be reflected back. This can not be achieved by ordinary electronic components, and special high speed devices are needed which may be costly.

The cost of the optical components needed for either kind of rangefinder is relatively low compared with the cost of the laser and electronic systems.

Technically, a system using the triangulation method is simpler and cheaper to construct than a time of flight device. However, triangulation systems are much more bulky and may be harder to accommodate within the bodywork of a vehicle. The time of flight system has the added advantage that it can cope with a larger measurement range than the triangulation system.

At this stage in the work it was not possible to determine which of the two approaches [i.e. triangulation and time-of-flight] was best for an automotive application. Accordingly it was decided to obtain commercial versions if both systems for evaluation. The results from these tests are presented in chapter 6.

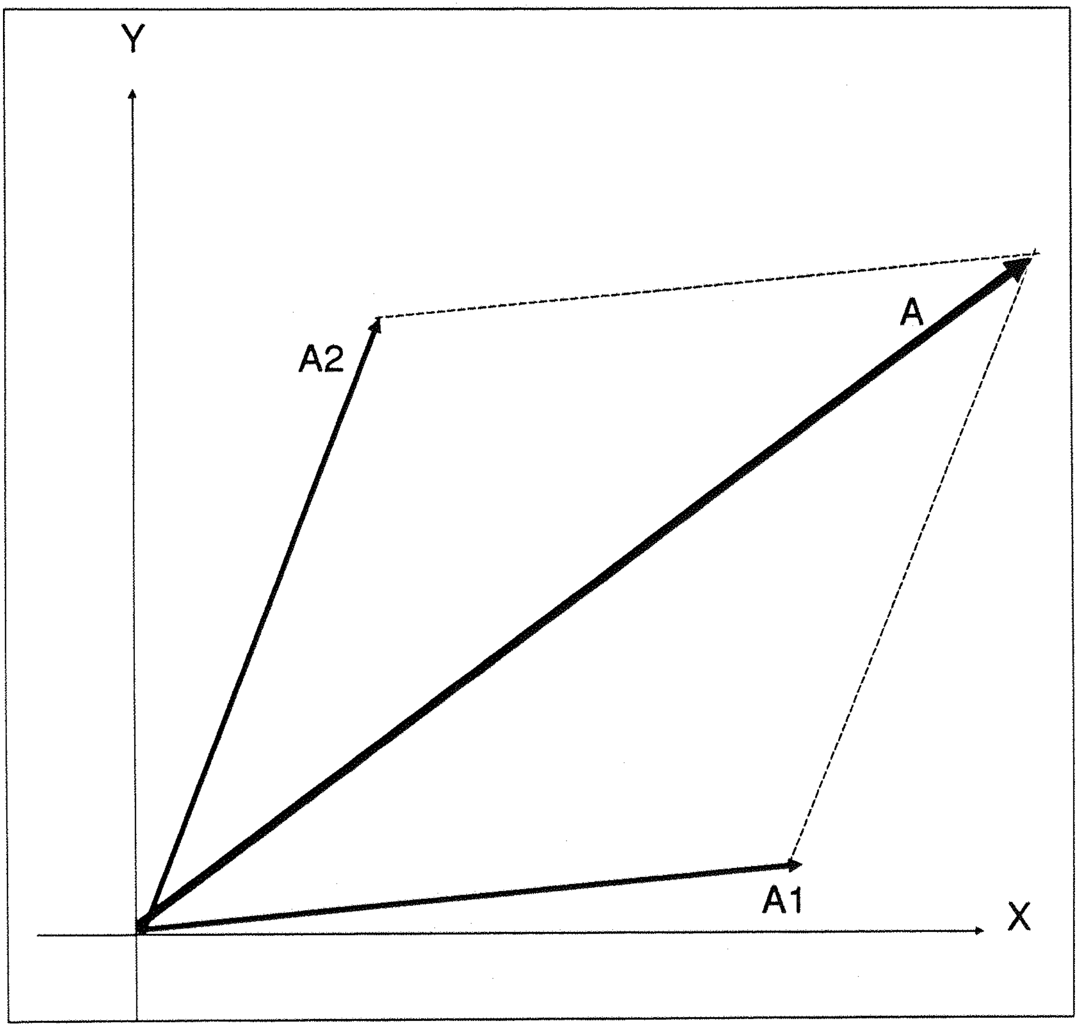


Fig 4.1 Resultant amplitude of two interfering waves

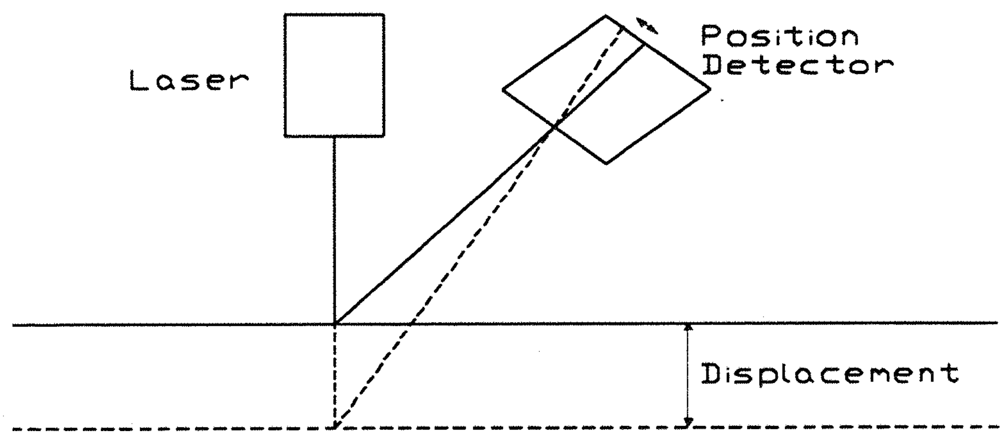


Fig 4.2 Diagram of the laser-based optical triangulation system

5. Experiments on ultrasonic ranging systems

A number of experiments have been carried out on ultrasonic devices to evaluate their suitability for use in active suspension range-finding. Three different systems have been investigated, one of which was built in the laboratory and two which were commercially available. The system built in the laboratory (called the Southampton system in the following discussion) was based on standard electronic devices supplied by RS Components. An ultrasonic range finder evaluation kit from Polaroid was also examined, as was an ultrasonic transducer used in an experimental vehicle by the Ford Motor Co. These systems are described in detail below.

5.1 Experiments on the Southampton ultrasonic ranging system

The ultrasonic range finder designed at Southampton has been kept as simple and cheap as possible. The device is based on the time of flight method, in which a distance is determined by measuring the time taken for a pulse of ultrasound to travel to and be reflected back from an object.

A further design criterion was to keep the system as flexible as possible. The Southampton ranging system is designed in such a way that other ultrasonic transducers may be connected to it with very little or no modification. In order to achieve this the ranging system is built upon a standard sub-rack. The whole system is attached to a BBC microcomputer and becomes an extension of it.

The ranging system is built in modular form and consists of five plug-in cards. One of the cards carries a circuit to interface the BBC computer's 1 MHz bus to the back panel of the sub-rack. A second card generates pulses which signal the start of a measurement.

This card is programmable by the BBC to generate pulses with frequencies between 20 Hz and 1 KHz. This part of the system also contains circuitry for decoding the address of the BBC 1 MHz bus. The third board carries a timing circuit which measures the time interval between the transmission of the outgoing pulse and the reception of the reflected pulse.The maximum range measurable by the system is fixed by the number of bits used in the timing circuit. The configuration used in the tests described here gave a maximum range of 1.4 m. The fourth circuit board generates 16 cycles of square wave at 40 KHz when the pulse signaling the beginning of the measurement is received. The fifth card consists of a circuit to condition the received reflection, and also generates a pulse to signal the end of the measuring period. Communication between the cards is through the back panel of the sub-rack. Circuit diagrams of the five circuit boards, details of their operation and backplane pinout diagrams are given in Appendix A. The complete system is shown in plate 1.

Software was written for the BBC microcomputer used to control the system. This software manages the communication between the sub-rack and the BBC. The program sets up the sample rate, and obtains the measured data from the ranging system. The program operates in two different modes, namely Test and Log mode. In Test mode, the program sets the sample rate (ie. the repetition) of the system, as instructed by the user. It then continues to read the measured value from the system and displays it on the screen of the monitor.

When the program is run in Log mode, the user is asked for the desired sample rate and the measurements are logged onto a floppy disk for subsequent analysis. The program listing and a flow diagram are given in appendix B.

A number of experiments were carried out to investigate the performance of the Southampton range finder. Amongst the features investigated were the emission pattern, the linearity, and the reflection of the ultrasonic waves within differing environments.

5.1.1.The emission pattern

The emission pattern of the transmitter was investigated first. The experiment was carried out in a large empty room to minimise strong reflections. The transmitter was connected to a circuit which generates a 12 V peak to peak 40 KHz square wave. The receiver was connected to the input of an oscilloscope and the peak-to-peak value of the received signal was measured. The receiver was placed at varying distances from the centre-line of the emission. The experimental set-up used is shown in Fig 5.1, and the results are given in Table 5.1 and Fig 5.2.

The emission pattern was found to be quite symmetrical around the centre line. Some difficulty in aligning the transmitter and receiver was experienced and this has led to the effect seem in Fig 5.2, where the peak output appear slightly offset from the excepted 0 degree position. This was thought to be because the alignment was carried out visually. There were also problems with noise in the measurement. The oscilloscope was very difficult to trigger and the trace on the screen was not very clear. It was particularly difficult to determine the magnitude of the received signal when the measurement was taken at an angle greater then 25° from the central line of emission.

From figure 5.2 it can be seen that the beam has a high intensity along the center line. The intensity decays quite rapidly at positions away from the center line.

5.1.2.**Calibration and linearity checking**

The transmitter and the receiver of the range finder were housed within a 15 x 50 x 75 mm PVC box with one end open. This box was secured to one end of a long table. A cardboard target was placed at various distances from the device on the same table. Thus, there was a continuous flat surface between the range-finder and the cardboard target. With this arrangement the reflection from the target was very strong. The computer program was set to run in the test mode. The indicated range was recorded as a binary value, together with the separately measured distance between the device and target. The results from this test are given in Table 5.2. It was found that the system is capable of giving a valid reading when the target is in excess of 2 m away. This appeared to be the limiting range of the device.

A straight line was fitted to the measured points by the least squares method [49]. Results (shown on figure 5.3) show that the measurements fall on a straight line with a standard deviation of ±0.01mm. The measurements also show that the resolution of the system is 5.5 mm.

The results of figure 5.3 suggest that the device is very linear. During the tests it was noted that the last digit of the measurement was not very stable and often changed by ±1. Thus the accuracy of the measurement is given as ±5.5 mm.

The device was also positioned so that there was no table surface between the cardboard target and the device. The reflected signal was, as expected, found to be weaker in this case. When operating with this arrangement the system was capable of giving a stable reading only for ranges up to 1.6 m.

The calibration test was extended to cover different materials. Flat specimens of brick, concrete and tarmac were placed in the path of the ultrasound, and the readings from the computer were recorded. The results shown in fig 5.4 demonstrate that the range-finder provides valid data for targets made from these materials.

Pieces of rock were also placed in the path of the ultrasound. It was found that the readings from the computer were no longer valid. This was due to the fact that the surfaces of the rocks were irregular and therefore not enough ultrasound was reflected back to be picked up by the receiver.

The effect of angling the target surface was also studied. It was found that the magnitude of the reflected wave dropped rapidly when the reflecting surface of the target was not perpendicular to the center line of the emission. When the target was at angle about 85 degrees to the axis of emission, the reflected signal was too weak to be picked up by the receiver. This confirms the observations made in earlier experiments.

5.1.3.Tests using various reflecting surfaces in the laboratory

An indoor experiment was carried out with the measuring device hanging from the ceiling of the laboratory as shown in Fig 5.5. The distance of the device from the wooden floor was measured, and the readings obtained from the range-finder were recorded. The results are given in Table 5.4.

Once again the least-square technique was used to fit a straight line to the points. The measured values and the line fitted to them are shown in Fig 5.6.

This experiment showed that the resolution of the system in this orientation was $\pm$5.2 mm and the standard deviation of the readings was 7.97. Thus it appeared that there was a large error in this experiment. This error was caused by the fact that the device tended to swing when it was hanging from the ceiling. The readings from the computer were also not as stable as in the previous experiment. The last digit of the reading varied by $\pm$3 units. A further source of error was due to the fact that the distance between the device and the floor may not has been accurately measured. However, the point of this experiment was not to obtain an accurate measurement, but to investigate the properties of the reflected signal. It was shown by this test that the range of the measurement was reduced because the reflected signal was weaker than in the previous experiment. The device could only measure ranges up to about 0.75 m. The reflected signal was so weak that it could only just be distinguished from the background noise at this distance. The signal to noise ratio did not improve when the angle of incidence was changed slightly to maximise the reflection. This weakening of the reflected signal suggests that the wooden floor may have absorbed rather than reflected some of the ultrasonic wave energy. This was confirmed by placing a piece of perspex on the floor, when it was noted that the reflected signal become stronger. The reflected signal was further improved when a piece of concrete was placed in the path of the ultrasound beam.

The results from these tests are given in Table 5.6 and Fig 5.7 respectively.

5.1.4.**Outdoorexperiments**

A series of tests were also conducted outdoors. In these experiments, the range finder was again used against a cardboard target. The distance between the range-finder and the target was independently measured.

Once again a line was fitted to the results as shown in figure 5.8. This showed that the resolution of the device was $\pm$5.3 mm, while the standard deviation was 19.6. Thus it again appears that there was some experimental error in the measurement. This experimental error was probably introduced by the fact that the distance between the range-finder and the target was not sufficiently accurately determined. The numerical results are given in Table 5.6.

It was noted that the signal to noise ratio achieved in the outdoor tests was much higher than in the other experiments carried out indoors. This is probably because outdoors there are fewer objects surrounding the device which can cause spurious reflections and thus increase the amount noise in the measurement. It was found that when operating outside, the system could measure ranges up to 1.4 m.

5.1.5 Possible improvements to the Southampton rangefinder

The range-finder built in the laboratory has several limitations which may be removed by modifying the system. At the moment the range finder is connected to a BBC microcomputer. The design makes it possible to connect it to other computers by replacing the interface card. The programmable pulse generator can also be removed if direct control of the sampling is desired. This is particularly important if the sampling is to be linked to the distance travelled by a vehicle rather than to a fixed time interval.

The limiting near-range of the present system is 0.5 m. The existence of this near-range comes about because there is some direct transmission from the transmitter to the receiver, and multiple reflections at the walls of the case housing the device. A masking signal is needed to prevent this transmission being mistaken by the timing circuit as the signal to stop timing. This masking signal is currently set to two and a half times the duration of the transmission period. If material which absorbs ultrasonic waves at that frequency are placed within the case, the direct transmission and multiple reflection problems may be reduced and as a result the masking time can be made shorter.

The far range of the device is always 1.35 m from the near range. This measuring range can be increased by a factor of two if the counter/timer circuit use more bits. However, for the purposes of these experiments the current system is satisfactory.

5.2.Investigation of the Polaroid ranging system

A Polaroid ultrasonic ranging system evaluation kit was obtained and examined. This kit consists of a Polaroid ultrasonic transducer, a driving circuit, a distance measuring board, a battery and a number of technical manuals.

The Polaroid ultrasonic transducer is a circular piezoelectric disk with a diameter of 4 cm and a thickness of 0.4 cm. The same transducer is used for both transmitting and receiving the ultrasound pulse. The driving circuit is attached to the transducer by means of a screened cable. The driving circuit is used to generate the transmit signal, and to condition the reflected signal picked up by the transducer. According to the technical manual[50], the user is recommended not to carry out any modifications to the driving circuit. However, there are several points on the driving circuit board which the user can access to control the board and to obtain information from it.

The distance measuring board supplied as part of the evaluation kit is connected to some of these points. The range over which the system operates is from 0.9 feet to 35 feet. The sample rate of the device is 9 Hz and the output is displayed digitally in tenths of feet.

A simple circuit as shown in Fig 5.9 (see Appendix A for details of the connections) was built to interface the Polaroid system to a BBC microcomputer for logging the range indicated by the circuit. A program was written to display the measurement on the screen and store the values on to a floppy disc. A number of tests were carried out in the laboratory to investigate the properties of the device.

In the first tests a cardboard target was placed in front of the device at various distances. The distance of the target from the device was measured, and the reading displayed by the computer was recorded. The results are given in Table 5.7. and they show that the device is fairly accurate.

Experiments with different materials were also conducted. Specimens of brick, concrete, Tarmac and stone were used as targets. The results shown that the reading for the range-finder was not affected by the nature of the surfaces reflecting the wave. The Polaroid range-finder was readily able to measure the distance of a rough rock surface. This shows that the Polaroid range-finder can make a valid measurement even when the surface reflecting the ultrasound is uneven. Tests were also carried out in which a piece of concrete with a flat surface was placed in the path of the beam and rotated away from the axis of emission. It was found that the range-finder give valid readings until the angle of the concrete surface was less than 80 degrees to the beam.

In another experiment, the device was placed at an angle to the surface of a table. The output of the range-finder in this case was not the distance between the transducer and the surface of the table. Instead, the reading was the distance of the wall, perceived by the transducer as an image reflected by the surface of the table. Similar situations were observed when the transducer was pointing toward a smooth wall at an angle. It was concluded that the signal emitted by the transducer was so strong that reflections can readily occur at the surface of a smooth or polished object if the transducer is placed too close to it.

The ranging system was also tested out of doors. In the first test the transducer was aimed at the ground, at an angle of about 45 degrees to the horizontal, to measure the distance of the ground from the device. The results showed that multiple reflections did not occur when the system was used against a rough surface in open air.

According to the technical manual supplied with the Polaroid system[50], the user can build circuits to initiate a measurement and acquire the result from the driving board. The user is also given access to the amplified and the processed echo. The Polaroid system is controlled by switching the power supply to the circuit on and off. To start a measurement, the user's circuit needs to turn on the power supply to the driving board. After an unpredictable delay, the transducer will send out a fixed number of pulses of the ultrasonic wave. At the same time a signal is generated by the driving board to indicate that transmission has taken place. The users' own timing circuits can than be used to measure the range. The power supply to the driving board has to be maintained until the echo is received by the transducer. To start another measurement, the power supply to the driving board must be switched off and on again. The minimum power-off time is 40 ms. For this reason the maximum sampling rate of the system cannot exceed 25 Hz.

From the tests that were carried out on the Polaroid system, it was concluded that although the transducer can generate a very strong ultrasonic pulse for the measurement, and although the device is able to measure the range of a surface at an angle, the system is unsuitable for our application because of the limited sample rate.

5.3.Review of the Ford ultrasonic device

An ultrasonic range finding device considered for use in load levelling in a Ford Sierra was obtained and evaluated. This device is mounted underneath the body of a Sierra and measures the height above the ground. The device consists of an ultrasonic transmitter and a receiver sealed inside a plastic housing, together with a circuit to generate and process the ultrasonic pulses. According to information from the workshop manual [51], the user is not supposed to carry out any adjustments or repairs to the device. This device resembles the Polaroid range finder, in that it has several connections which allow other circuits to be interfaced to it. The inputs to the device include the power supply, earth, and a "start" signal input which initiates the measurement. The outputs from the device include a signal to indicate that an echo has been received, and a logic level which indicates the status of the device. Descriptions of these are given in Appendix C.

The device was tested in a number of ways. In the first test power was applied and a start signal was generated by a signal generator producing pulses at 100 Hz with duration of about 5 ms. The amplified receiver signal output was examined as well as the logic output of the device. The amplified output produced a very strong signal when the main reflection was received by the sensor. In fact the reflected signal was so strong that the output of the device went into saturation at +5 V. The amplified signal contained very little noise. It was very much clearer than the amplified receiver signal of the Southampton range-finder described earlier. The device was able to detect the presence of an object up to about 1.5 m away.

Unfortunately, it was found that the logical output of the device did not behave as described by the data sheet. It emerged after some discussion that personnel at Ford had experienced the same problem when the device was used in their laboratory.

This experiment shows that the device is better than the Southampton range-finder in terms of its signal processing abilities. It would be possible to control the device using the rack system developed for the Southampton range-finder. The only modification required is to provide an interface board to the sub-rack for this device. However, the sample rate of the device is still governed by the speed of sound, ie. inversely proportional to the range to be measured as described earlier. Thus limitation makes it unsuitable for use in controlling a suspension system.

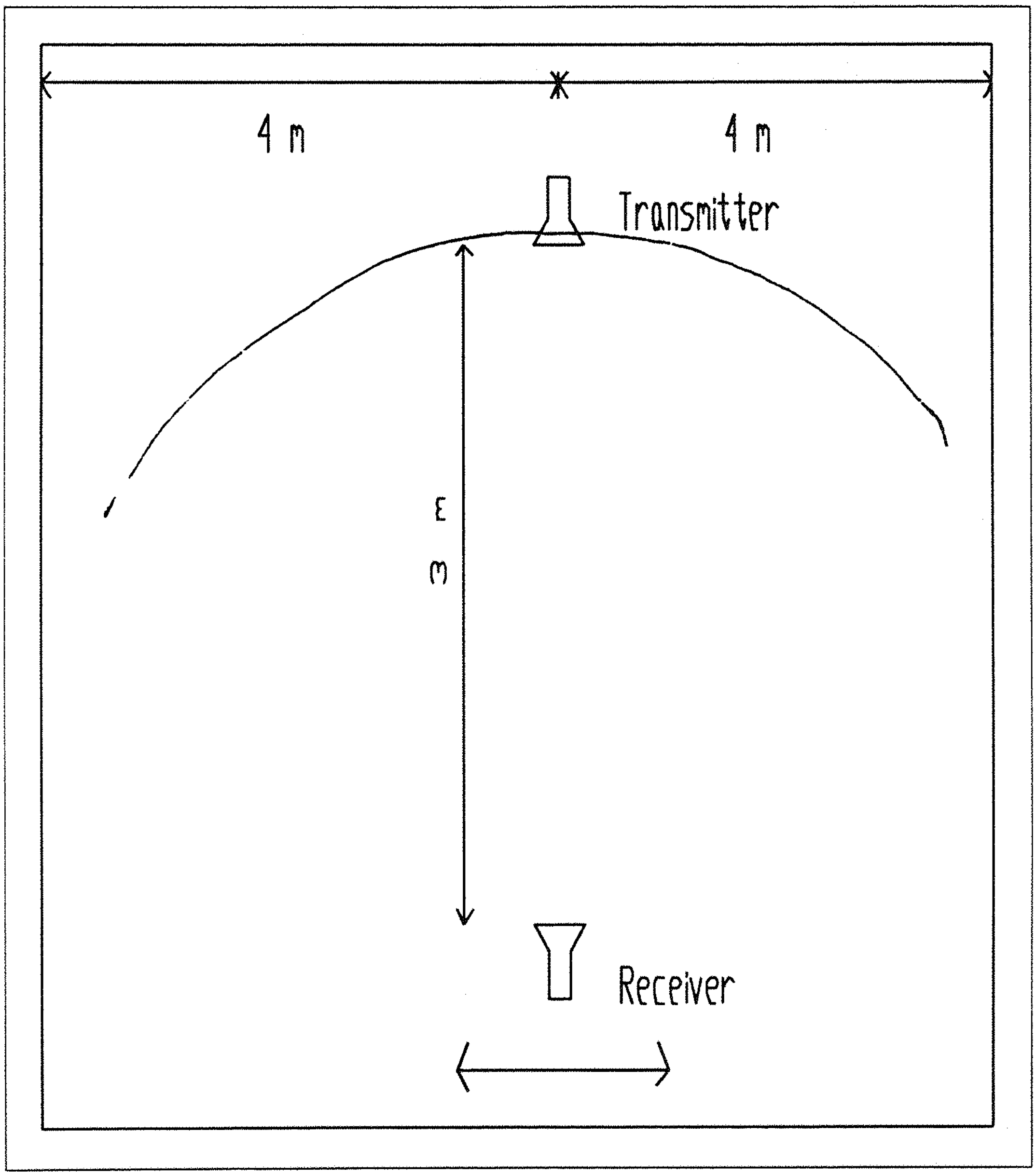


Fig 5.1 Simplified diagram of the set up used for the emission pattern test

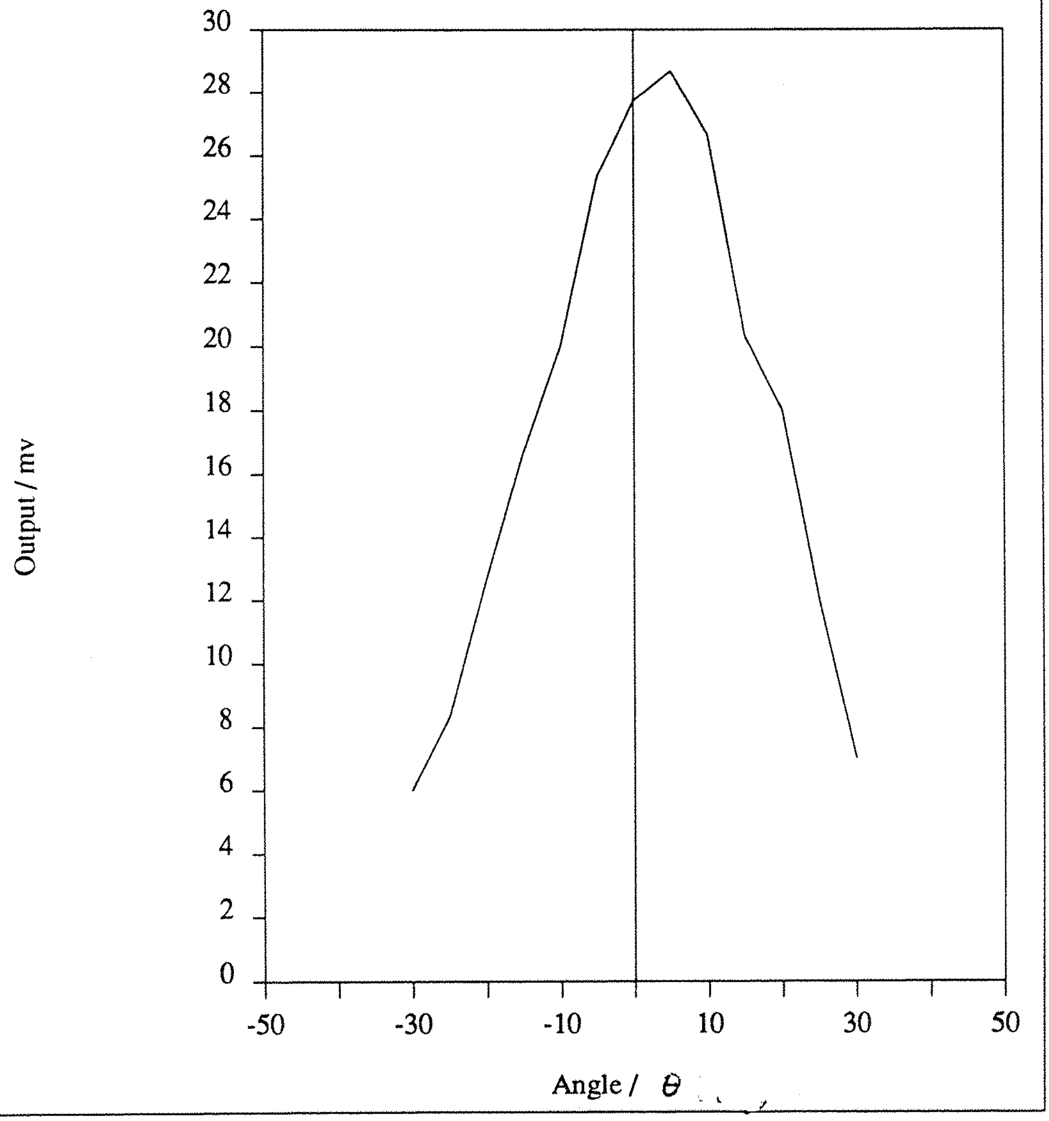


Fig 5.2 Plotting of the emission pattern test (L fixed at 3 m)

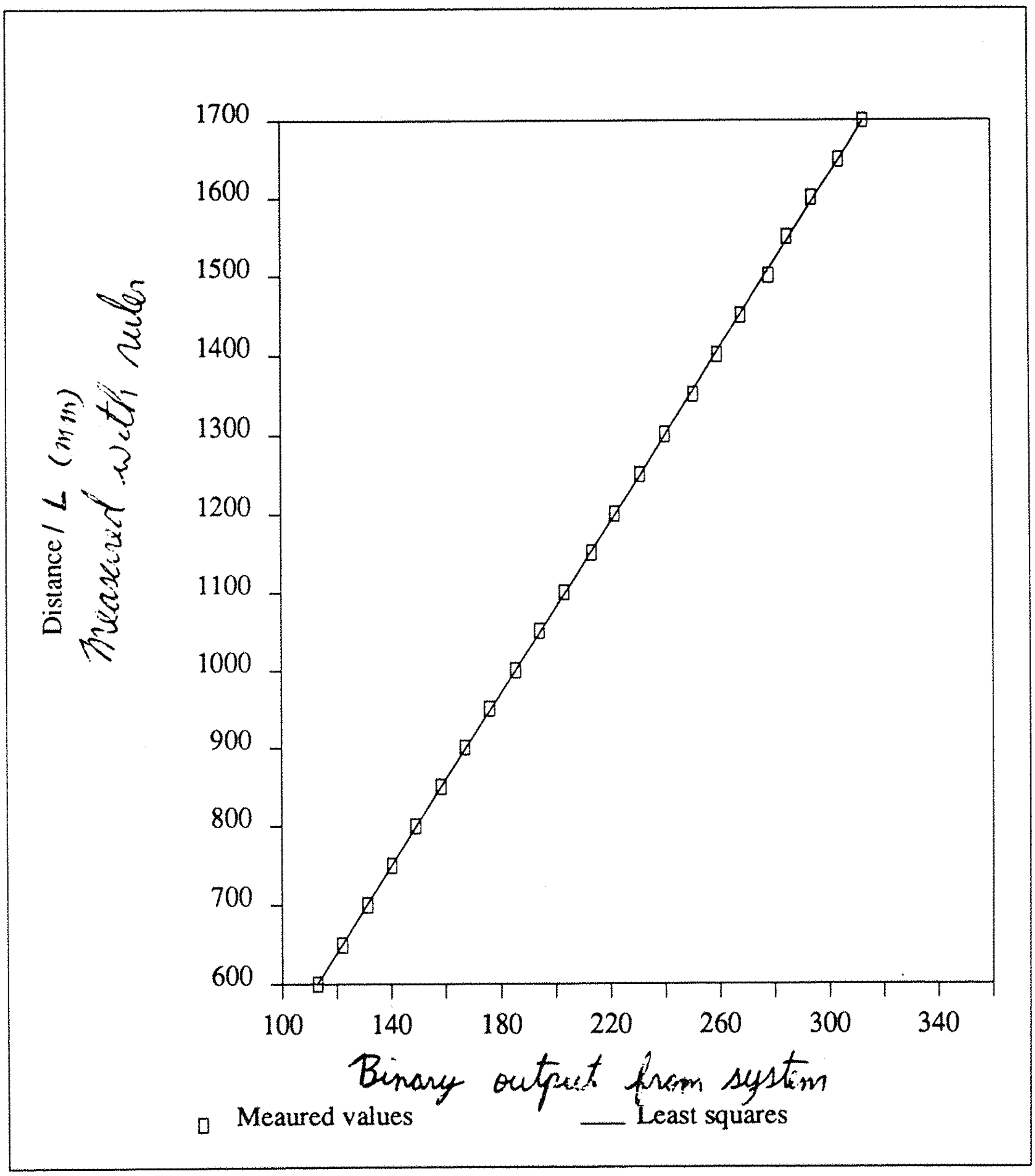


Fig 5.3 Plot of the calibration test (fixed at 0 degree)

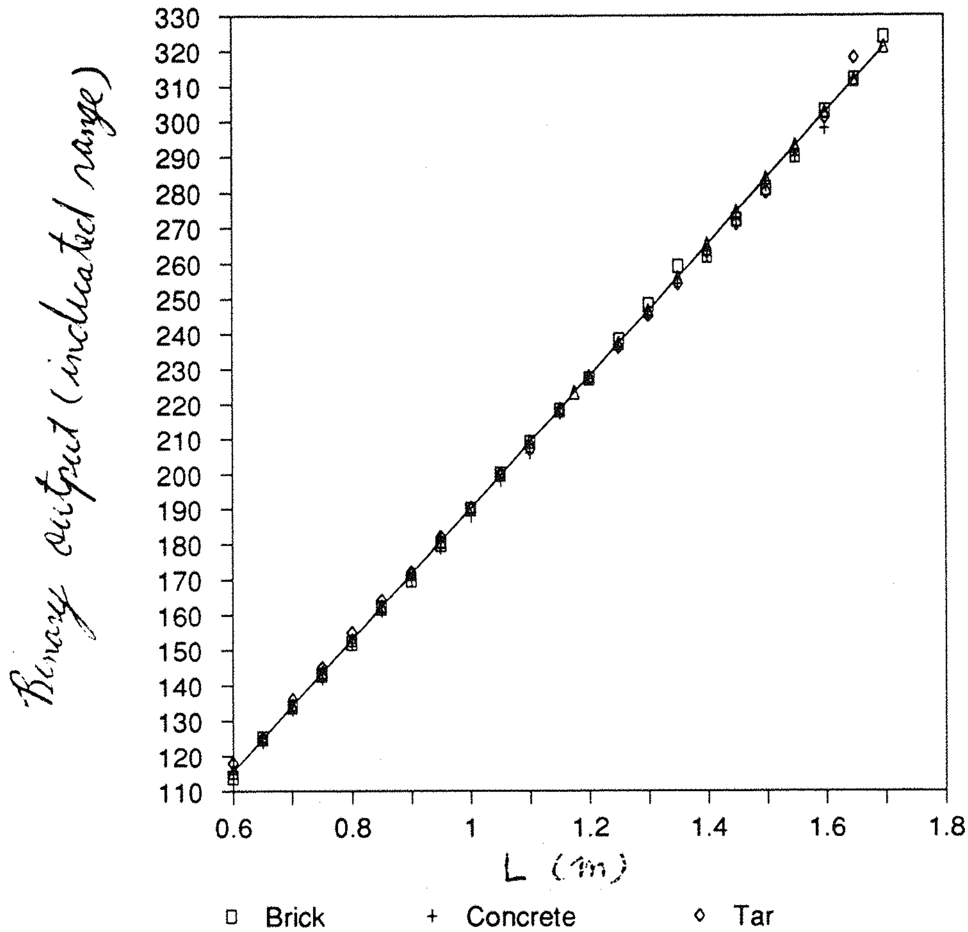


Fig 5.4 Plot of the measurements by using different material as reflecting surface

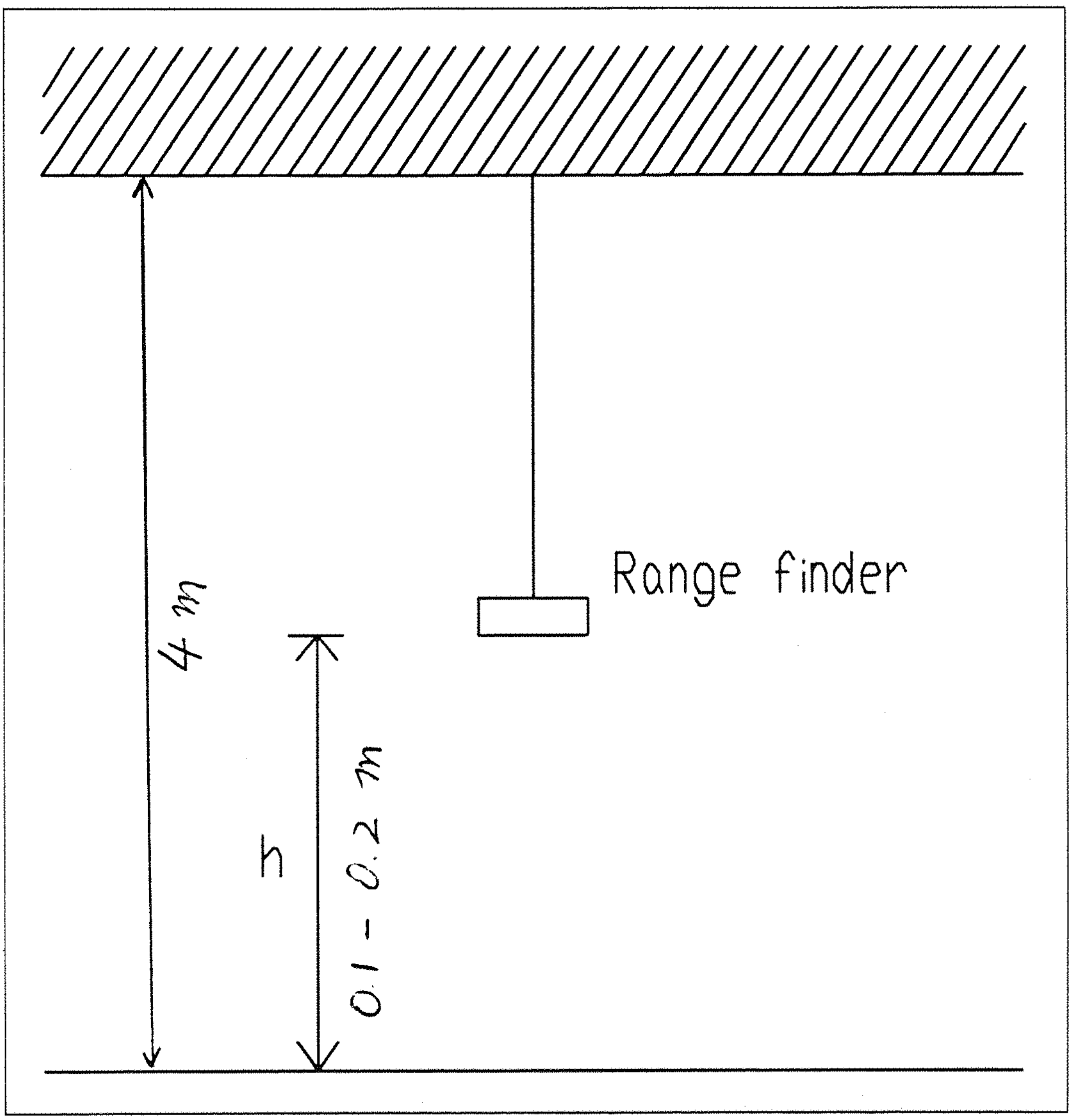


Fig 5.5 Simplified diagram of the set up for the reflection properties test

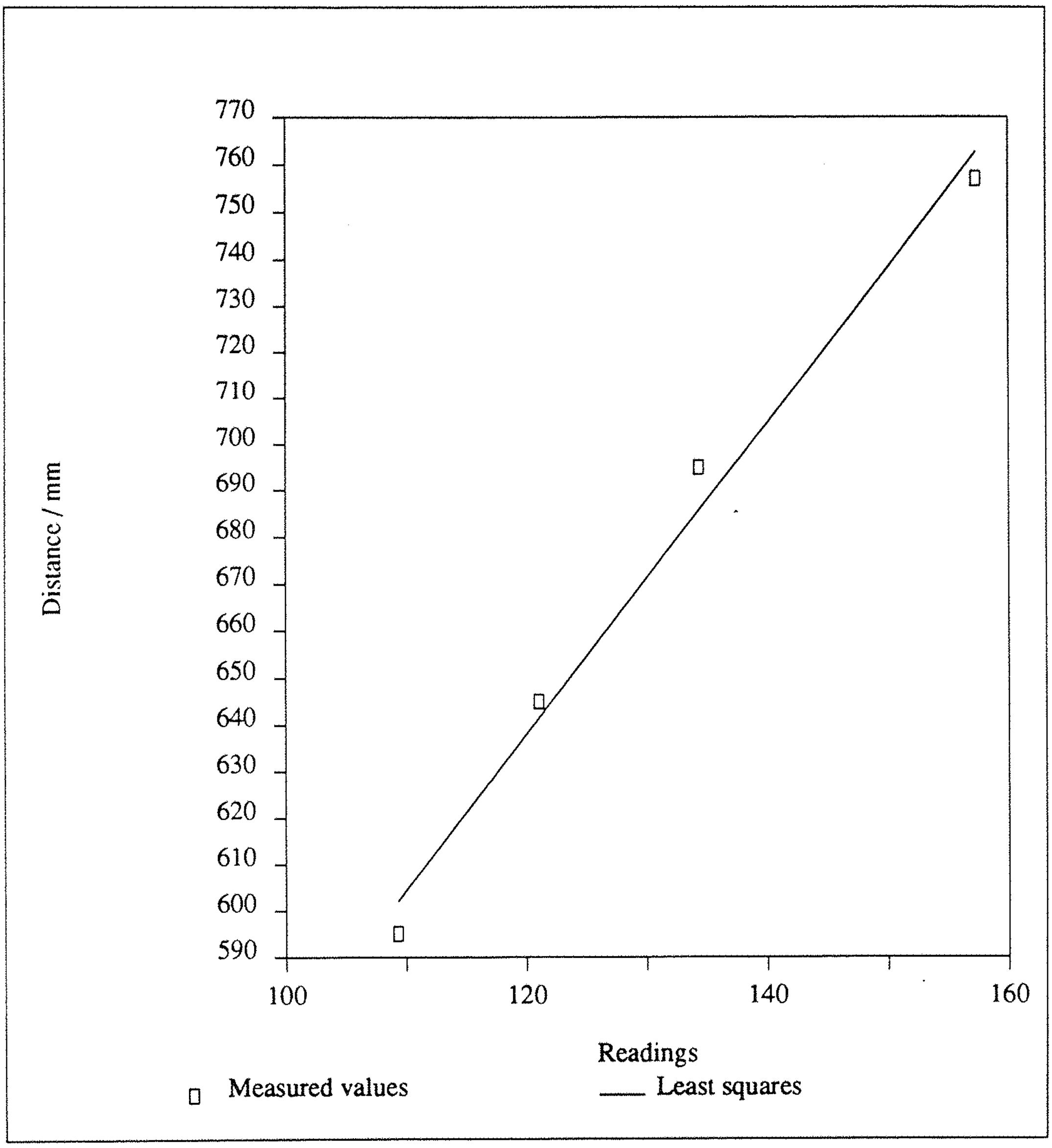


Fig 5.6 Plot of the measurements on a wooden floor

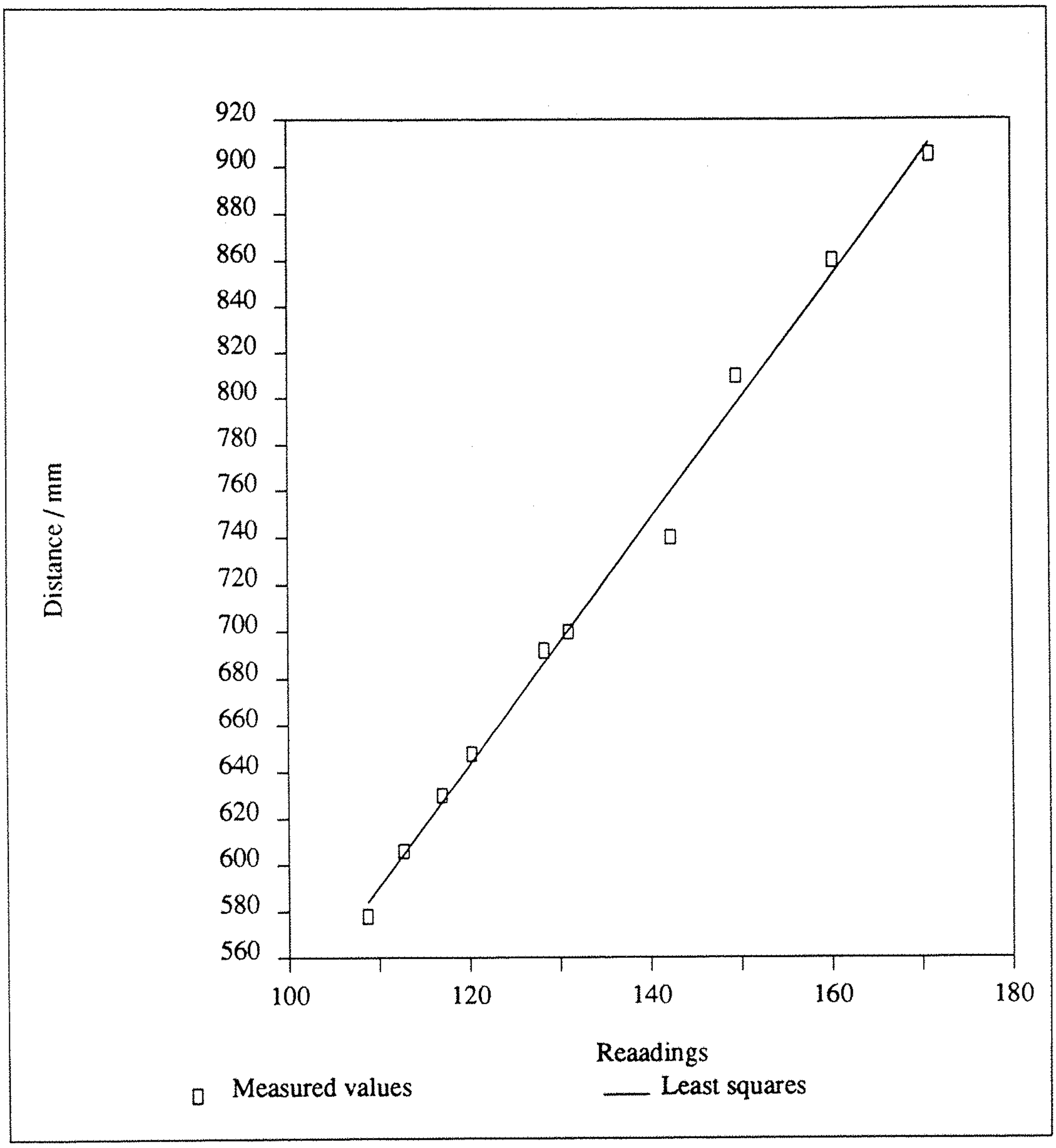


Fig 5.7 Plot of the measurements on a perspex covered floor

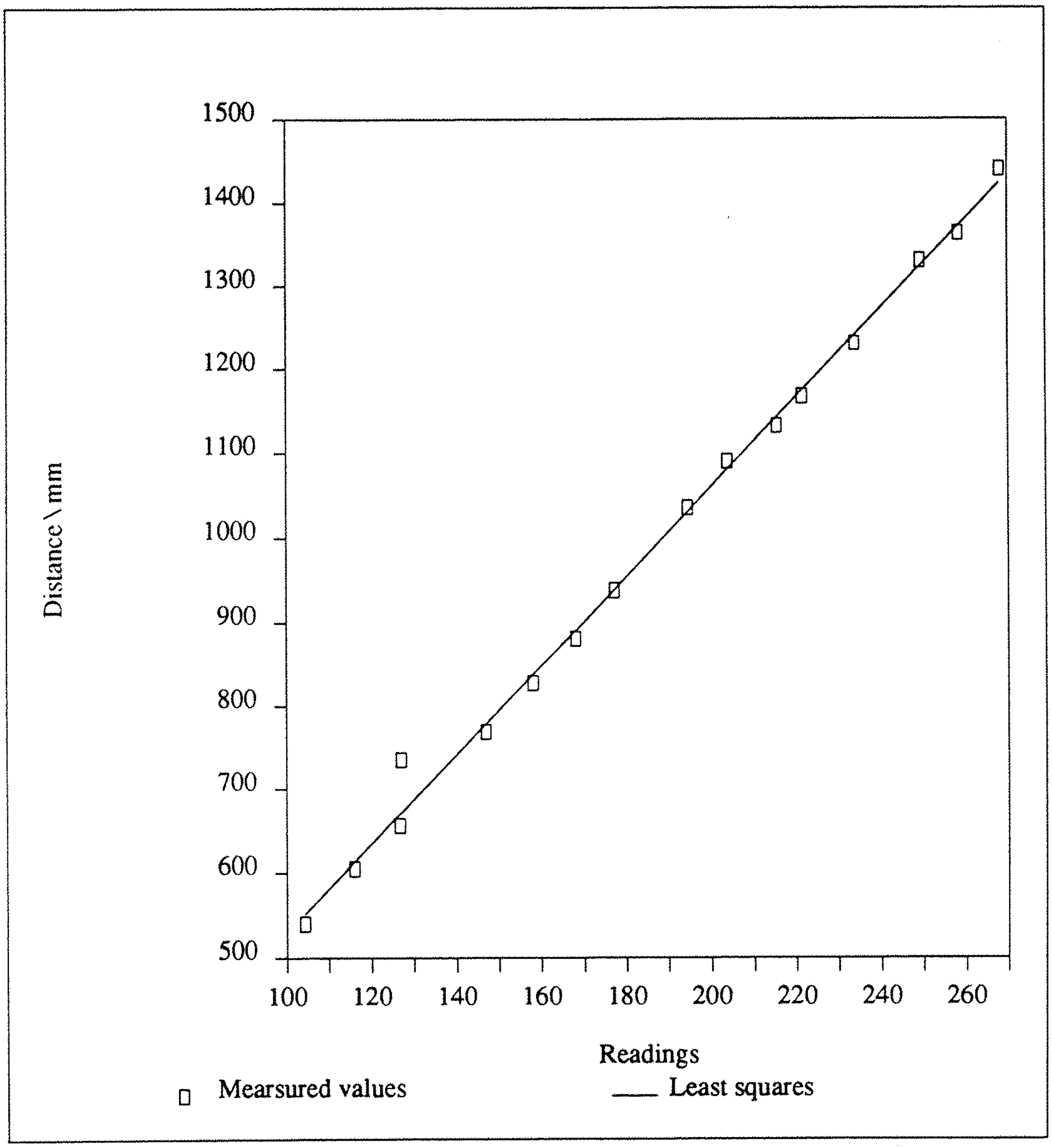


Fig 5.8 Plot of the outdoor experimental results

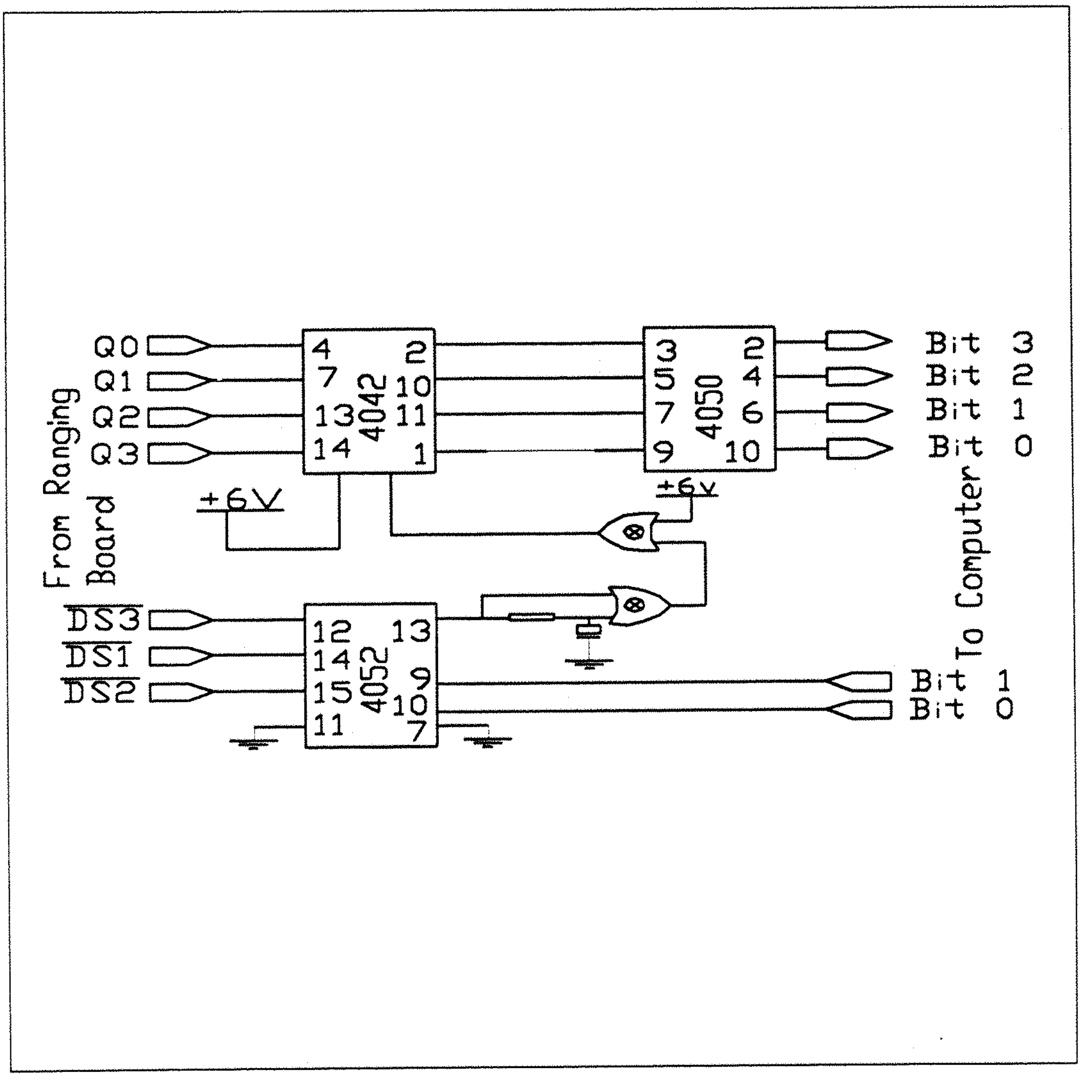


Fig 5.9 Circuit diagram of the interface between the BBC computer and the Polaroid ranging board

Angle	left	right
30	6.00	7
25	8.33	12
20	12.67	18
15	16.67	20.33
10	20.00	26.67
5	25.3	3.67
0	27.75	

Table 5.1 Results of the emission pattern test

Distance mm	output V	Least squares	Residual
113	600	601.4360	1.436041
122	650	650.8239	0.823975
131	700	701.8581	1.858175
140	750	751.2461	1.246109
149	800	798.9877	-1.01222
158	850	850.0219	0.021979
167	900	897.7636	-2.23635
176	950	947.1515	-2.84841
186	1000	999.8320	-0.16795
194	1050	1047.573	-2.42628
203	1100	1096.961	-3.03834
213	1150	1151.837	1.837135
222	1200	1197.383	-2.61621
231	1250	1248.966	-1.03325
240	1300	1298.354	-1.64532
251	1350	1356.522	6.522687
259	1400	1404.264	4.264357
268	1450	1452.006	2.006027
278	1500	1508.527	8.527775
285	1550	1545.294	-4.70565
294	1600	1594.682	-5.31771
304	1650	1649.557	-0.44223
313	1700	1698.945	-1.05429

The equation is given: $Y = 5.487548x - 18.6569$

Standard deviation : 3.382259

Table 5.2 Calibration of the Southampton ranging system

Distance mm	Brick	Concrete	Tar
600	114	115	118
650	125	124	125
700	134	133	136
750	143	142	145
800	152	152	155
850	162	161	164
900	170	170	172
950	180	179	182
1000	190	188	190
1050	200	198	200
1100	209	206	207
1150	218	217	218
1200	227	227	227
1250	238	236	236
1300	248	245	245
1350	259	254	254
1400	262	262	263
1450	272	272	271
1500	281	282	280
1550	290	290	292
1600	303	298	301
1650	312		318
1700	324		

Table 5.3 Measurements by using different material as reflecting surface

Distance mm	Output V	Least squares	Residuals
109	595	602.1974	7.197405
121	645	641.3185	-3.68144
134	695	685.7896	-9.21039
157	757	762.6944	5.694431

The equation is given by : $y = 3.34x + 236.7$

Standarddevation:9.555459

Table 5.4 Measurements on a wooden floor

Distance mm	Output V	Least squares	Residuals
109	578.00	583.84	5.84
113	606.00	604.78	-1.22
117	630.00	627.29	-2.71
120	648.00	644.56	-3.44
128	692.00	686.44	-5.56
131	700.00	700.57	0.57
142	740.00	759.72	19.72
150	810.00	797.93	-12.07
160	860.00	853.93	-6.07
171	905.00	909.94	4.94

The equation is given by : $y = 5.23x + 14.87$

Standard devation : 9.23

Table 5.5 Measurements on a perspex covered floor

Distance mm	Output V	Least squares	Residuals
104	540	551.59	11.59
116	605	613.84	8.84
127	657	670.78	13.78
127	735	672.38	-62.62
147	769	778.80	9.80
158	827	837.33	10.33
168	880	890.54	10.54
177	938	938.43	0.43
194	1035	1030.48	-4.52
204	1090	1080.50	-9.50
215	1132	1142.23	10.23
221	1167	1174.15	7.15
234	1230	1240.13	10.13
249	1330	1323.14	-6.86
258	1363	1371.03	8.03
268	1440	1422.65	-17.35

The equation is given by : $y = 5.32x - 3.40$

Standard devation : 19.68

Table 5.6 Results of the outdoor experiment

Distance ft	Output ft
2.0	2.0
2.5	2.4
3.0	3.0
3.5	3.5
4.0	4.0
4.5	4.6
5.0	5.0
6.0	6.0

Table 5.7 Measurements on the Polaroid ranging system

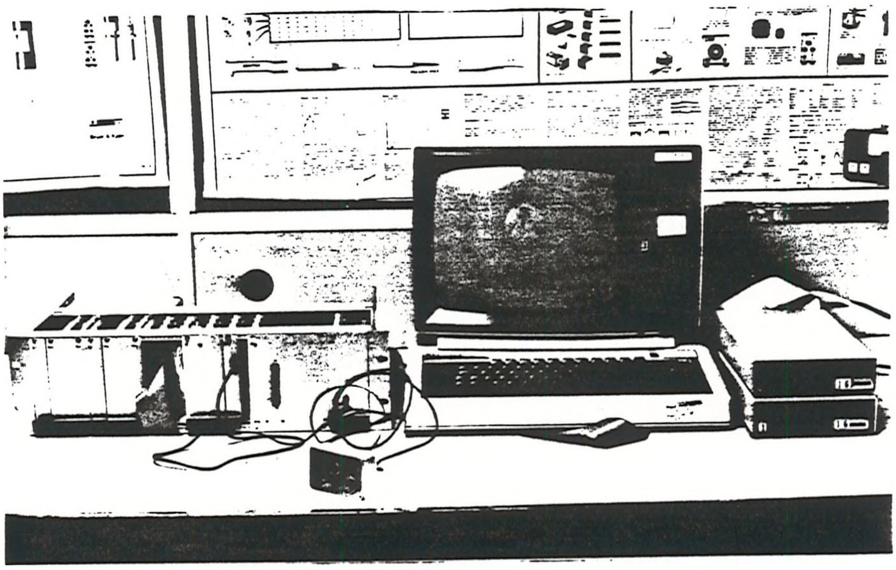


Plate 1 The Southampton Ranging system

6.Review of commercial optical range finders

6.1.The "Optocator" - a typical triangulation rangefinder

The Optocator is an optical range finder developed by Selcom of Sweden. It uses the principle of triangulation to determine the distance of an object from the system. The Optocator is widely used in industry. It is used in the rubber and plastics industries for profiling, high speed quality control and thickness measurement. It is also used in the steel and aluminum industries for measuring the flatness of hot and cold rolled products. The device has been used in robotic systems for position control and 3-D coordinate measurement[52]. It has been used by the Swedish Road & Traffic Research Institute (VIT) to measure road and air-field runway profiles for maintenance purposes [25].

A standard Optocator system consists of a measuring probe and a rack of electronics as shown in plate 2. The measuring probe houses the laser, the optical sensor and the drive electronics. The laser source in the Optocator is a semiconductor device emitting infra-red radiation. The emission is in pulse form, with a maximum power of 115 mw for a duration of 350 ns. The Optometer is used as the position detector. The Optometer is an optical sensor which produces a voltage output related to the position of a light spot falling onto its active surface[47]. The electronics within the measuring probe drives the laser and controls the output from the optometer.

The associated rack of electronics contains the power supply and allows the addition of optional circuit boards to the system. The options available include a receiver board, an averaging board, a microprocessor board, an analog board and a digital board.

The receiver board is for amplifying the output from the measuring probe and converting the information to parallel form. The averaging board reduces the output data rate by averaging a number of measurements from the receiver board. The number of readings used in one average can be preset by jumpers on the board. The updating rate of the board varies from 8 kHz to 62.5 Hz. The microprocessor board consists of an 8-bit 8035 microprocessor, a display and a control panel. The microprocessor acquires the data from one or more receiver boards, converts the measured data to millimeters or inches, and presents the result on a numerical display. This board can also compare the measurement with a preset value and display the result. The analog board conditions the data from the probe to analog form. The digital board provides the measurement in a digital form. An external computer, data collection system or other control equipment can be connected directly to the digital board for data acquisition purposes.

There are several standard measuring probes for the system, with different stand-off distances, (see chapter 4). The cost of a typical Optocator system is around £6,000.

6.1.1 **Experiments on the Optocator**

A standard Optocator was borrowed from the UK distributor. The probe supplied was model 2005-554, which has a stand-off distance of 300 mm and a measuring range of 256 mm. The Optocator weighs 5 kg, and has dimensions of 500x145x90 mm. The sub-rack contained the power supply and a receiver-averaging board. The receiver-averaging board can provide the measurement data in both digital and analog form.

According to the user's manual, the Optocator can operate against many different materials such as steel, brick, concrete and wood. It is also capable of measuring the distance of the surface at a wide range of angles. The only limitation on the angle of measurement is that produced by the position of the probe and the surface geometry of the surface.

A number of experiments were carried out to investigate the feasibility of using an Optocator as part of an automotive active suspension system. Specimens of brick, concrete, asphalt road surface and stone were placed at a number of distances from the Optocator. The analog output from the averaging board was used for simplicity, and the voltage was measured by a multimeter. The results together with those theoretically calculated (based on measuring the distance between the samples and the range-finder) are given in Table 6.1. The results are also plotted in Fig 6.1.

From figure 6.1 it can clearly be seen that the measured values agree well with the predicted values. It is also shown that the Optocator can measure the distance of a surface made from a variety of materials.

A second experiment was carried out to investigate the Optocator's ability to measure a distance when the surface of the specimen is at a shallow angle to the laser beam. In this experiment an asphalt surface was placed 300 mm (in the centre of the measuring range) from the Optocator. The surface was angled to the laser beam and the output of the receiver-averaging board was recorded. The results are given in Table 6.2.

Since the laser light emitted by the Optocator system is invisible, an infra-red viewer was used in the experiment to "see" where the laser spot was on the surface. The main source of error in these experiments was the difficulty experienced in measuring the distance between the laser aperture and the asphalt surface. However, the results show clearly that the use of a shallow incident angle does not create any problems for the measurement.

A third experiment was carried out to investigate the effect of a film of water applied to the surface of the test specimen. The intention was to simulate a wet road. In these tests, specimens of brick, asphalt, and concrete were placed at various angles to the laser beam. Water was sprayed onto the surface of each specimen. The results indicated that the Optocator gave a stable reading even when the surface of the specimens was wet. However the output of the Optocator became unstable and gave false readings just after the spraying process, when water was running across the surface of the specimen. This suggests that the output of the Optocator was affected adversely by the presence of running water on the surface. It also noted that this effect worsened when a shallow incident angle was used. The results from this experiment are given in Table 6.3.

From the information given by the manufacturer, the accuracy of the Optocator is very high. It is capable of resolving to 1/4000 of the measuring range. It is potentially a low cost device, since the components may be obtained for £10-£20. The problems associated with the Optocator are mainly due to its large size, and the fact that it is not eye-safe. The Optocator, together with the electronics sub-rack, is much larger and heavier then the IBEO time-of-flight system which was finally used. The size of the sub-rack can be reduced if customised logic devices are used, but the Optocator cannot be made smaller since the transmitter and receiver need to be physically separated for triangulation to function properly.

A further concern about the Optocator is the dirt accumulated on the surface of the lens system. Since the principle of triangulation relies on the position of a light spot on the detector, the clearness of the lens is very important. Dust and water on the lens will affect the transmission of light through the lens, which in turn will affect the accuracy of the measurement. In contrast the time-of-flight system only uses the lens to collect light and indicate that a reflection has been received by the system. Time of flight systems are therefore less vulnerable to dust.

The biggest problem remains the concern over safety. For triangulation systems such as the Optocator, there is a distance within which the laser beam is harmful to the eyes. For the particular model tested the hazardous range was about 2 m from the lager aperture. According to the user's manual supplied with the Optocator [52], this distance increases with the stand-off distance of the device. From the graph given in the user's manual, the safe distance from the device may be as great as 8 m for a device with a stand-off distance of 2 m. These hazards will obviously make it difficult to use triangulation systems for automotive suspension control. It is not possible to reduce the power of the laser to class I, since the high power is necessary to obtain a usable amount of reflected light from, for example, an asphalt surface, or when working at shallow angles.

Using an Optocator is potentially a low cost method for non-contact distance measurement. However, since safety is of prime importance it seems unlikely that an Optocator or other triangulation system can be used for the development of a road profile sensing system.

6.2 The Stripe profiling system

A system called STRIPE (Scanning Triangulation Range Image Package for Engineering) has been developed by the National Engineering Laboratory in Glasgow [53]. This system uses the principle of triangulation to measure the surface profile of an object placed at a fixed distance form it.

The system consists of a 10 mW HeNe laser, a scanning unit, a CCD camera, electronics for signal processing and a monitor to display the topography of the object.

Light emitted by the laser is reflected by a rapidly rotating mirror to generate a stripe which illuminates the length of the object under measurement. The scattered light from the object is reflected into a camera again by the scanning mirror. The CCD camera records the image of the reflected stripe. From the view point of the camera, which is positioned some distance from the laser source, the stripe appears to be deformed by the topography of the object. The output from the CCD camera is analysed to work out the topography of the object. The technique can be extended into three dimensions by rotating the mirror to scan across the width of the object. By analysing images from a series of light stripes, range data can be obtained over the full scene. Data related to the topography of the object can be displayed on a monitor using gray scales. A simplified diagram of the system is shown in Fig 6.2.

The most interesting point about the system from the part of view of the author is not its ability to measure surface profiles nor the use of the triangulation method for the measurement, but the way in which the 10 mW HeNe laser is used. A 10 mW HeNe laser produces radiation strong enough to be classified as class IIIb. Class IIIb radiation is harmful to the eye. However in the STRIPE system a rotating mirror is used to scan the beam across the surface to be measured. Because of this scanning, the radiation power at any point on the surface is greatly reduced. In fact, the power of the radiation is so low that it can be classified as class I and is totally safe.

The system is also designed to be fail safe. In the event that the scanning mechanism fails to operate properly, the whole system is shut down to make sure that no radiation is emitted by the laser.

One of the unresolved problems in the design is the complexity of the scanning system. The scanning is carried out by a rotating mirror, which is quite large and complicated and probably fragile. An alternative smaller and more rugged design is needed if a simple and maintenance free system is to be produced. A further problem is whether a low cost sensor such as the 'Optometer' can pick up the low radiation scattered by the surface. In the STRIPE system, the sensor is an expensive CCD camera which has very high sensitivity. If the problems inherent in building a rugged and simple version of the scanning system can be overcome, and if a suitably sensitive detector can be found, this approach may be worth pursuing in the future.

6.3. The IBEO pulsar electronic distance measuring system

Many commercially available optical range finders use the time of flight principle described in chapter 3. All the commercial systems are expensive, costing £10,000 or more. They are all highly accurate with resolutions of the order of ± 1 mm. The main problem associated with these systems (apart from the cost) is their sampling rate. This is usually fairly low, since most such systems are designed to be used in surveying, to measure the distance to a stationary object. Typically the sample rate is between 10 and 20 Hz. This is too slow for our application. It can readily be demonstrated that, for example, if it is required to measure the vehicle/road surface distance every 2 cm from a vehicle travelling at 70 mph, a sample rate of around 1500 Hz will be necessary.

Fortunately, the manufacturer IBEO in Germany was able to provide us with a custom made time of flight device, which will ultimately have a 1 KHz sample rate.

This custom made system is a modified version of a device from the "Pulsar" range of Electronic Distance Measuring (EDM) survey equipment. The dimensions of the customised device are 204 x 115 x 98 mm. The size of the electronic circuits and optical systems within the case is however much less than this. It is therefore possible to repackage the device in a smaller form.

The light source in the device is a semiconductor laser, working with very low power emission. The output power of the laser is low enough to be classified as class I. For this reason the device is totally eye-safe. The device is capable of measuring the distance to an object without a special reflector as required by some systems. It is also possible to measure ranges at very shallow incident angles, down to 10 degrees. The customized device can measure ranges up to 5 m, with a resolution of 1 cm.

The device is rugged enough to be used in an automotive environment. It is capable of operating within the temperature range -10 to +40°C. The device is splashproof. It can have an IEEE 488 standard or a RS232 serial interface output. It is also possible to rearrange the output of the device into other digital or analog forms. The device may be powered by an ordinary car battery and has a power consumption of about 6.5 W during measurement and 0.65 W when standing-by. The cost of this customized device is around £10,000. However, according to the representative of the company, the cost of the device will be greatly reduced if it is purchased in volume. A decision was made to purchase such system after the Optocator and Stripe systems were evaluated.

The customisation of the device is to be carried out in two stages. In the first stage, the device is supplied to us with a 20% increase in sample rate compare with the standard device. In the second stage, a 1 kHz sample rate can be achieved using a transputer interface card.

The device currently has the first state of customisation implemented. The power output has been raised to make sure that it is capable of operating at shallow angles and against non-uniform targets. The device has been reclassified as containing a class III laser, although according to the manufacturer the power output of the laser is still within the eye-safe limit. The output power of the device can easily be reduced back to class I if necessary. A more powerful laser is required initially to make measurements in a large number of different environments. Reducing the power will be considered when a satisfactory profiling system has been built.

6.3.1 Experiments on the customised Pulsar optical rangefinder

6.3.1.1 Configuration of the test system.

In order to automate the experiments, a computer has been used to set up an automatic data collection system. This system consists of the rangefinder, an IBM AT-compatible lap-top personal computer and a high speed serial interface. The computer runs the MS-DOS operating system and programmes are written in Turbo C. The rangefinder was initially powered by a rechargeable lead battery supplied by the manufacturer as a standard power source. Later it was found that the operating period between recharges was very short. For this reason the lead battery has been replaced by a mains-driven DC power supply.

The high speed serial interface enables the lap-top computer to communicate with other serial devices at speed up to 50 Kbaud. During the experiments 12.6 kbaud was used.

6.3.1.2 Different operating modes of the rangefinder

The rangefinder is capable of operating in a combination of the following modes : Single/Continuous measurement, Echo Limit/Free, Quality/Timer mode with surplus of 25%, 50%, 100% 200%, and accuracy of 3, 5, 10 or 20 mm. With different combinations of operating modes, the sample rate of the rangefinder varies. A detailed explanation of the operation of the device is given in appendix C.

6.3.1.3 The sampling rate experiment

A program was written in C to test the sample rate of the rangefinder. The program carried out one thousand distance measurements in each of the possible operating modes of the device, and measured the time taken so that the sampling frequency of the device may be calculated. It was found that the rangefinder can only operate very slowly in the single measurement mode, where each measurement has to be initiated by the computer. The sample rate in this mode is so low (around 3.25 Hz) that it has little practical use. The results are given in table 6.3.

While in continuous mode, it was found that the rangefinder is not capable of operating in six of the forty possible operating modes. The highest sample rate available in this mode is 86.5 Hz. With this sample rate it is just possible to build a prototype profiling system for our project by using the device. The results from these tests are given in table 6.4.

6.3.1.4 Measurements with different materials

Specimens of rock, concrete, tarmac,and brick were placed in the path of the rangefinder and a series of measurements were taken. The measurements show that the rangefinder is able to produce a valid measurement whatever the nature of the surface against which it is measuring. The results of the tests are shown in Fig 6.3

It was noted that there is an offset error in the measurements. This is due to the fact that it is not possible to know exactly where the origin of the measurements is. In the user manual supplied with the IBEO system the origin of the measurement is stated to be at the semiconductor laser diode, which is inaccessible from the outside of the device.

6.3.1.5 Measurements under different incident angle to the material surface

An experiment on the effect of different incident angles was undertaken. Specimens of tarmac, brick and concrete were placed at a distance of 1.5 m from the device. The specimens were rotated so that the surfaces were at various angles to the incident beam. The rotation started from a situation in which the surface was perpendicular to the incident beam, and continued until the beam was at 5 degrees to the surface of the specimen. The results showed that the measurement is not affected by the incident angle within these limits. The results of the experiments are given in Fig 6.4. It was noted out that the device still produced a valid reading when the angle of the incident beam was well below 5 degrees. However, the facilities available in the laboratory did not permit accurate measurements below 5 degrees so the actual angle was not recorded. It was concluded however that the device is capable of operating at very shallow angles.

6.3.1.6 Measurement with water

Water was sprayed on the test surfaces to examine the effect of a wet road. Specimens of tarmac, brick, rock and concrete were placed at a distance of 1.5 m away from the device, and water was sprayed on the surfaces. The result was a constant indication of 1.5m range, showing that the measurements were not affected by the presence of water. A further experiment in which the specimens were rotated was carried out. Again water was sprayed on the surface. The results also demonstrate that there is little effect on the measurement if the surface is covered with water.

6.3.1.7.

Conclusions

The tests described in this chapter have shown that neither a triangulation system nor one in which a scanning laser is used (such as STRIPE) are suitable for use as part of an automotive active suspension system. A time-of-flight system meets the required technical specification, although at high cost. However, there is reason to hope that the costs of laser and optical components may reduce in the future. Accordingly, after discussion with the project sponsor, the decision was taken to proceed with the construction of a ranging system based on the time-of-flight principle. The intention was to prove the feasibility of remote profile measurement, even though at present the costs are prohibitive for mass-market automotive use.

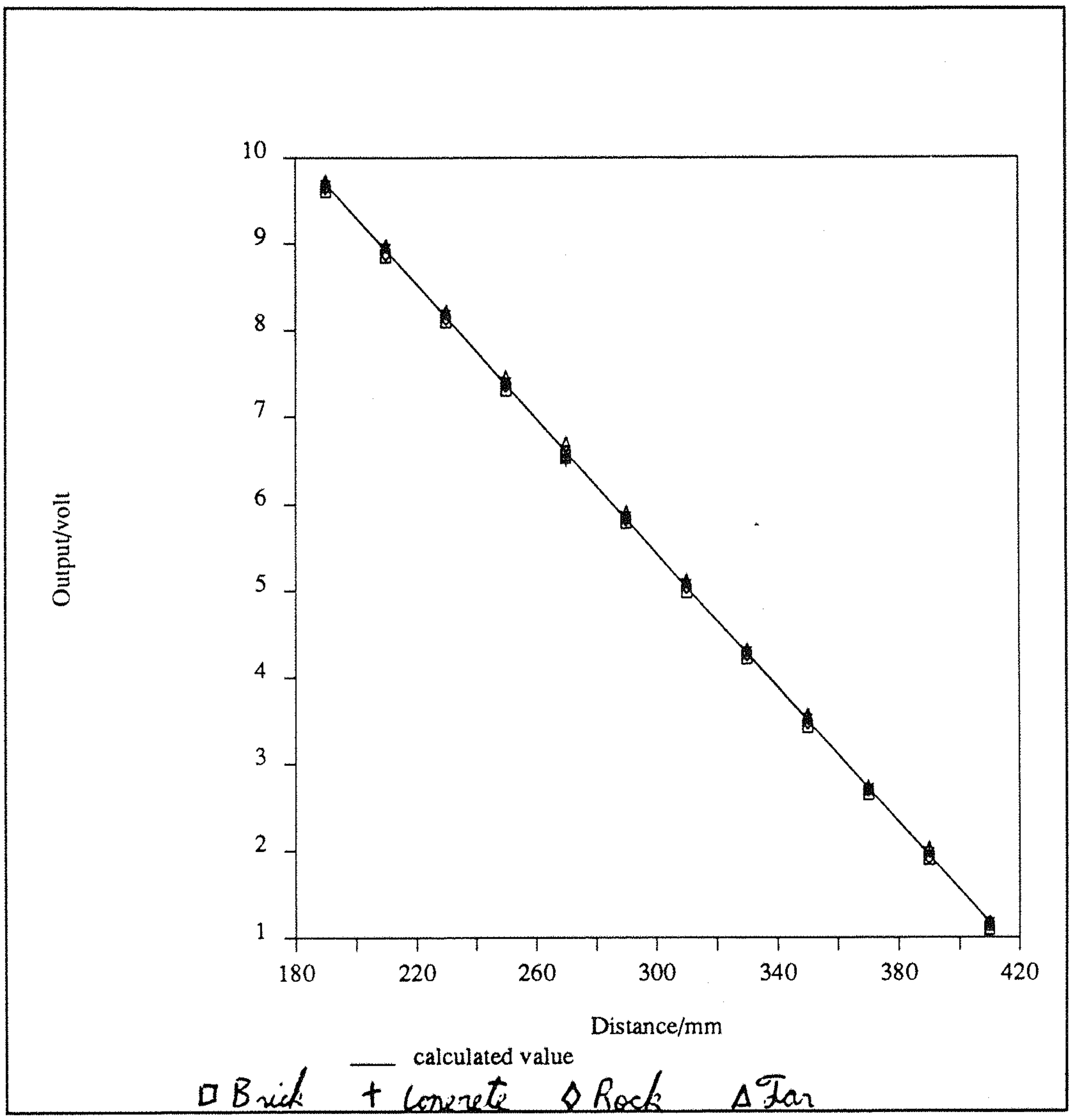


Fig 6.1 Plot of the test on Optocator

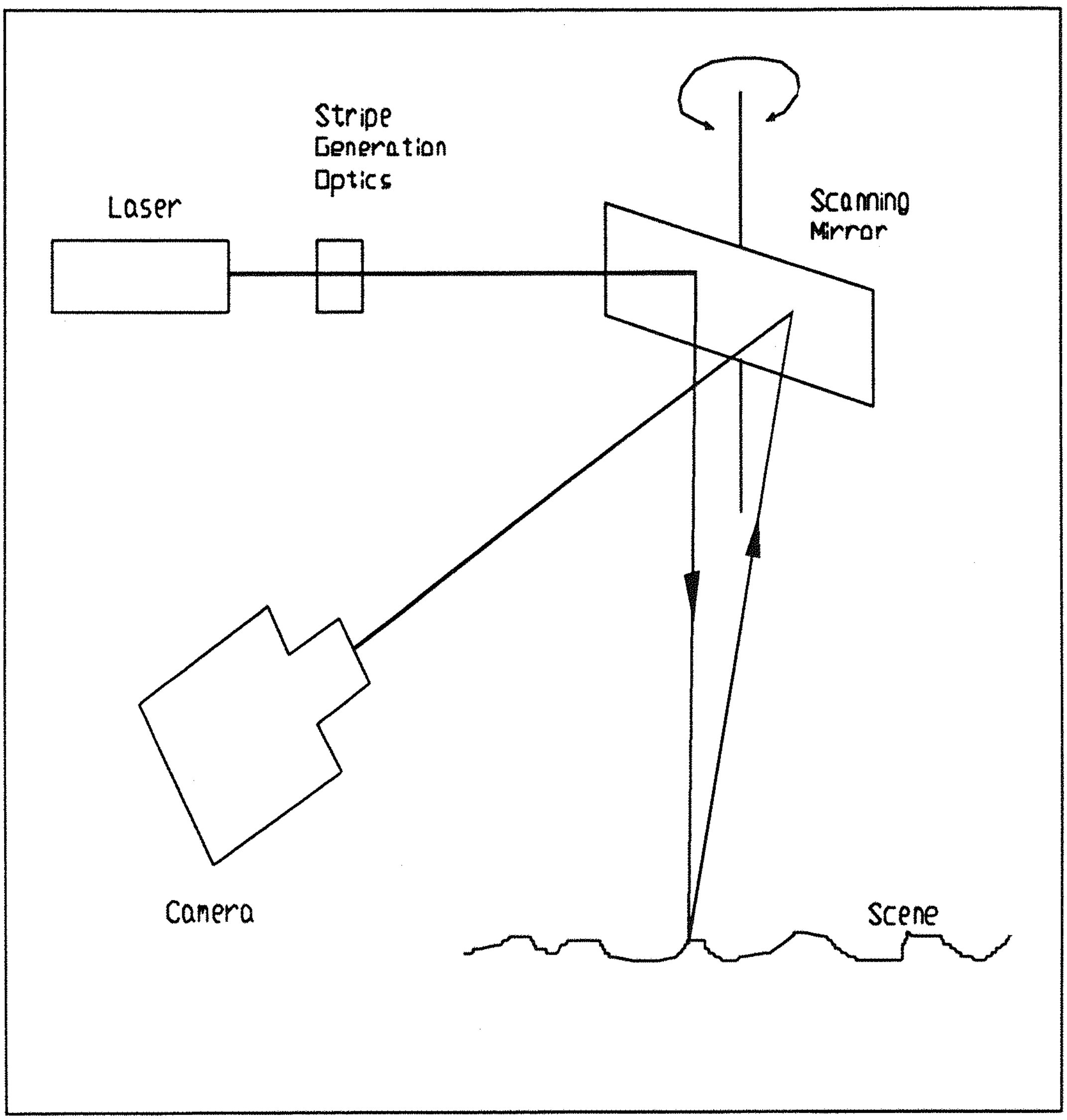


Fig 6.2 Simplified diagram of the STRIPE profile system

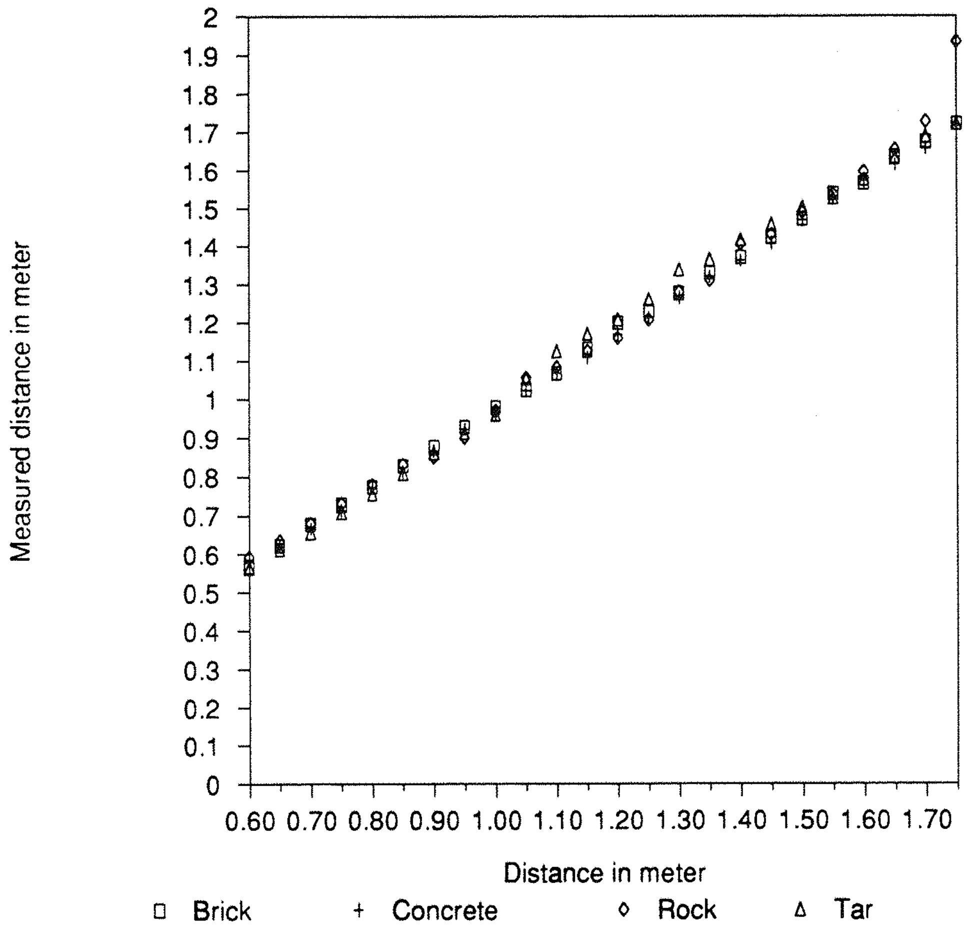


Fig 6.3 Measurement on IBEO device with different materials

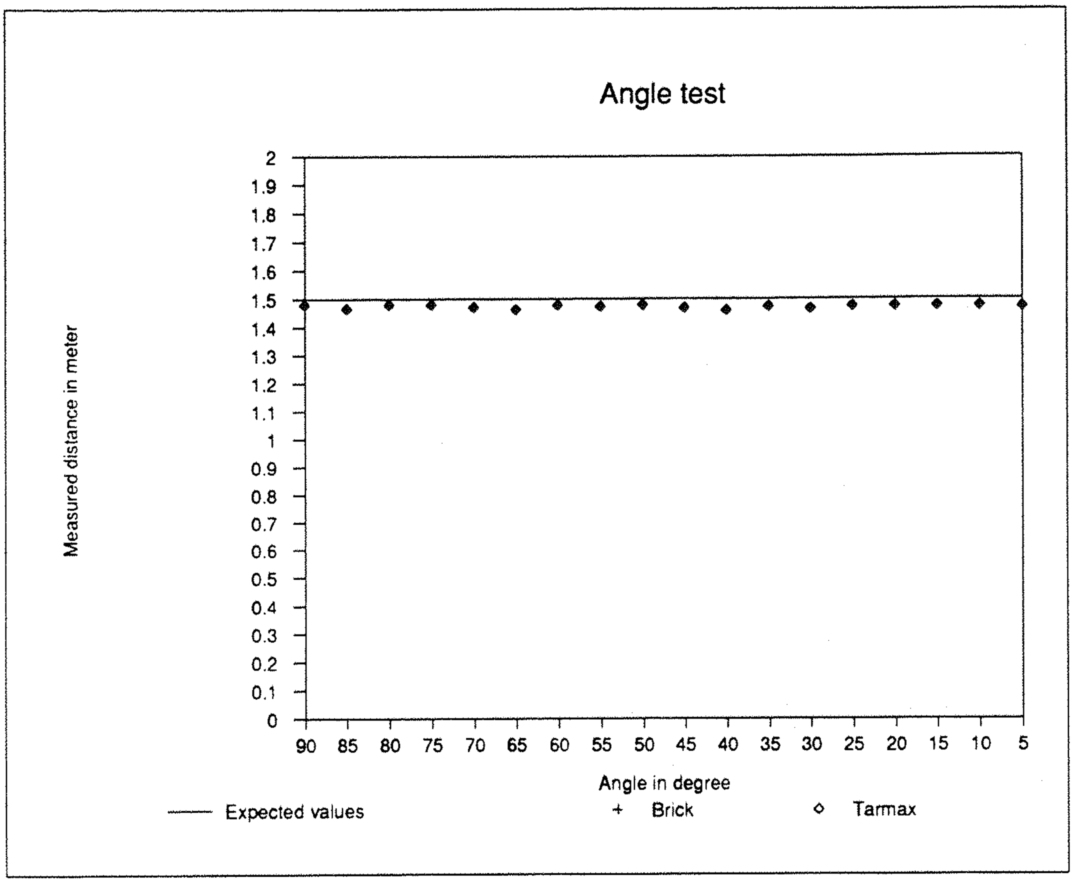


Fig 6.4 Measurement on IBEO under different incident angles

Distance meter	Brick	Concrete	Rock	Asphalt
0.60	0.5670	0.5770	0.5920	0.5640
0.65	0.6220	0.6210	0.6350	0.6130
0.70	0.6770	0.6660	0.6800	0.6560
0.75	0.7270	0.7130	0.7290	0.7090
0.80	0.7740	0.7700	0.7790	0.7540
0.85	0.8280	0.8120	0.8320	0.8090
0.90	0.8760	0.8670	0.8500	0.8620
0.95	0.9290	0.9240	0.9000	0.9140
1.00	0.9780	0.9640	0.9700	0.9630
1.05	1.0240	1.0220	1.0540	1.0530
1.10	1.0660	1.0670	1.0840	1.1250
1.15	1.1290	1.1080	1.1250	1.1710
1.20	1.1990	1.1680	1.1590	1.2080
1.25	1.2290	1.2110	1.2070	1.2600
1.30	1.2760	1.2650	1.2790	1.3390
1.35	1.3310	1.3200	1.3100	1.3660
1.40	1.3710	1.3630	1.4060	1.4170
1.45	1.4230	1.4080	1.4310	1.4570
1.50	1.4720	1.4680	1.4870	1.5020
1.55	1.5380	1.5260	1.5350	1.5260
1.60	1.5650	1.5710	1.5950	1.5750
1.65	1.6350	1.6150	1.6530	1.6330
1.70	1.6740	1.6580	1.7270	1.6890
1.75	1.7220	1.7150	1.9350	1.7220

Table 6.1 Measurement test on Optocator

Distance at : 1.5 m

Angle	Brick Measurement meter	Tarmax Measurement meter
90	1.480	1.461
85	1.466	1.453
80	1.480	1.454
75	1.479	1.464
70	1.471	1.466
65	1.462	1.462
60	1.477	1.469
55	1.473	1.454
50	1.478	1.452
45	1.468	1.451
40	1.459	1.462
35	1.473	1.490
30	1.465	1.480
25	1.474	1.460
20	1.474	1.460
15	1.474	1.490
10	1.474	1.460
5	1.470	1.440

Table 6.2 Measurement at different angles

Stat. error	Echo type	Quality mode	Timer mode 25%	50%	Surplus 100%	200%
20	Limit	3.52	3.53	3.52	3.48	3.41
	Free	3.53	3.54	3.51	3.47	3.40
10	Limit	3.20	3.22	3.16	3.03	2.81
	Free	3.31	3.23	3.17	3.04	2.82
5	Limit	2.63	2.46	2.31	2.07	1.71
	Free	2.63	2.47	2.32	2.07	1.71
3	Limit	1.45	1.26	1.12	0.91	0.66
	Free	1.45	1.27	1.12	0.91	0.66

Table 6.3 Sampling rate on sigle measurement mode

Stat. error	Echo type	Quality mode	Timer mode Surplus 25%	50%	100%	200%
20	Limit	n/a	n/a	n/a	76.47	51.27
	Free	n/a	n/a	n/a	76.47	51.27
10	Limit	38.56	30.90	25.82	19.40	12.95
	Free	38.64	30.95	25.82	19.38	12.95
5	Limit	9.72	7.78	6.49	4.87	3.25
	Free	9.73	7.78	6.49	4.87	3.25
3	Limit	2.44	1.95	1.62	1.22	0.81
	Free	2.44	1.95	1.62	1.22	0.81

n/a - not available due to manufacturer design fault

Table 6.4 Sampling rate on continuous mode

Plate 2 The Optocator

7.The demonstration road profile sensing system developed at Southampton

7.1.Systemconfiguration

The Southampton profiling system consists of a 1m high trolley with shelves 0.4, 0.7 and 1m above the floor. These enable the rangefinder to be fixed at different heights. The rangefinder is fixed to a sloping platform so that the angle between the beam and the surface over which the trolley is travelling can be varied. A shaft encoder is fitted to one of the wheels of the trolley. This generates a sequence of square pulses which indicate the distance travelled. These pulses are used to provide an interrupt signal to the computer and initiate a range measurement. An interface circuit has been built to connect the shaft encoder output to the computer. A circuit diagram of this interface is given in appendix A. The interface circuit allows the user to select the required measurement interval by specifying the distance to be travelled between range measurements. The circuit also allows the user to specify which interrupt on the AT expansion bus is to be used, to avoid conflict with other devices installed in the machine.

7.2.The profile measuring experiments

A number of experiments were carried out in which the profile sensor on its trolley was pushed across various obstacles of differing shape. The purpose of these tests was to investigate the behaviour of the profile measuring system when operating at different angles within the range from 10 to 50 degrees to the horizontal. The rangefinder was mounted 0.4m above the floor. This was necessary since the room in which the tests were undertaken was of limited size, and a greater height would have given an unacceptably large lookahead distance. The shaft encoder interface was set up to initiate a measurement every 5.25mm. The rangefinder operating mode chosen was "continuous, quality and echo free, with 10mm standard deviation". A full description of the various operating modes provided by the IBEO rangefinder is given in appendix C.

Figure 7.1 shown the set up of the experiments. Figures 7.2, 7.3 and 7.4 show the dimensions of the obstacles used.They were made from cardboard for ease of manufacture, since preliminary trials indicated that the nature of the surface did not affect the results (see 6.3.1.6). Figures 7.5 to 7.31 show the measured profiles obtained.

The data from the rangefinder was first checked for errors manually. It was noted that occasionally characters were missed during serial data transmission from the rangefinder to the data collecting computer. These errors appeared to occur randomly, at the rate of about one every 50 measurements. These errors were easily eliminated by a simple smoothing process. When a measured value was markedly different from both its predecessor and the subsequent reading, it was replaced by a value equivalent to the mean of the neighbouring readings.

Once the error checks and any necessary corrections had been made the data was imported into a spreadsheet program. Each measured value was multiplied by the sine of the angle between the laser beam and the horizontal. This is because the measured range is inclined at an angle to the floor, whereas what is required is the vertical height of an obstacle.

The next data processing step is to establish a zero point for the measured profile. This is done by subtracting the constant measured range (obtained when the beam is traversing a level floor) from each measurement. The complete data processing procedure can be expressed as:

Result = [range x sinθ] [minimum value of (range x sinθ)](1)
Where θ is the angle to the horizontal

One source of error in the equation above is due to the determination of the angle. From figures 7.4 to 7.15 it can be seen that the measured profiles are fairly close to the actual profile as long as the incident angle of the measuring beam is greater than about 30 degrees. The height of each obstacle is accurately measured as long as θ exceeds 30 degrees. For shallower angles the errors in height measurement increase, and may be unacceptable. This effect can be explained by noting that the sine function is not linear, and that therefore when θ is small any uncertainty in θ may lead to large errors in height estimation.

At shallow angles the profile of each obstacle becomes blurred (see figures 7.19 to 7.30). This is partly because decreasing the angle increases the lookahead distance, and the likelihood of stray reflections from objects around the laboratory increases. In addition using a small angle causes discontinuous results since a shadow region behind the obstacle is created.

From these experiments it has been shown that it is not practical to measure the profile of the road ahead of a vehicle with any accuracy at angles less than about 30 degrees to the horizontal. At shallow angles too much information is lost because of shadowing effects. However, the information obtained from range measurements made at shallow angles is sufficient to determine the type of surface over which the vehicle is moving, even if an exact profile measurement is not possible. Such a system might be useful for controlling a modeswitching suspension system.

It must also be borne in mind that a car is not a stable platform and that range measurements may be being made while the vehicle undergoes pitching or rolling motion. Sensors such as tilt meters will in any case be necessary to compensate the rangefinder data. If a shallow angle is used for the range measurment, these vehicle attitude sensors will have to be highly accurate and have a fast response since as already noted, small errors in determining can cause large errors in range determination. Thus, using a shallow angle to obtain a longer lookahead distance will not only result in erroneous results but may actually increase the cost of the complete system. The automotive manufacturer must specify more completely than at present exactly what is required from a road profile sensor before the best compromise between lookahead distance and accuracy can be achieved.

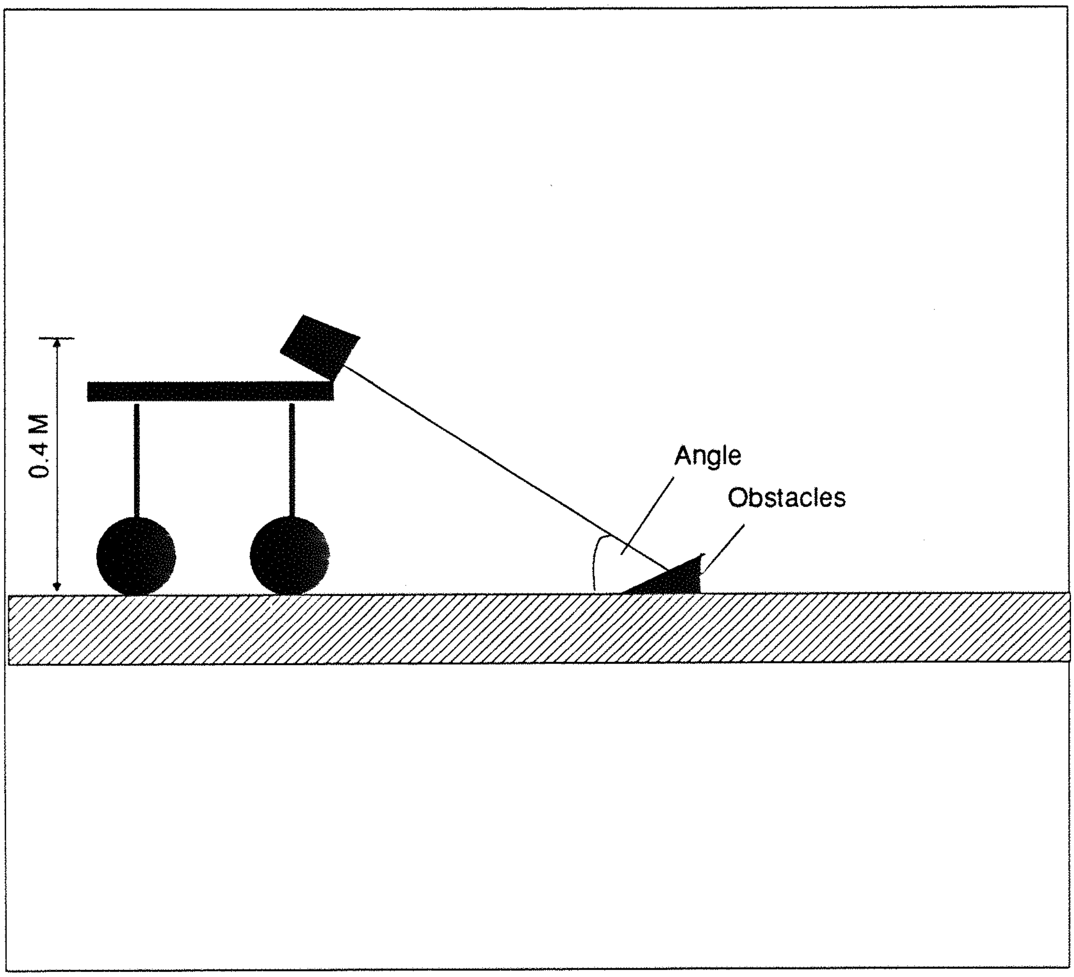


Fig 7.1 Arrangement of the profile measuring experiments

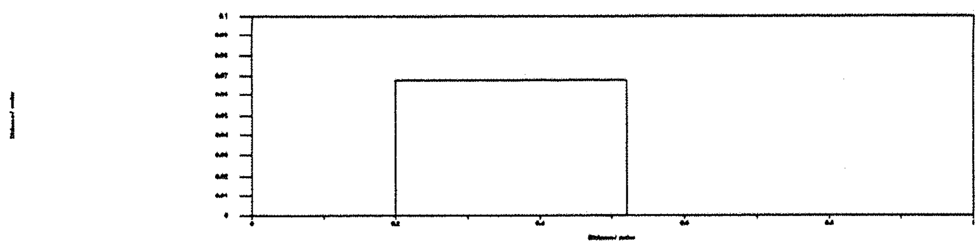


Fig 7-2 Dimension of the box used in the experiments

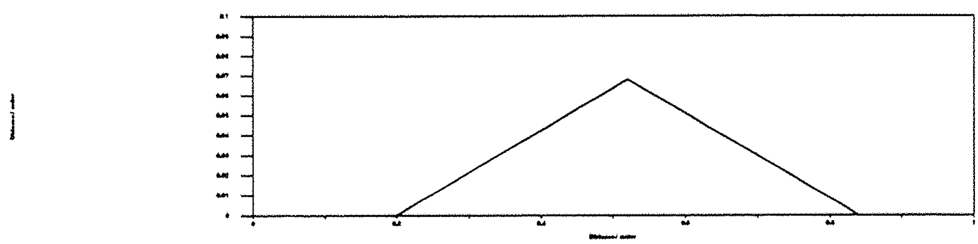


Fig 7-3 Dimension of the ramp used in the experiments

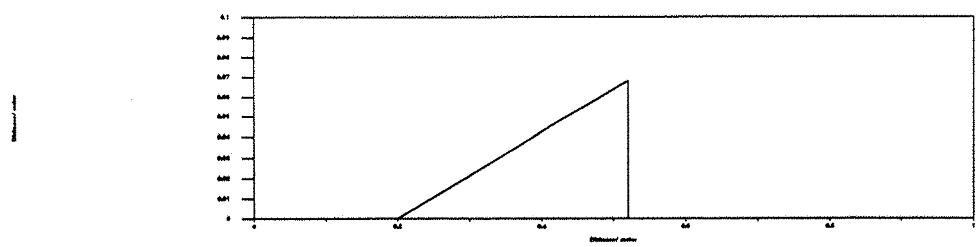


Fig 7-4 Dimension of the wedge used in the experiments

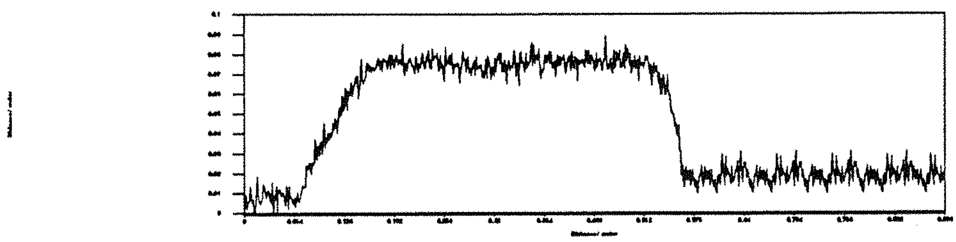


Fig 7-5 Measured profile of the box at 50 degress

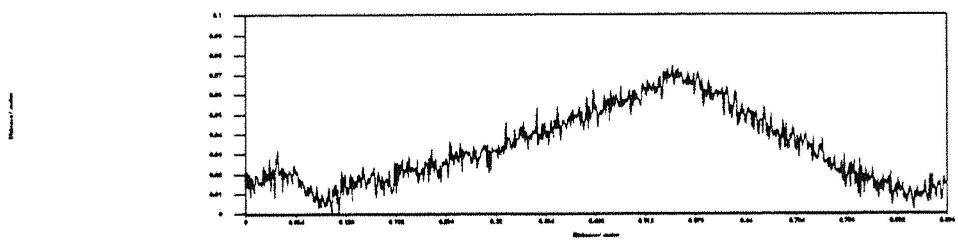


Fig 7-6 Measured profile of the ramp at 50 degress

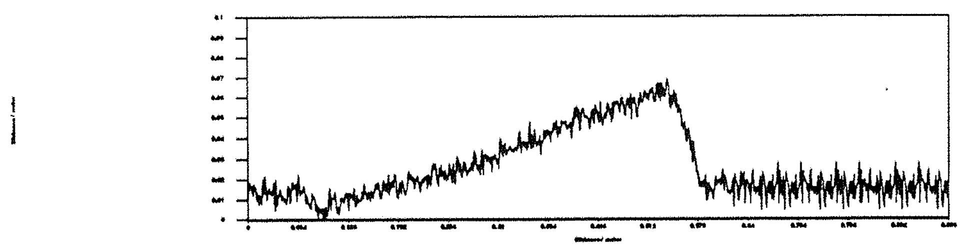


Fig 7-7 Measured profile of the wedge at 50 degress

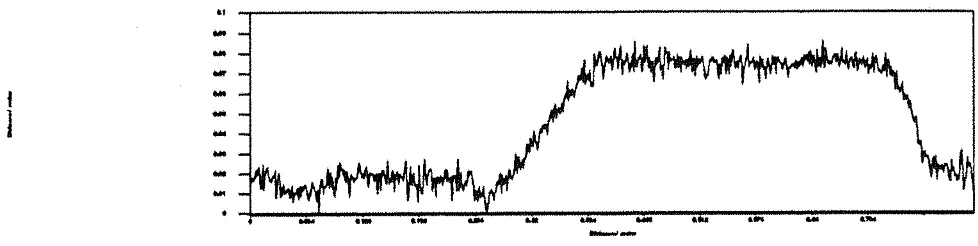


Fig 7-8 Measured profile of the box at 45 degrees

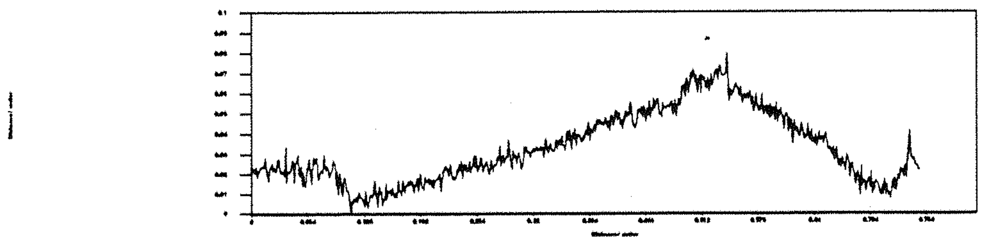
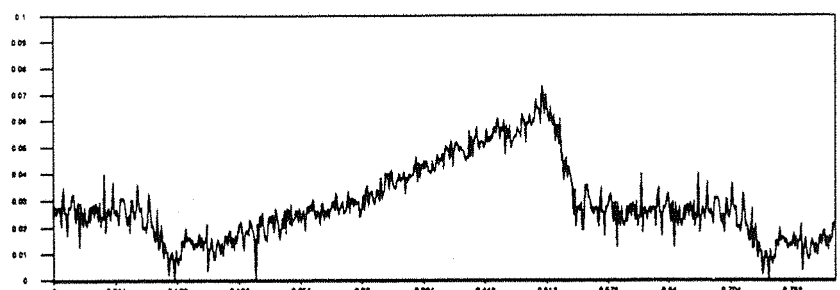


Fig 7-9 Measured profile of the ramp at 45 degrees



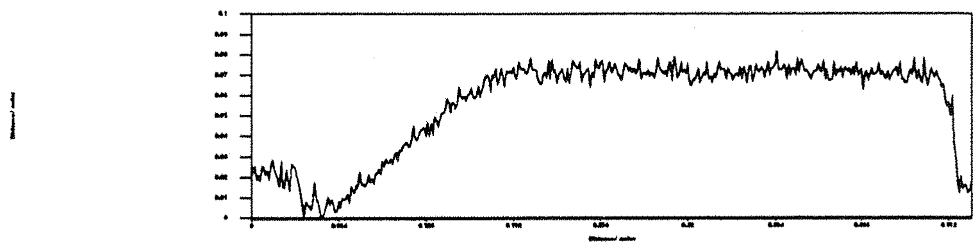


Fig 7-10 Measured profile of the box at 40 degrees

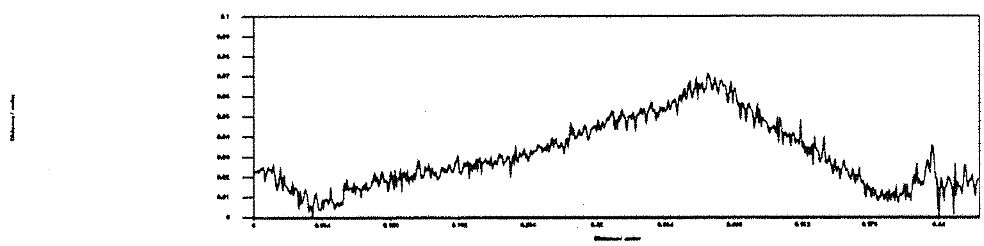


Fig 7-11 Measured profile of the ramp at 40 degrees

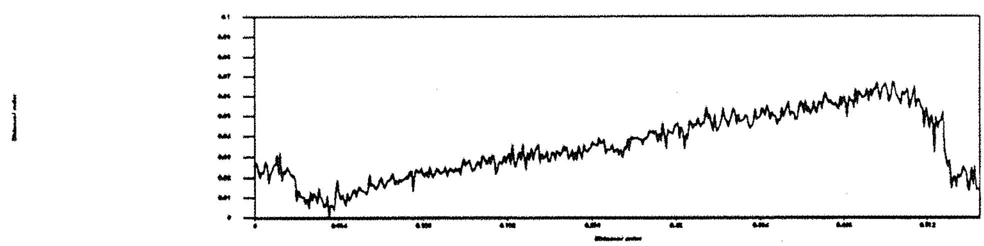


Fig 7-12 Measured profile of the wedge at 40 degrees

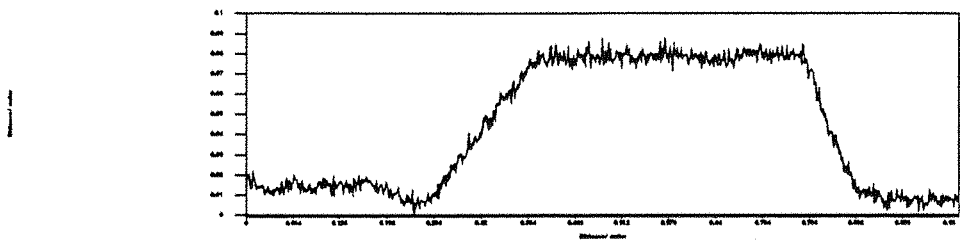


Fig 7-13 Measured profile of the box at 35 degrees

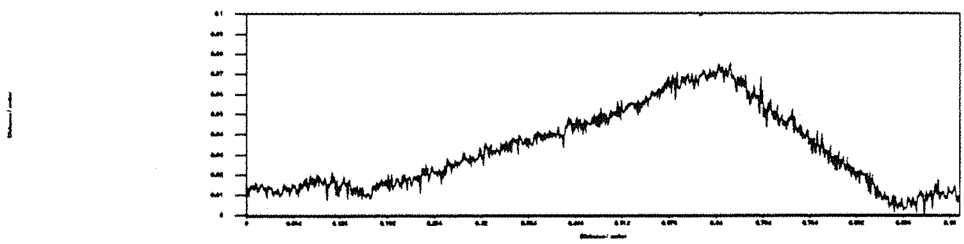


Fig 7-14 Measured profile of the ramp at 35 degrees

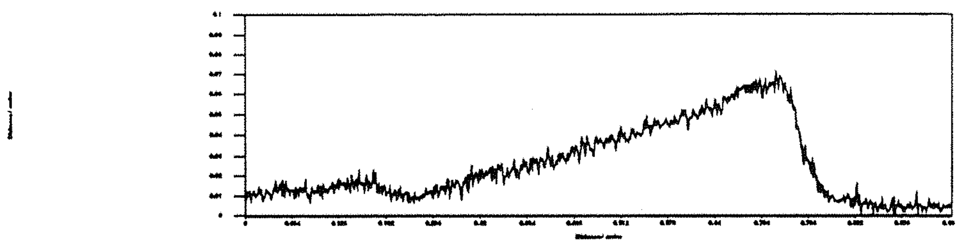


Fig 7-15 Measured profile of the wedge at 35 degrees

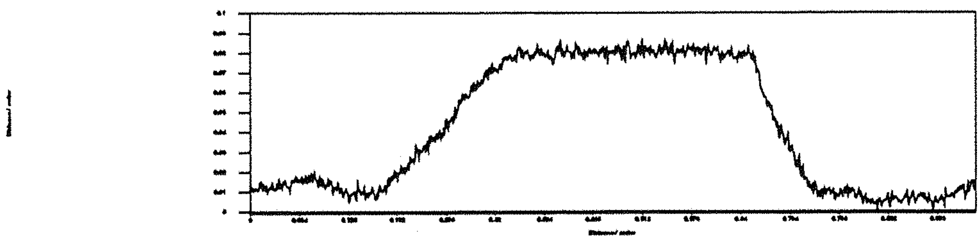


Fig 7-16 Measured profile of the box at 30 degrees

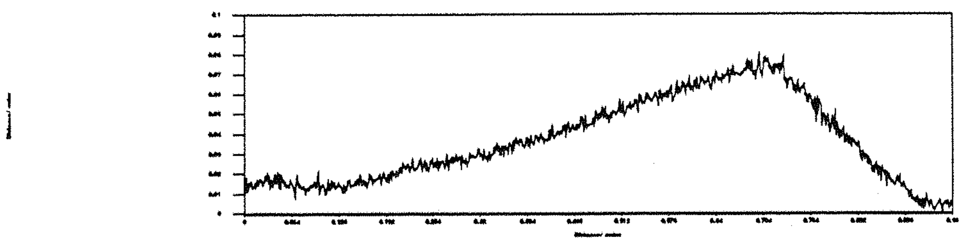


Fig 7-17 Measured profile of the ramp at 30 degrees

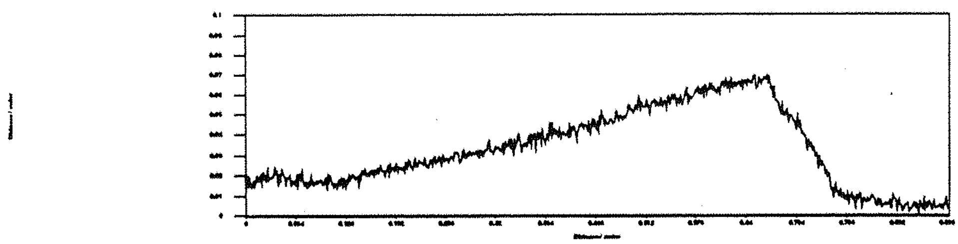


Fig 7-18 Measured profile of the wedge at 30 degrees

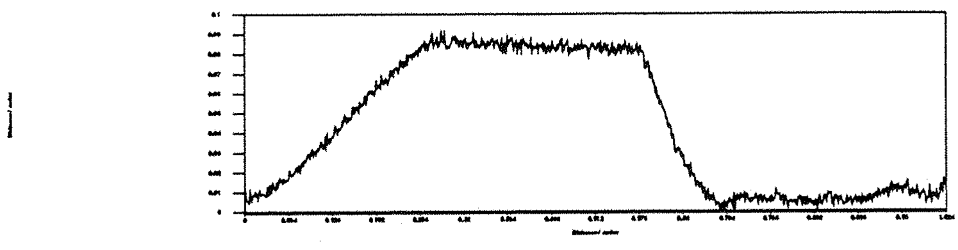


Fig 7-19 Measured profile of the box at 25 degrees

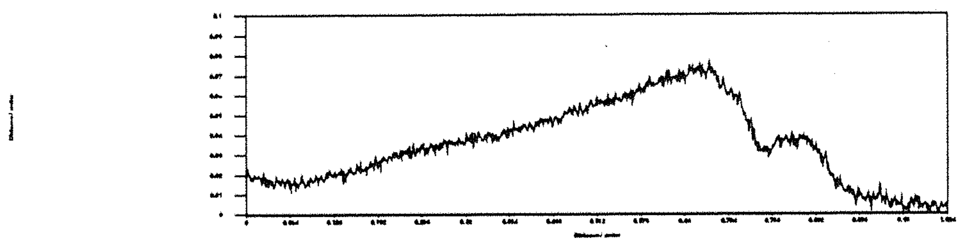


Fig 7-20 Measured profile of the ramp at 25 degrees

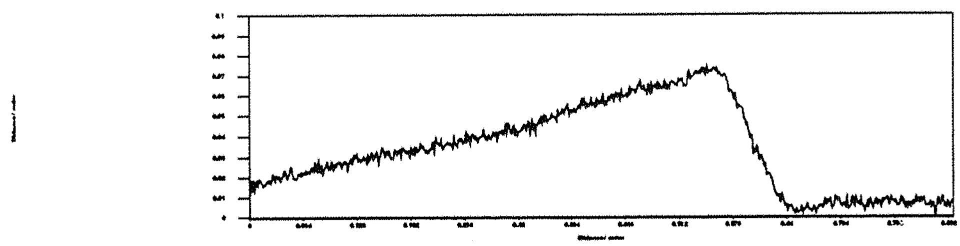


Fig 7-21 Measured profile of the wedge at 25 degrees

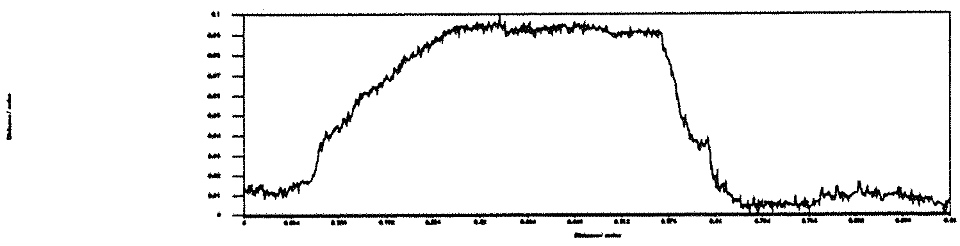


Fig 7-22 Measured profile of the box at 20 degrees

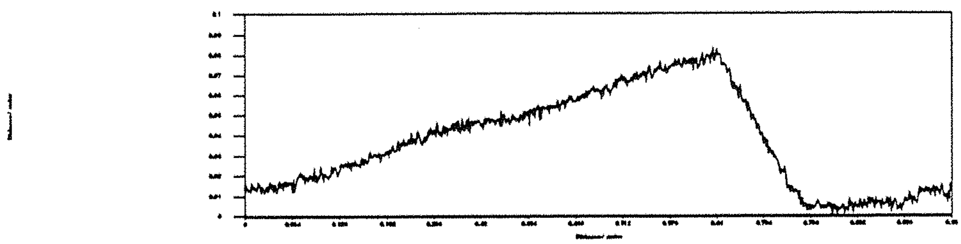


Fig 7-23 Measured profile of the ramp at 20 degrees

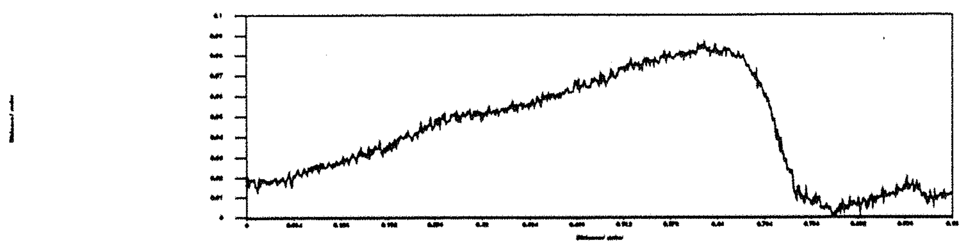


Fig 7-24 Measured profile of the wedge at 20 degrees

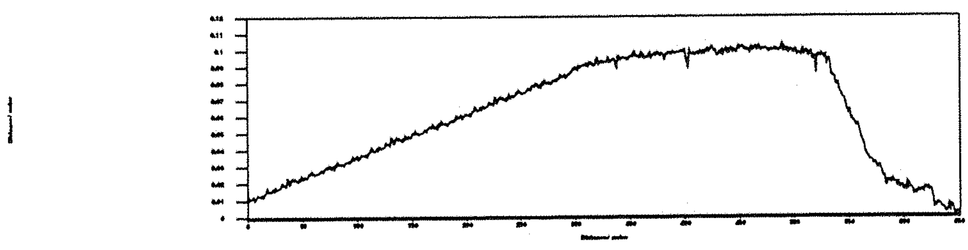


Fig 7-25 Measured profile of the box at 15 degrees

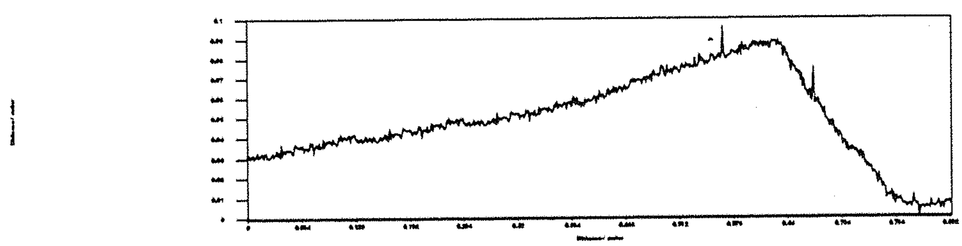


Fig 7-26 Measured profile of the ramp at 15 degrees

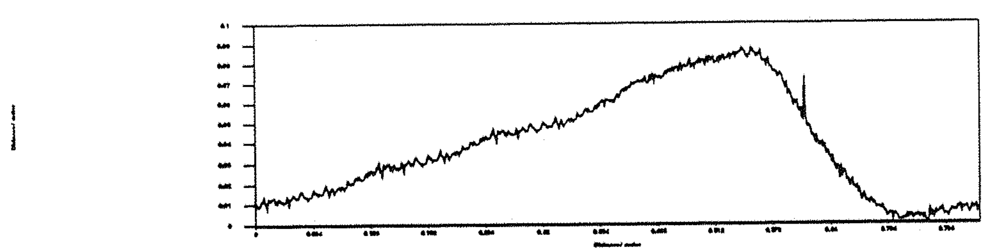


Fig 7-27 Measured profile of the wedge at 15 degrees

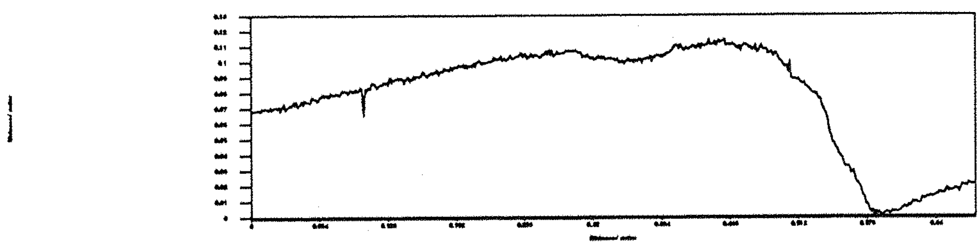


Fig 7-28 Measured profile of the box at 10 degrees

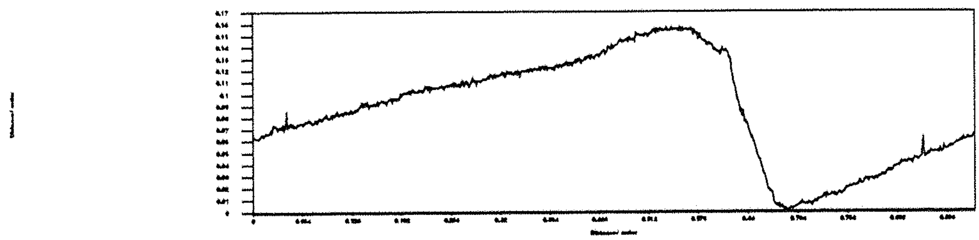


Fig 7-29 Measured profile of the ramp at 10 degrees

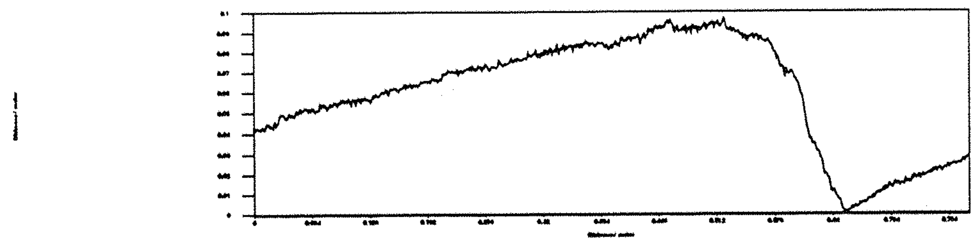


Fig 7-30 Measured profile of the wedge at 10 degrees

8.Conclusions and further work.

8.1.Conclusions

In chapter 2 it was concluded that a method of predicting the forces an active suspension is required to counter will be necessary if a significant improvement is to be achieved over the performance given by a mode switching or semi-active type. The use of an optical road profile sensor has been shown to provide a practical method of "warning" an active suspension control system of the loads it is to be required to counteract in sufficient time for the necessary adjustments to be made. However, even the use of a road profile sensor will probably only allow the construction of a low frequency (say up to 3 Hz) active suspension system. The power required for an active suspension system capable of meeting all the forces applied to the body of a vehicle is probably prohibitive.

The original specification for a road profile sensor (given in chapter 1) was drawn up by the project sponsor. The experiments described in chapter 7 have shown that this specification cannot be met by a sensor mounted within the vehicle's headlight (the location envisaged by the sponsor). This location together with a look-ahead distance of 1.5 - 2m would give an unacceptably shallow angle of incidence between the measuring beam and the road surface.

The work described in chapter 7 showed that reliable results can only be obtained for angles of 30 degrees or more. This gives a look-ahead distance of around 0.3m for a headlight-mounted sensor, which corresponds to a required reaction time of around 20 ms for the suspension (a vehicle travelling at 60km/hr covers 0.3m in 20 ms). The active suspension system currently being developed by the project sponsor has a reaction time of about 50ms. Thus, either a faster system or a higher mounting position for the sensor is required. It might be possible to put the rangefinder on the roof of the vehicle, or to mount it alongside the rear view mirror in such a way that it operates through the windscreen. However, the length of the vehicle bonnet may mean that neither of these options give any improvement in the operating angle. The best solution is undoubtedly to reduce the reaction time of the suspension system. Discussions with the project sponsor indicates that this is probably feasible.

From the work on ultrasound described in chapter 5 it was concluded that it is not feasible to use an ultrasonic rangefinder as part of an active suspension system. There are several reasons for this. First, the speed of sound places a limit on the repetition rate that can be achieved. This means that true profile measurement is impossible at vehicle speeds in excess of about 20 mph. However, it may be possible to use an ultrasonic system to give an indication of surface unevenness inn the form of an "r.m.s. roughness". Second, the scattered ultrasound from some surfaces may be too weak to be detected.

Ultrasonic rangefinders may be useful however as attitude sensors, which are necessary to correct the rangefinder data for vehicle pitching and rolling motion. The frequencies of vehicle body motion are well within the range that may be measured by an ultrasonic rangefinder.

Ultrasonic rangefinders may have other automotive applications, for example as obstacle detectors in low-speed manoeuvres such as parking.

In chapter 6 two optical rangefinding systems were evaluated. Both use a laser light source, but they operate on different principles. One system (the Pulsar) uses triangulation and a continuously operating laser. The other (IBEO) system uses a pulsed laser and a time-of-flight approach. The Pulsar system requires a high-powered laser, which is not eye-safe, but uses low-cost signal processing electronics. The IBEO system is much more expensive since very high speed electronics are required, but it uses a pulsed laser which is eye-safe. Both systems were shown to be capable of meeting the requirements of this project, but in view of the intended application it was decided that safety was of overriding importance and the IBEO system was purchased.

Both laser systems were capable of operating at shallow angles, down to 10 or 15 degrees. However, as discussed in chapter 7 it was found to be impossible to reconstruct the road profile from measurements at such shallow angles. An angle of at least 30 degrees is necessary if exact profile measurement is required. However, the information obtained from range measurements made at shallow angles is sufficient to determine the type of surface over which the vehicle is moving, even if an exact profile measurement is not possible. Such a system might be useful for controlling a mode-switching suspension system.

The physical size of the two optical systems used was too great for automotive use in an unmodified form. It would be difficult to reduce the size of the Pulsar system since the triangulation approach necessarily requires a long baseline for measurement. However, the IBEO system could fairly easily be made smaller.

The IBEO system was much more expensive than the Pulsar device. However, it was used because of the overriding importance of safety. It seems likely that, in line with other electronic and optical products such as CD players, the price of electro/optical systems will fall in the future. Thus, although the use of a laser rangefinder as part of an active suspension system is probably ruled out on economic grounds today, it may well become feasible in the future. In addition there must be scope for reducing the cost of a time-of-flight system such as that supplied by IBEO by mass production. The IBEO system is hand-built to customer order, and the price reflects this. If the automotive industry were to construct tens of thousands of such systems annually, the unit cost would be bound to fall dramatically.

The laptop computer used for testing the IBEO profile measuring system was capable of accepting range measurements over a serial link at a maximum repetition rate of 120 Hz. This is much lower than the sample rate of 1kHz required by a vehicle moving at 70 mph (see chapter 1). However, a transputer interface card is available as an option from IBEO which will permit operation at data rates in excess of 1000 measurements per second. If further development of the optical profile sensor developed at Southampton is envisaged, a transputer interface card should be purchased.

8.2.Further work required.

This study has confirmed that a road profile measuring system can be constructed using a laser rangefinder as its primary sensor. The IBEO device is a suitable candidate for further development. The major improvement required is to reduce the cost of the system.

Secondary sensors to measure the vehicle attitude will be necessary. These could take the form of two or more ultrasonic height sensors, or alternatively conventional tilt sensors.

Powerful real-time computer processing of the measured data is required. As discussed earlier in this chapter, to achieve the repetition rate required it will be necessary to use a transputer card such as the one available from IBEO. This is currently an expensive item, but once again it is likely that the costs of computing power will fall. The essence of this project has been to demonstrate the feasibility of using a laser rangefinder to control an active suspension system. It has clearly been shown that this is feasible. The fact that the costs today (1990) preclude the commercial application of the work should not be taken as meaning that this will always be so.

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S-581 01 Linköping

Sweden

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Transducer Technology

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Selcom

Selective Electronic Co AB

Box250S-43325

Partille 1

Sweden

28 Ultrasound Ranging System

Polaroid Corporation

Commerical / Battery Division

575 Technology Square - 3

Cambridge

Massachusetts 02139 (617) 577 - 4681

USA

29 Back scanner
Matsushita Communication Industrial Co., Ltd
Nissan Trading Co., LTD,
15 - 5 Ginza, 7 - Chime,
Chuo - Ku
Tokyo 104
Japan
Tel (03) 545-2355
Telex 2525023 NITCO J

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Motonolu Matsuda
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Catalog 1986 Edition
Telefunken Electronic
Theresienstrasse2
PO Box 1109
D-7100 Heilbronn
Tel (07131) 67 - 0
Telex 728746 TFKD

47 Appication of Precision Position Sensitive Photodetectors
Lars Lindholm
Sitek Electro-Optics
PO Box 261 S-433 25 Partille
Sweden
Tel (031) 440670
Telex 858865 TESAFI G

48 Laser Altimeter
Thorn EMI Electronics
Defence Systems Division
Victoria Road, Feltham
Middlesex
TW13 7DZ
Tel 01-890 3600 Telex 24325

49 Turbo Pascal Numerical Methods Toolbox

Borland International INC

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Polariod Corporation

Commercial / Battery Division

575 Technology Square - 3

Cambridge

Massachusetts02139

USA

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Selcom

Selective Electronic Co AB

Box250S-43325

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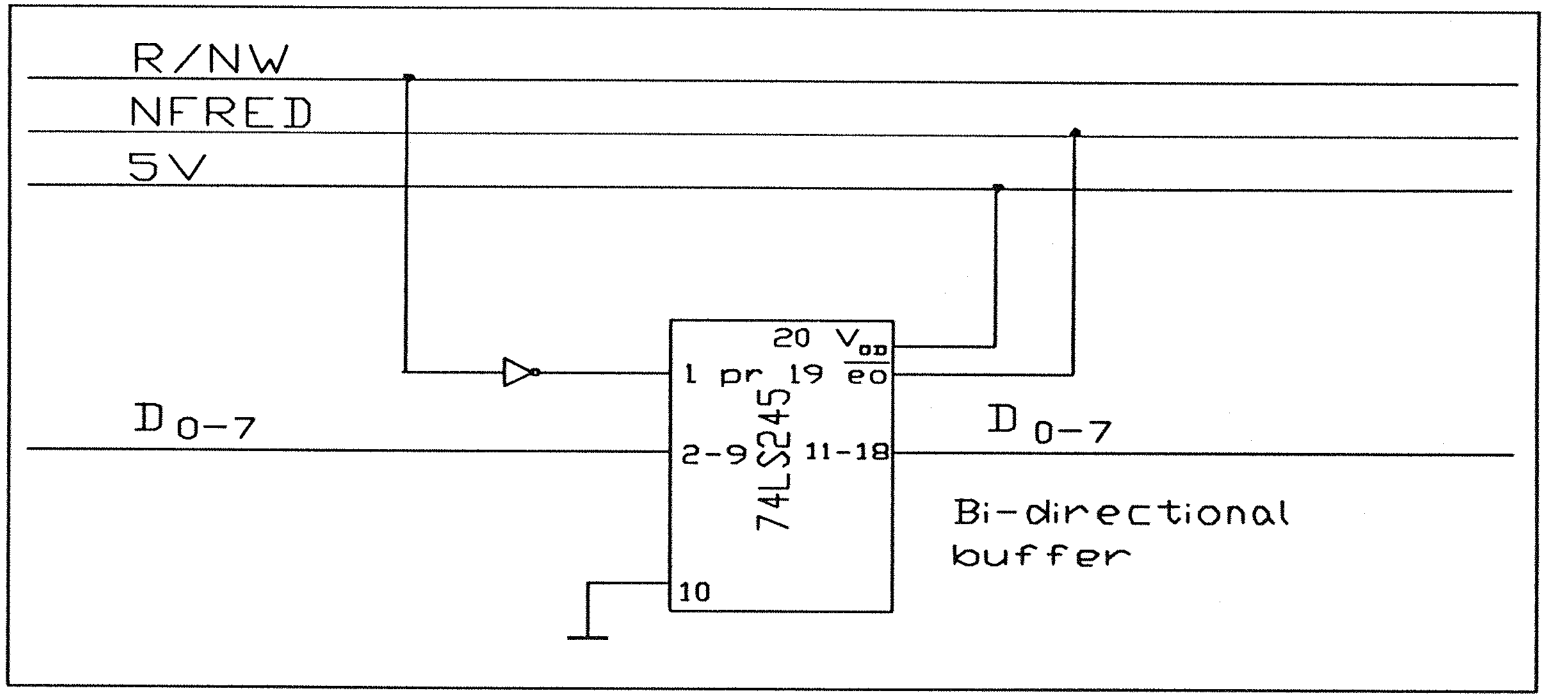
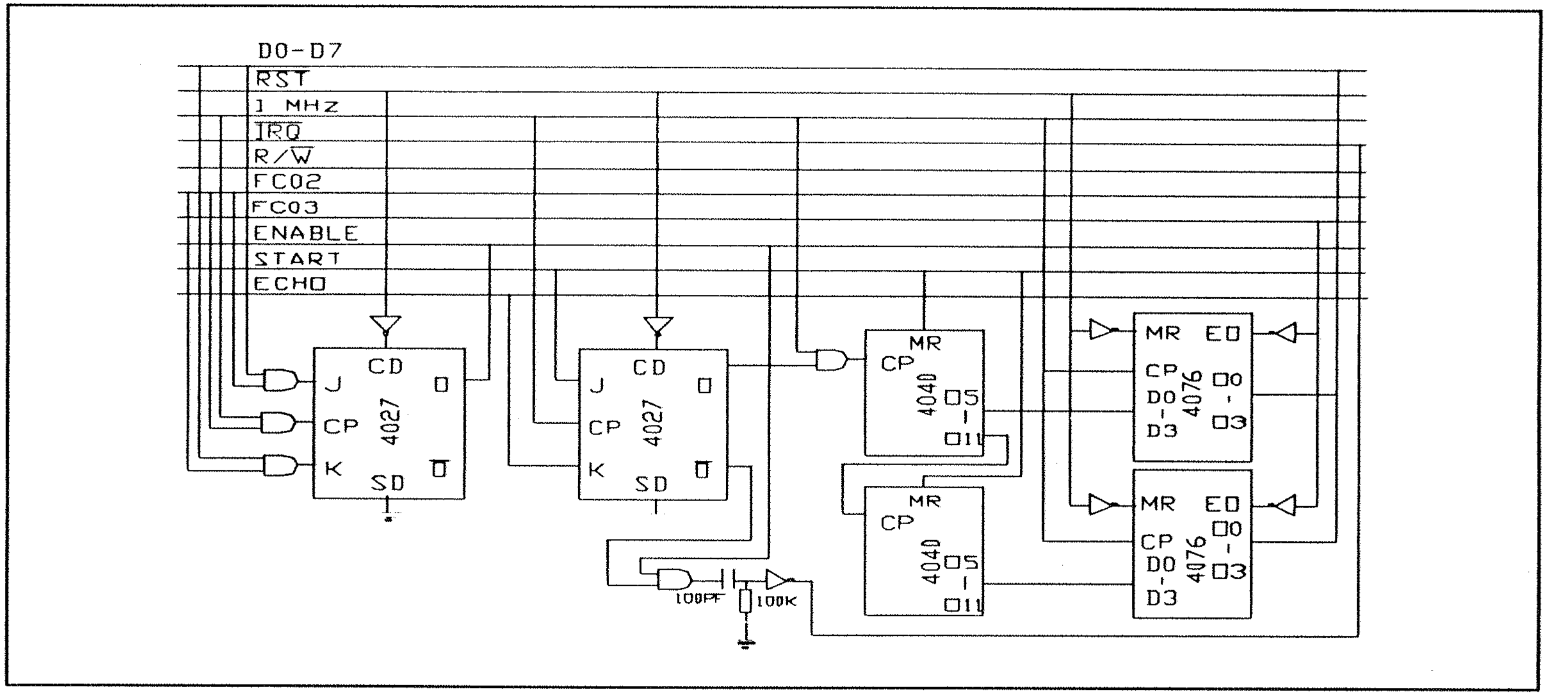
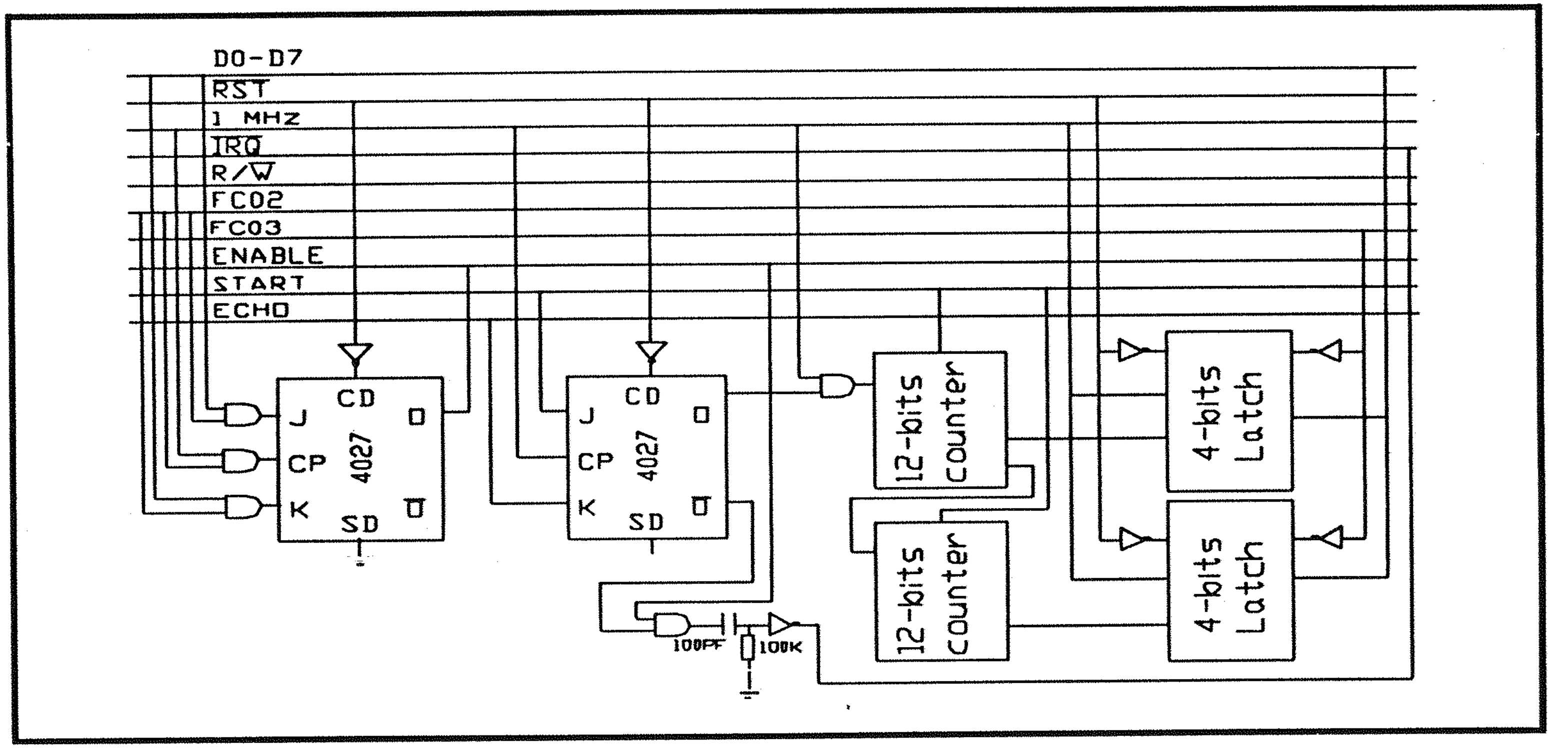
Appendix A
Circuit diagrams



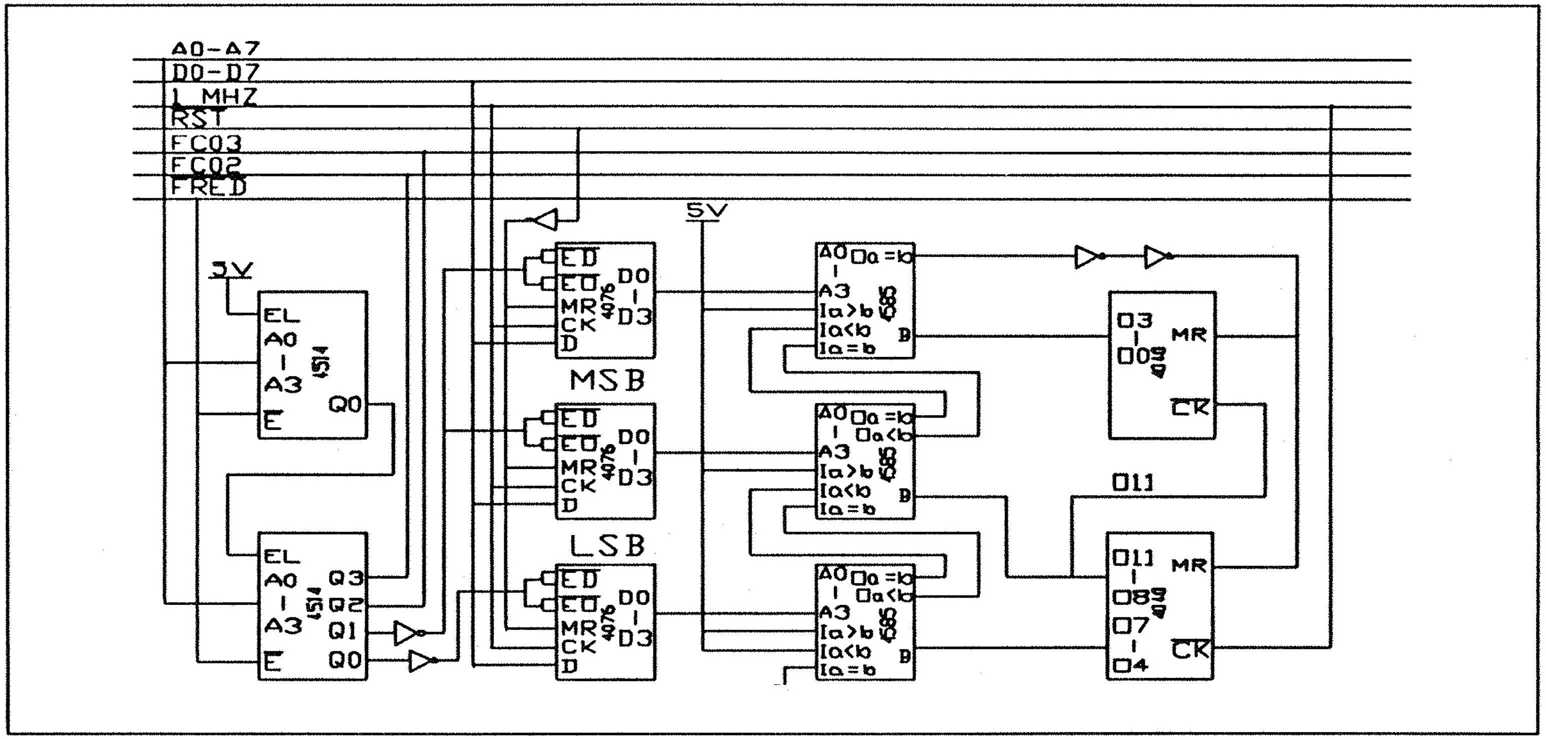
Interface circuit for between the BBC 1MHz bus and the rack of the Southampton ranging system



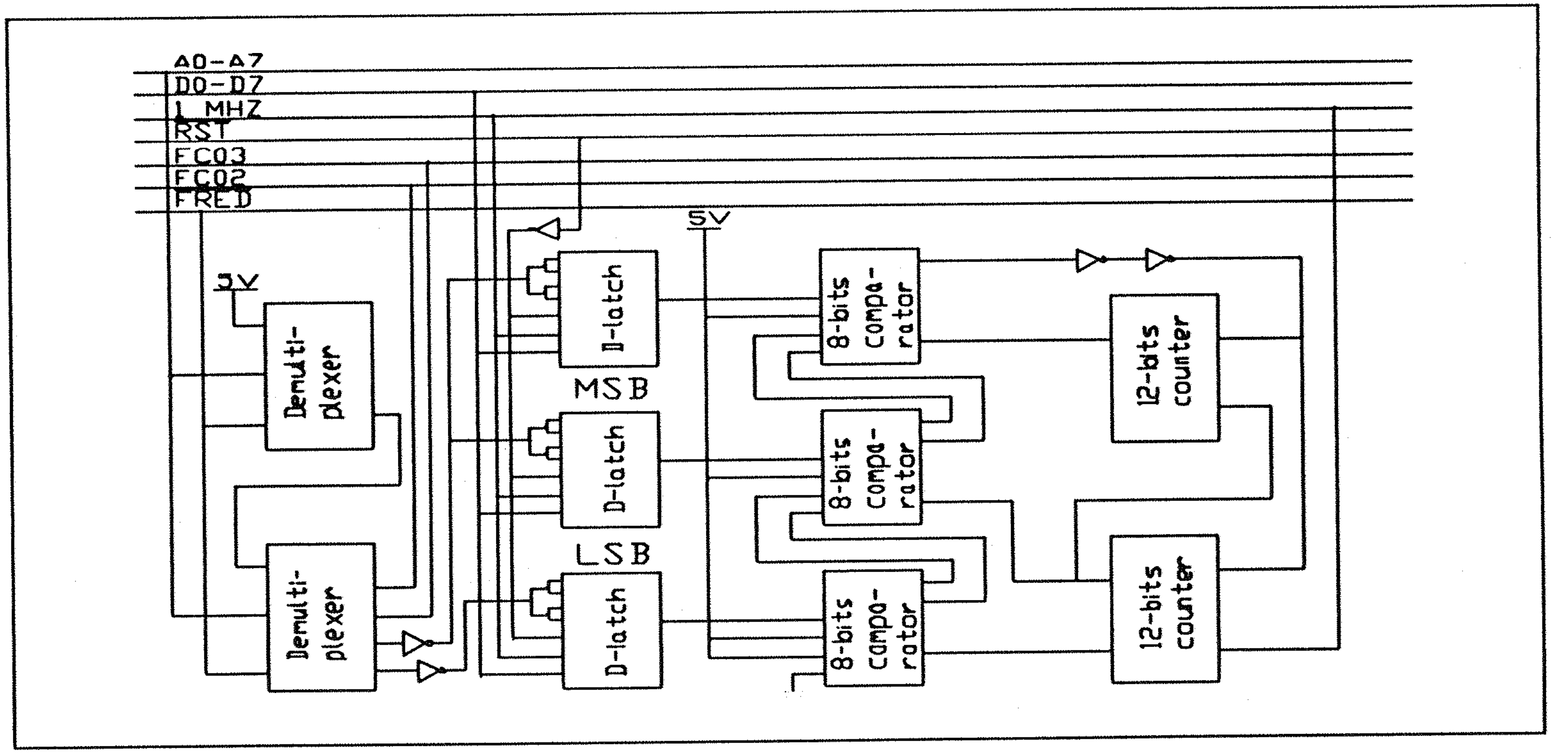
The pluse generating circuit



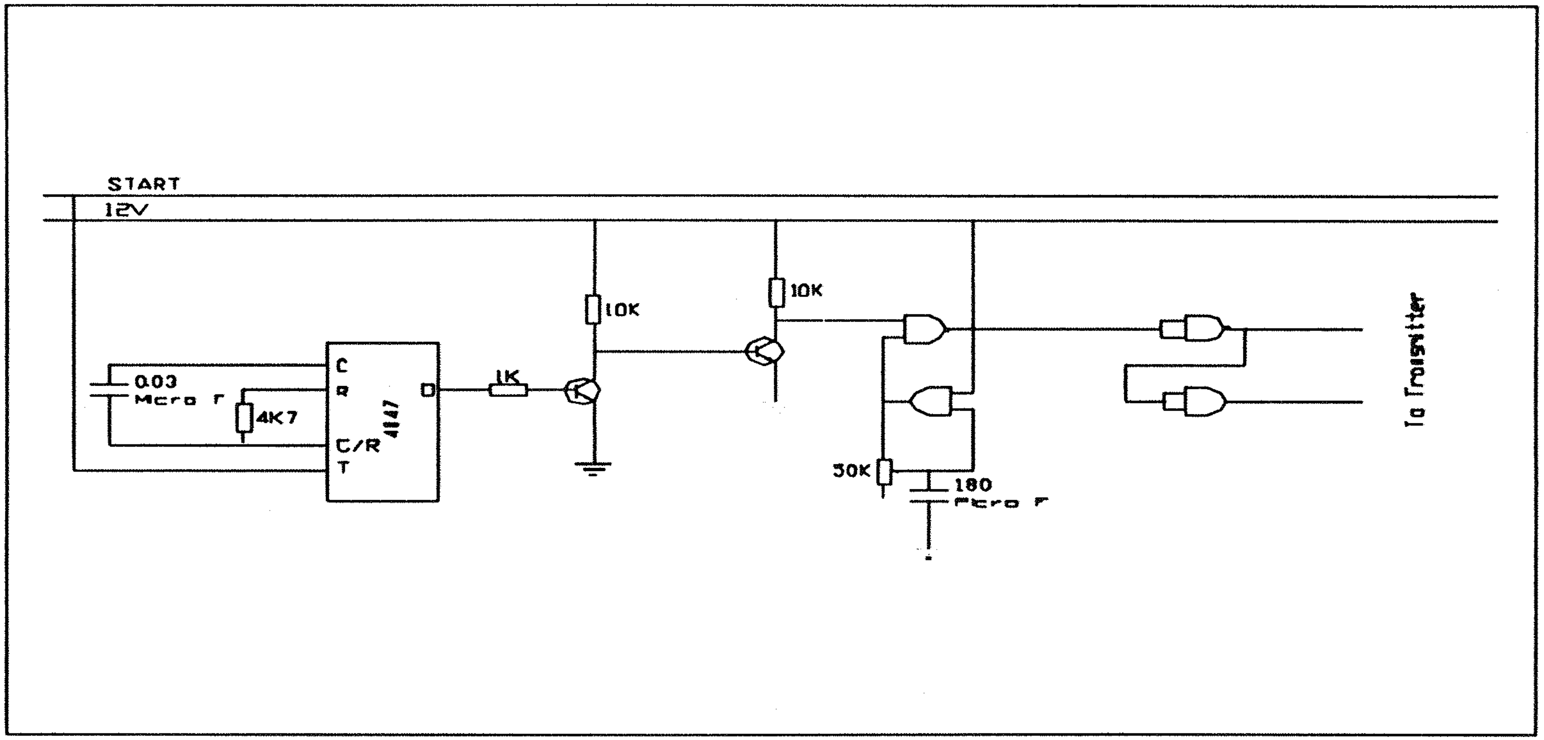
Block diagram of the pluse genseaing circuit



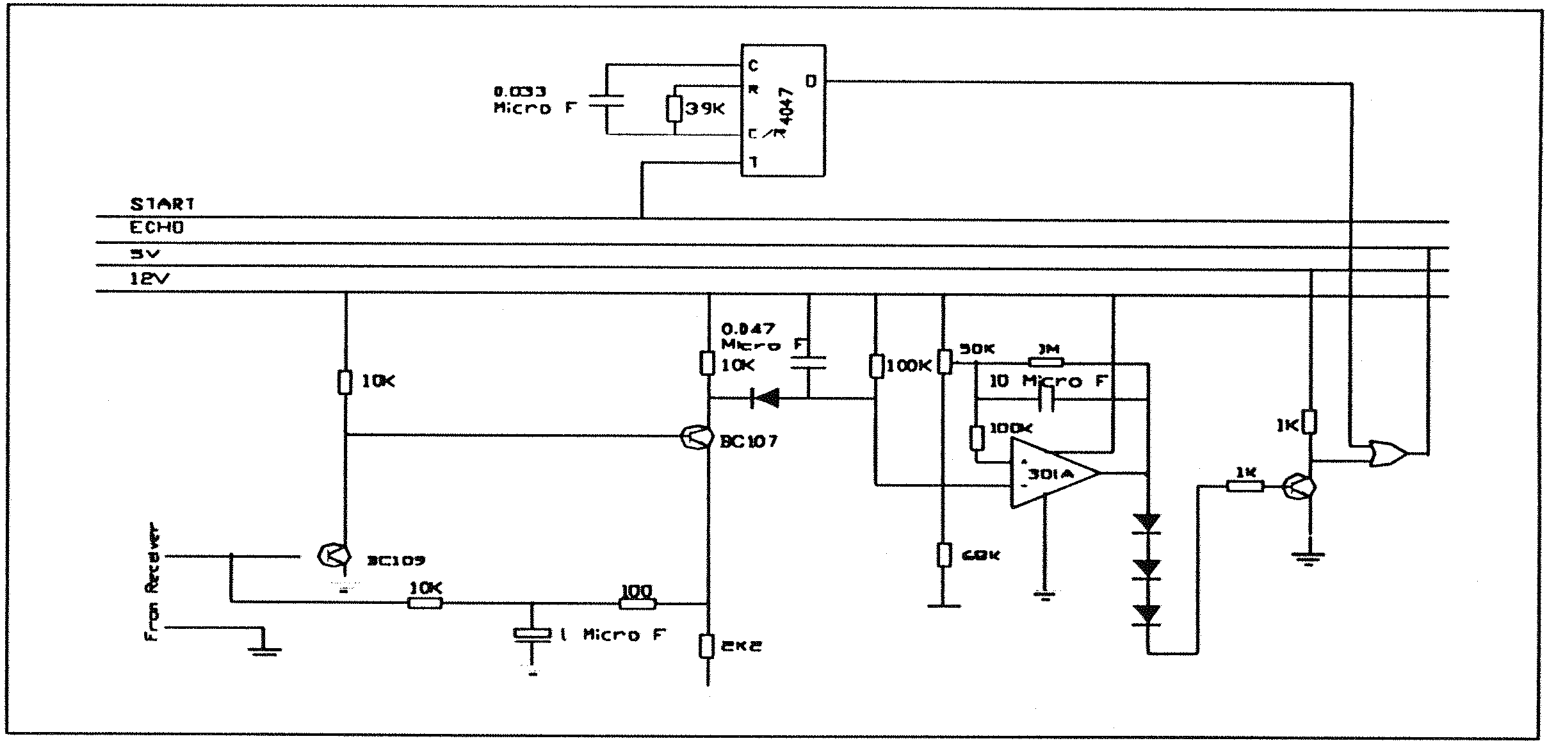
The timing circuit for measuring the echo time



Block diagram of the timing circuit



The circuit to drive the ultrasonic transmitter

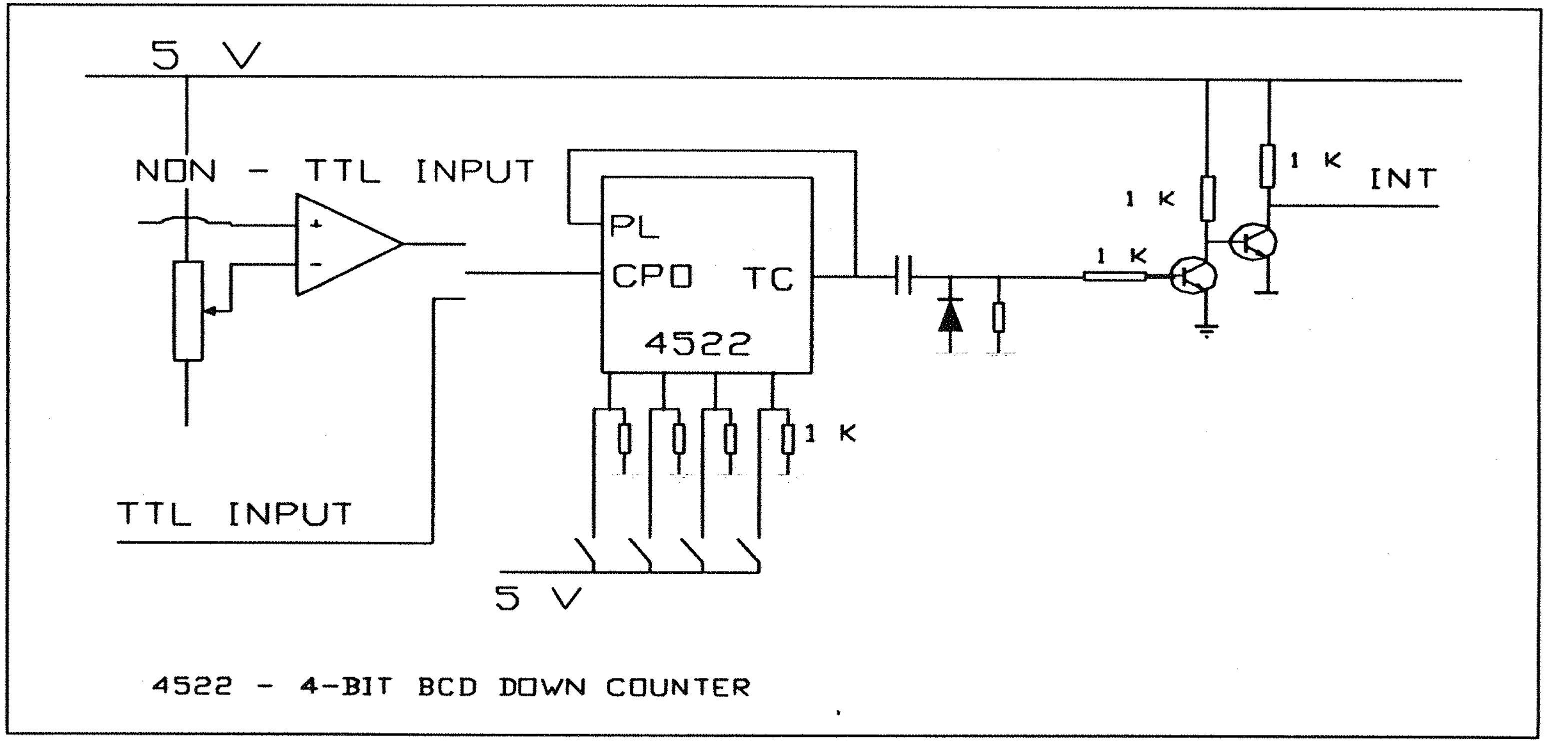


The circuit to handle the received signal from the ultrasonic receiver

Pin number	Useage	Pin number	Useage	Pin number	Useage
1	-5V	2	12V	3	0V
4	A0	5	A1	6	A2
7	A3	8	A4	9	A5
10	A6	11	A7	12	D0
13	D1	14	D2	15	D3
16	D4	17	D5	18	D6
19	D7	20	R/NW	21	1 MHZ
22	NIRQ	23	NPFRED	24	RST
25	FC02	26	FC03	27	
28	START	29	ENABLE	30	ECHO
31	12V	32	5V		

Pin difiniton of the sub rack back panel connector

definition



Interface between the shift encoder and the lap top computer

Outline of the circuit boards

The Southampton ultrasonic rangefinder consists of five circuit boards which plug into the back panel of the sub-rack.

The card interfacing the BBC 1MHz bus and the rack consists of a 74LS245 bi-directional buffer. This buffer chip provides buffering protection for the data bus of the 1MHz bus. Other signal lines in the 1MHz bus are already buffered, therefore they do not require such protection.

The pulse generation card consists of three D-latches, three 8-bit comparators, two 12-bit counters and two demultiplexers. The function of the card is to generate the pulses required to initiate the measurement in a preset period and provide address decoding facilities for the 1MHz bus. The D-latches hold the reading which is equal to the number of system clock cycles between the pulses to be generated. The comparators compare this value with the output of the counters. When the values are the same, the comparators will reset the counters and generate the pulse which signifies the beginning of the measurement.

The timing circuit consists of two JK flip-flops, two 12-bit counters and two 4-bit latches. The function of the circuit is to measure the traveling time of the echo and to generate the interrupt request. One JK flip-flop is used to generate the enable signal of the rangefinder which signals that the BBC computer is properly setup and ready to receive an interrupt from the rangefinder. The other JK flip-flop is used to generate the interrupt request by pulling the NIRQ signal line of the BBC 1MHz bus. The counter chips are used to measure the travel time of the echo and the 4-bit latches are used to hold the value until it is read by the BBC computer.

The board containing the circuit to drive the ultrasound transmitter consists of an astable, two transistors and a 4 x two input schmitt trigger nand gate ic. The function of the circuit is to generate 16 cycles of 40 KHz 12 V peak-to-peak oscillation. The astable generates a pulse with time width equal to 16 cycles of 40 KHz when the START signal is received by the circuit. The transistors together with the resistors form a TTL circuit to convert the 5 V pulse to a 12 V pulse. The schmitt trigger nand gates are arranged to form an oscillator of 40 KHz. The frequency of the oscillation can be changed by adjusting the 50 Kohm potential divider.

The circuit board which handles the received signal from the ultrasonic receiver consists of an astable, an operational amplifier and some discrete components. The astable is used to generate the masking signal to stop the circuit triggering due to the pick up of unwanted multiple reflections by the casing of the rangefinder. The operational amplifier is arranged into a level detector and the signal level which it will trigger off the ECHO signal is set by the 50 Kohm potential divider. The rest of the circuit consists of a standard transistor amplifier and a low pass filter.

Appendix B
Programme listing

```
10 DIM OLDV 1
20 DIM R 0                                    : REM Reserve memory for R
30 DIM FULL 1                                 : REM Indicator of data buffer
40 DIM ST_DATA 0                              : REM Semaphore to store data
50 DIM FINISH 0                               : REM Finish sampling
60 SIZE = 1                                   : REM Number of Kbyte
70 DIM RE SIZE*&400                           : REM Reserve memory to store samples
80 DIM CODE% 500                              : REM Reserve memory for machine code
90
100                              REM Set up parameters
110
120 OSBYTE    = &FFF4
130 OSWORD    = &FFF1
140 COUNTER   = &FC03
150 H_INT     = &FC03
160 IRQ2V     = &206
170 EVENT     = &220
180 WRFRED    = &93
190 D_POINTER = &70                         : REM User zero page address
200 ?FULL     = 0
210 ?ST_DATA  = 0
220 ?FINISH   = 0
230 ?R        = 0
240
250 FOR I = 0 TO 3 STEP 3
260 P% = CODE%
270 [
280           OPT I                        \ Assembler option
290
300           \ Initiation rountine
310
320           \ Initialise rountine for testing
330
340 .INIT_T   LDX £TEST AND &FF            \ Load registers with address
350           LDY £TEST DIV &100
360           SEI                          \ Disable interrupts
370           LDA IRQ2V
380           STA OLDV
390           LDA IRQ2V + 1
400           STA OLDV  + 1
410           STX IRQ2V
420           STY IRQ2V + 1
430           CLI                          \ Enable interrupt
440           RTS                          \ Return from Init
450
460           \ Initialise rountine for sampling
470
480 .INIT_F   LDX £FILE AND &FF
490           LDY £FILE DIV &100
500           SEI
510           STX IRQ2V
520           STY IRQ2V + 1
530           LDA £RE AND &FF              \ Calcuate the boundary of the buffer
540           STA FULL
550           LDA £SIZE * &4
560           ADC £RE DIV &100
570           STA FULL + 1
580           JSR RESET_P
590           CLI
600           RTS
610
```

```
620             \ The monitor rountine
630
635
640 .MONITOR    LDA ST_DATA
650             CMP £1
660             BNE MONITOR
670             RTS
680
690             \ Keyboard event handler
700
710 .KEYBD      LDA £1
720             STA ST_DATA
730             STA FINISH
740             RTS
750
760             \ Interrupt rountine fnr testing
770
780 .TEST       LDA &FC                 \ Save registers
790             PHA
800             PHP
810             PHA
820             TXA
830             PHA
840             TYA
850             PHA
860
870             LDA COUNTER             \ Load reading from counter
880             STA R                   \ Store the reading into R
900
910 .EX         PLA                     \ Restore registers
920             TAY                     \ and return from handler
930             PLA
940             TAX
950             PLA
960             PLP
970             PLA
980             STA &FC
990       RTS
1000            JMP OLDV               \ Jump to old rountine
1010
1020            \ Interrupt handler for sampling
1030
1040 .FILE      LDA &FC                 \ Save registers
1050            PHA
1060            PHP
1070            PHA
1080            TXA
1090            PHA
1100            TYA
1110            PHA
1120
1130            LDA COUNTER             \ Load reading from counter
1140            LDX £0
1150            STA (D_POINTER,X)       \ Store data to address
1160                                    \ pointed by D_POINTER
1170            LDA FULL                \ Compare the lower byte
1180            CMP D_POINTER
1190            BEQ HI_BYTE
1200
```

```
1210 .CONT      LDA D_POINTER
1220            CLC
1230            ADC £1
1240            STA D_POINTER          \ D_POINTER = D_POINTER + 1
1250            BCS PG_FULL            \ Jump to subrountine PG_FULL
1260                                   \ if the current page is full
1270            JMP EX
1280
1290            \ Subrountine HI_BYTE
1300
1310 .HI_BYTE   LDA FULL + 1            \ Compare the high byte
1320            CMP D_POINTER + 1
1330            BEQ BF_FULL
1340            JMP CONT
1350
1360            \ Subrountine PG_FULL
1370
1380 .PG_FULL   LDX D_POINTER + 1      \ Increment the page pointer
1390            INX
1400            STX D_POINTER + 1
1410            JMP EX
1420
1430            \ Subrountine BF_FULL
1440
1450 .BF_FULL   LDA £0
1460            STA H_INT
1470            LDA £1
1480            STA ST_DATA
1490            JMP EX
1500
1510            \ Subrountine reset_pointer
1520
1530 .RESET_P   LDX £RE AND &FF
1540            LDY £RE DIV &100
1550            STX D_POINTER
1560            STY D_POINTER + 1
1570            RTS
1580
1590 ]
1600 NEXT I
1610 REM========================MAIN BODY=================================
1620
1630                          REM Set up the sampling frequency
1640                          REM and set up sampling mode
1650 CLS
1660 PRINT TAB(1,10);"LOWEST SAMPLING FREQUENCY IS 16 HZ"
1670 PRINT TAB(1,8);"Input sampling frequency in Hz : ";
1680 INPUT FREQ%
1690
1700 EXIT = FALSE
1710 REPEAT
1720  PRINT TAB(1,12);"Test mode (T) or Filing mode (F) : ";
1730  INPUT MO$
1740  IF (MO$ = "T") OR (MO$ = "t") THEN EXIT = TRUE : REM CALL INIT_T
1750  IF (MO$ = "F") OR (MO$ = "f") THEN EXIT = TRUE : CALL INIT_F
1760  IF NOT EXIT THEN VDU 7 : PRINT TAB(1,14);"INVAILD OPTION";TAB(36,12);
1770 UNTIL EXIT
1780 CLS
1790
```

```
1800 A% = WRFRED                         : REM Write number of cycles
1810 X% = 0                              : REM into the pluse generation circuit
1820 Y% = ((1/FREQ%)*1E6) MOD &100 : REM Least significant byte
1830 CALL OSBYTE
1840 A% = WRFRED
1850 X% = 1
1860 Y% = ((1/FREQ%)*1E6) DIV &100 : REM Most significant byte
1870 CALL OSBYTE
1880
1890                                   REM Run the chosen sampling mode
1900 IF (MO$ = "T") OR (MO$ = "t") THEN PROCTEST
1910 IF (MO$ = "F") OR (MO$ = "f") THEN PROCFILE
1920
1930 CLS
1940 END
1950
1960 REM***********************************************************************
1970                                  REM PROCTEST
1980
1990 DEF PROCTEST
2000
2010 PRINT TAB(1,10);"PRESS SPACE BAR TO STOP"
2020 PRINT TAB(1,12);"READING : ";
2030
2040 A% = &E7
2050 X% = &FF
2060 Y% = 0
2070 CALL OSBYTE
2080
2090 REM PROC_ENABLE_H_IRQ
2100
2110 REPEAT
2120
2130  CALL TEST
2140  IF ?R <   10 THEN PRINT TAB(11,12);"00";?R;
2150  IF ?R <  100 THEN PRINT TAB(11,12);"0";?R;
2151  IF ?R >= 100 THEN PRINT TAB(11,12);?R;
2160
2170 UNTIL INKEY(-99)
2180
2190 PROC_DISABLE_H_IRQ
2200
2210 A% = &E7
2220 X% = &FF
2230 Y% = 0
2240 CALL OSBYTE
2250
2260 ENDPROC
2270
2280 REM************************************************************************
2290                                  REM PROCFILE
2300 DEF PROCFILE
2310
2320 EXIT = FALSE
2330
```

```
2340 REPEAT
2350   PRINT TAB(1,10);"INPUT DATA FILE NAME : ";
2360   INPUT FILENAME$
2370   LE = LEN(FILENAME$)
2380   IF (LE < 1) OR (LE >10)
         THEN VDU 7 : PRINT TAB(1,12) "INVAILD FILE NAME";
         ELSE EXIT = TRUE
2390 UNTIL EXIT
2400
2410 PRINT TAB(1,14);"Press any key to stop"
2420
2430 REM HANDLE% = OPENOUT (FILENAME$)  : REM Open file for output
2440
2450                  REM Set up keyboard event
2460                   : REM Flushes the current input buffer
2470 *FX21,0
2480 ?EVENT  = KEYBD  AND &FF
2490 EVENT?1 = KEYBD  DIV &100
2500 *FX14,2
2510
2520 REPEAT
2530   PROC_ENABLE_H_IRQ
2540   CALL MONITOR
2550   PROC_STORE
2560 UNTIL ?FINISH = 1
2570
2580 REM CLOSE£ HANDLE%
2590
2600 ENDPROC
2610
2620 REM**********************************************************************
2630                     REM PROC_ENABLE_H_IRQ
2640 DEF PROC_ENABLE_H_IRQ
2650
2660 A% = WRFRED
2670 X% = 2
2680 Y% = 1                      : REM Enable interrupt
2690 CALL OSBYTE
2700
2710 ENDPROC
2720
```

```
2730 REM*********************************************************************
2740                      REM PROC_DISABLE_H_IRQ
2750 DEF PROC_DISABLE_H_IRQ
2760
2770 A% = WRFRED
2780 X% = 2
2790 Y% = 2                       : REM Disable interrupt
2800 CALL OSBYTE
2810
2820 ENDPROC
2830
2840 REM*********************************************************************
2850                      REM PROC_STORE
2860 DEF PROC_STORE
2870
2880                      REM Work out start and stop addresses
2890 START = RE
2900 ST    = ?D_POINTER + (?(D_POINTER+1)*&100) - 1
2910
2920 FOR ADDRESS = START TO ST
2930 REM   BPUT£ HANDLE%,?ADDRESS
2940 NEXT ADDRESS
2950
2960 CALL RESET_P
2970
2980 ENDPROC
2990 REM***********************************************************r***
```

The logic of the main programme :

Line 1660-1680Ask the user to input the desired sample frequency.

Line 1700-1780 Ask the user to select the desired mode. The question will repeat until a valid operating mode is selected.

Line 1800-1870 Work out the sample frequency in terms of the number of system clock cycles. The OSBYTE function to output a byte to the FRED area of the memory map is used to output the values to the registers of the ranging system.

Line 1900-1910 Either one of the procedures PROCTEST or PROCFILE is called according to the chosen operating mode of the program.

Procedure PROCTEST :

PROCTEST is a procedure to output the measurement from the rangefinder to the screen continually until the space bar of the computer is pressed.

Line 2010-2020 Tell the user that the programme can be terminated by pressing the space bar and display the words "Reading : " which form the header of the output.

Line 2040-2070 The OSBYTE to enable an interrupt is called. This called enable the BBC computer to handle an interrupt.

Line 2090 Enable interrupt from the ranging system.

Line 2110-2170 Is a loop to display the reading. Zeros are padded to the left of the reading to form a three digits output at all time.

Line 2190 Disable interrupt from the ranging system.

Line 2210-2240 The OSBYTE to disable the handling of interrupt in by the BBC is called.

Procedure PROCFILE

PROCFILE is a procedure to write the value of the measurements into a file.

Line 2320-2390 The user is asked to input a file name to store the data. These lines form a loop. The only way to exit from the loop is after a valid file name is given.

Line 2430 Open the file.

Line 2470-2500 Set up the keyboard event. The procedure will terminated if any key in the keyboard is pressed.

Line 2520-2560 Is the main body of the procedure to store the data into the file. A assembler routine MONITOR is called to input the measurement from the rangefinder and the procedure PROC_STORE is called to store the data from the buffer into the disk.

Line 2580 Close the file.

Procedure PROC_ENABLE_H_IRQ

This procedure sends a byte to one of the registers of the rangefinder to enable the interrupt from the rangefinder.

Procedure PROC_DISABLE_H_IRQ

This procedure is the reverse of procedure PROC_DISABLE_H_IRQ.

Procedure PROC_STORE

This procedure stores the data in the buffer into the file.

Line 2890 Work out the start and stop address of the buffer which stores the measurement.

Line 2920-2930 Writes the data onto the file.

Line 2960 The assembler routine RESET_P is called to reset the pointer of the buffer.

Assembly routine INIT_T

This routine initialises the computer for the test mode. The routine initially loads the higher and the lower byte of the address of the test routine into the X and Y register respectively. The interrupts of the computer are disabled. The Higher and lower bytes of the content of the user interrupt vector IRQ2V are stored into the array variable OLDV.The higher and lower byte of the new vector are stored into the position of IRQ2V. Interrupt is enabled before return.

Assembly routine INIT_F

This routine initialises the computer for the filing mode. The routine initially loads the higher and the lower byte of the address of the file routine into the X and Y register respectively.The interrupts of the computer are disabled. The higher and lower byte of the new vector are stored into the position of IRQ2V. The address of the boundary of the data buffer is calculated and is stored in the array FULL. The routine RESET_P is called. Interrupts are enabled before return.

Assembly routine MONITOR

The monitor routine keeps testing the least significant bit of the variable ST_DATA. This variable is used as a flag to indicate whether we need to store data into the file.

Assembly rounine KEYBD

This is the keyboard event handler. This routine will be invoked if any key in the keyboard is pressed. The routine set the two flags ST_DATA and FINISH which are used to terminate the filing mode.

Assembly routine TEST

This is the interrupt routine for the test mode. This routine reads the count from the register of the rangefinder and stores it in the variable R

Assembly routine EX

This routine tidies up the stack of the computer before return from the interrupt routine.

Assembly routine FILE

This is the interrupt handler for the filing mode. This routine reads the count from the register of the rangefinder and stores it to the address pointed by the variable D_POINTER. The variable FULL is compared with the lower byte of the pointer D_POINTER. If they are equal, either the buffer is full or a particular page is full. If they are equal the routine HI_BYTE is called to determine the situation by looking into the higher byte of the pointer. If they are not equal, execution will automatically flow into the routine CONT.

Assembly routine CONT

This routine increases the pointer D_POINTER and in the case of an overflow the routine PG_FULL will be called.

Assembly routine HI_BYTE

This routine compare the higher byte of the pointer D_POINTER with the higher byte of the variable FULL. If they are equal, it indicates the data buffer is full and the routine BF_FULL is called. If they are not equal execution is transferred to the routine CONT.

Assembly routine PG_FULL

This routine increases the higher byte of the pointer D_POINTER.

Assembly routine BF_FULL

This routine disables the interrupt from the rangefinder and set the flag ST_DATA.

Assembly rountine RESET_P

This routine resets the pointer D_POINTER to the beginning of the data buffer.

```
/* Single.c */
/* Program to carry out measurement one at a time */

#include stdio.h
#include   .fcntlh
#include bios.h
#include conio.h
#include    c:\program\c\prolib.h

main()
{
/* variables declaration */
 int handle;
 float reading;
 unsigned char com_setting, stat_error, mode, echo_type, measurement,

               filename[20],  full_name[35]  =  "c:\\program\\c\\results\\",
              decision = 'y', vaild = 'n', space =' ';

FILE *stream;

/* Ask the user whether to open a file to store the data or not */
 clrscr();
  printf("\nDo you want to save the data in a file ? ");
 cscanf("%c",&decision);
  if (decision == 'Y') decision = 'y';
  printf("\n");

/* if the user want to save the data in a file */
 /* ask the user for that name */
  if (decision == 'y')
   while (vaild == 'n')
   {
    printf("Enter a file name for not more that 8 characters \n");
   scanf("%s",&filename);

if ( 8 = strlen(filename))
     {
     strcat(filename,".dat");
     strcat(full_name,filename);
      stream = fopen(full_name,"a");
```

```
    clrscr();
    printf("The data is going store in file : %s\n",full_name);

    if (stream == 0) printf("File cannot be open, try again !\n");

      else
       vaild = 'y';
   }

  else
    printf("\n\nInvaild file name !\n");

 }



/* Set up the rangfinder for the measurement */
 measurement = SINGLE;
 stat_error  = S10;
 mode        = QUALITY;
 echo_type   = FREE;
bioscom(1,measurement,1);
bioscom(1,stat_error,1);
 bioscom(1,mode,1);
 bioscom(1,echo_type,1);

/* Set up the screen */
 printf("\n%20cPress Esc to stop or any other key to continue \n",space);
   printf("\n\n\n\n");
 do
  { printf("\r%49c",space);
  bioscom(1,START,1);
    reading = Measure();
   printf("\r%30cReading : %9.4f",space,reading);
    if (decision == 'y') fprintf(stream,"%9.4f\n",reading);
  } while ( 27 != getch());

if (decision == 'y') fclose(stream);

}
```

Single.c

Single.c is a program to carry out distance measurement by using the lap-top computer. It enables the user to store the measurement into a file. The structure of the program is as follow :

Include the header files:
stdioio.h
fcntl.h
bios.h
conio.h
c:\program\c\prolib.h

main()
{
Declare variables.
Ask the user whether to open a file to store the data or not. The user can press the Y key on the keyboard in both upper and lower case.

If the answer is "Y" then the variable DECISION is set to lower case 'y'.
If the variable DECISION is 'y' then the following steps will carry out :
{
Ask the user to enter the file name. If the file name has less than or equal to 8 characters then the following step are carried out :
{
Add the extension ".DAT" to the file.
Add the path "c:\program\c\results\" to the file.
Try to open the file. If the file cannot be open the message "File cannot be open, try again !" will be displayed. Otherwise, the variable VAILD is set to 'y'.
}

else
The message "Invalid file name !" will be displayed.

The above process will continue until a valid file name is given.

}

Set the rangefinder up to the following mode:
SINGLE measurement
Statistical error of 3 mm

QUALITY
ECHOFREE

and the appropriate values are assigned to the variables.

The commands are sent to the rangefinder by using the function bioscom();

The screen is set up to display the reading

The program will take a measurement display it on the screen and wait for the user to press any key before the next reading is going to be taken or pressing the ESC to exit the program.

If a file is open then it is close before the program exits.

}

```
/* Freqtest.c */

#include  stdio.h
#include  fcntl.h
#include  bios.h
#include    c:\program\c\prolib.h

main()
{
 /* variables declaration */
 int handle;
 float freq, time_taken;
 long start_time, stop_time;
 unsigned char new_setting, stat_error, surp, mode, echo_type, measurement,
               decision = 'y';
 unsigned int count1, count2, count3, count4, lcount1, lcount2,lcount3,
              num_of_test = 1000;
 FILE *stream, *stream2;

/* open the file which store the previous counters values and turn it into a stream */
  stream  =  fopen("c:\program\c\results\lastcoun.dat","r");
 /* If the file dose not exist then initiate test values */
  if (stream == NULL)
   lcount1  =  lcount2  =  lcount3  =  0;

/* Otherwise read the previous values form the file */
 else
  {
  fscanf(stream,"%d,%d,%d\n",&lcount1,&lcount2,&lcount3);
  /* Close the file */
  fclose(stream);
  }

/* open the results file and turn it into a stream */
 stream = fopen("freq.dat","a");


 /* if the opening fail then do nothing other carry on with the test */
  if (stream == NULL)
printf("fail to open file\n");
```

```
else
  {
  /* Only print the heading if the file is empty */
   if (lcount1 == 0 && lcount2 == 0 && lcount3 == 0)
   {
    /* Print Heading */
    fprintf (stream,"Stat.   Echo    Quality       Timer mode Surplus\n");
    fprintf (stream,"error   type    mode    25%     50%     100%    200%\n");
   }

for (count1 = 1; count1 = 4; count1++)     /* e= 20, 10, 5 or 3 */
   {  /* count1 */
    for (count2 = 1; count2 = 2; count2++)   /* Select LIMIT or FREE */
    {  /* count2 */
     /* Print Rows label */
     if (!((count1   lcount1) ||
           (count1 == lcount1 && count2 = lcount2)
          )
        )
      { /* if */
      switch (count1)
        {/* switch 1 */
         case 1 : if (count2 == 1)
                    fprintf (stream,"e = 20 ");
                else
                    fprintf (stream,"      ");
                break;

           case 2 : if (count2 == 1)
                    fprintf (stream,"e = 10 ");
                else
                    fprintf (stream,"      ");
                break;

           case 3 : if (count2 == 1)
                    fprintf (stream,"e =  5 ");
                else
                    fprintf (stream,"      ");
                break;
```

```
      case 4 : if (count2 == 1)
               fprintf (stream,"e =  3 ");

else
               fprintf (stream,"     ");
           break;
      }/* switch  1 */

switch (count2)
      {/* switch 2 */
      case 1 : fprintf (stream," Limit  "); break;

case 2 : fprintf (stream," Free  "); break;
      }/* switch 2 */
     } /* if */

     for (count3 = 1; count3 = 5; count3++) /* Quality */
     { /* count3 */                    /* Surp = 25, 50, 100, 200, */
     if (!((count1  lcount1) ||
          (count1 == lcount1 && count2   lcount2) ||
           (count1 == lcount1 && count2 == lcount2 && count3 = lcount3)
          )
        )

       { /* if */
      /* Select the continuous measurement mode */
        measurement = CONT;


/* Select the measuring mode */
         switch (count1)
          { /* switch 1 */
           case 1 : stat_error = S20;
                   break;

           case 2 : stat_error = S10;
                   break;

           case 3 : stat_error = S5;
                   break;
```

```
  case 4 : stat_error = S3;
          break;
} /* switch 1 */

switch (count2)
 { /* switch 2 */
  case 1 : echo_type = LIMIT;
          break;

  case 2 : echo_type = FREE;
          break;
} /* switch 2 */

switch (count3)
 { /* switch 3 */
  case 1 : mode = QUALITY;
          break;

  case 2 : mode = TIMER;
          surp = SURP25;
          break;

  case 3 : mode = TIMER;
          surp = SURP50;
          break;

  case 4 : mode = TIMER;
          surp = SURP100;
          break;

  case 5 : mode = TIMER;
          surp = SURP200;
          break;
} /* switch 3 */
```

```
/* Set up the appropriate measurement */
      bioscom(1,measurement,1);
      bioscom(1,stat_error,1);
         bioscom(1,echo_type,1);
         bioscom(1,mode,1);

         if (count3  1) bioscom(1,surp,1);

/* Tell the user that the measurement begins */
         printf("\n\nStart    measuring\n\n");

/* Read current time */
       start_time = biostime(0,0);

/* Start the measurement */
      bioscom(1,START,1);

/* The measurement */
         for (count4 = 1; count4 = num_of_test; count4++)
        {
        Measure();
        }

/* Read finish time */
       stop_time = biostime(0,0);

/* Work out the time taken */
         time_taken = (stop_time - start_time) / 18.2;

/* Work out the frequency */
         if (time_taken == 0)
           freq = 0;

         else
        freq = num_of_test / time_taken;

/* Ask if the measurement is all right */
         printf("\n\nA set of %5d measurements has just been taken \n",num_of_test);
      printf("It took %9.2f seconds to finish \n", time_taken);
        printf("The frequency of the measurement was %7.2f Hz\n", freq);
       printf("Do you want to save this result and contiuous ? \n");
```

```
printf("y or Y for yes, s or S for save and quit\n");
cscanf("%c",&decision);
 if (decision == 'y' | decision == 'Y' |
    decision == 's' | decision == 'S')

 {if (count3 == 5)
   {
  fprintf (stream,"%6.2f\n",freq);

   /* write data to disk file close it and reopen it*/
   fclose(stream);
   stream = fopen("freq.dat","a");

/* Update the count file */
  stream2 = fopen("lastcount.dat","w");
 fprintf(stream2,"%d,%d,%d\n",count1,count2,count3);
 fclose(stream2);
   }

  else
   {
fprintf (stream,"%6.2f   ",freq);

   /* write data to disk file */
   fclose(stream);
   stream = fopen("freq.dat","a");

   /* Update the count file */
  stream2 = fopen("lastcount.dat","w");
 fprintf(stream2,"%d,%d,%d\n",count1,count2,count3);
 fclose(stream2);

   }

 }

else break;

 if (decision == 's' | decision == 'S') break;

} /* if */
```

```
} /* count3 */

      if (!(decision == 'y' | decision == 'Y')) break;
     } /* count2 */

    if (!(decision == 'y' | decision == 'Y')) break;
   } /* count1 */

fclose(stream);
  }

}
```

Freqtest.c is a program to measure the sampling frequency of the laser rangefinder under the ITS/rangefinder configuation.

The structure of the program is as follows :

```
Include the header files
  stdio.h
  fcntl.h
  bios.h
Include  the  file  c:\program\c\prolib.h
main()
{
 declare variables
```

Try to open the file LASTCOUNT.DAT which stores the information about where the last measurement was stop. If the file does not exist then the variables lcount1, lcount2, lcount3 will be given the value 0, otherwise their values will be read from the file and the file is closed.

Try to open the file FREQ.DAT for appending. If the file can not be opened then the message "Fail to open file" will be printed and the program will terminate. If the file exists or is created by the file opening function, then the following procedures will be carried out.

Set the COM1 of the computer up to work at 9600 band, no parity and 8 bits in data length by using the function call BIOSCOM()

If the values of the variables lcount1, lcount2 and lcount3 are 0, ie, there is no previous measurement, then the heading of the table is written to the file. The heading is :

"Stat. Echo Quality   Timer mode Surplus"
 "error type mode 25% 50% 100% 200%"

There are three nested loops one inside another controlled by the variables count1, count2 and count3. Count1 determines the accuracy of the measurements (= 20, 10, 5 or 3 mm). Count2 determines whether the echo type of the rangefinder (LIMIT or FREE mode). Count3 determines the surplus of the pluses in TIMER mode or to set the rangefinder into QUALITY mode. (Read the operators manual of the rangefinder for details).

The program will then do nothing untill the counters has stepped through the same number of steps that the previous measurement had taken. Once this is done the computer will then start to carry out the new measurements.

The appropriate heading for the statistical error and echo type are printed by the first two switch statements (SWITCH(COUNT1) AND SWITCH(COUNT2)) appear before the third loops (count3).

Inside the third loop, the program uses the switch statements to determine which measuring mode the rangefinder should be set up to. The variables STAT_ERROR, ECHO_TYPE, MODE and SURP are assigned with the appropriate values.

Once the values of the variables are determined, the function BIOSCOM() is called to send the control data to the rangefinder. The control data about the surplus will only be sent to the rangefinder if the rangefinder is going to run in the TIMER mode, ie, when (COUNT3 1).

After all the control data is sent to the rangefinder, the current time is read from the computer by calling the function BIOSTIME().

The inner most loop (COUNT4) carries out the measurement. The number of measurements is determined by the variable NUM_OF_TEST which is initiated at the time the variable is declared.

The finishing time is then taken by calling the function BIOSCOM() after the inner most loop is exited.

The actual time taken for the measurement is worked out by subtracting the starting time from the finishing time and divide it by 18.2, this number is given by the turbo C reference manual under the function BIOSTIME(). Hence, the frequency of the measurement is found.

Messages will then be output to the computer screen to ask the user whether he wants to store the measurement into the data file. The user can choose among store and continuous by answering y or Y, store and terminate the program by answer s or S, or abort by pressing any other key.

If the answer of the user is to store the data, the result of the measurement will be written into the file FREQ.DAT and the values of the counters COUNT1, COUNT2 and COUNT3 will be stored into the file LASTCOUNT.DAT. These files are closed and reopened again to ensure that the data are actually written on the files on the disk instead of storing them in the file buffers of the program. The reason for doing this is to prevent the loss of data due to sudden termination of the program.

The program will be terminated if all the measurements have already been taken or it is terminated by the user as well as rebooting the system. In the case of a system reboot, the only effect on the program is aborting the present incomplete measurements. This is the only way to terminate the program if for example the battery of the rangefinder is running low during the measurement.

}

```
/* Ptype */
#include bios.h   .
#include   c:\program\c\prolib.h

void interrupt event(float reading)
{
  unsigned char space = ' ';
  reading = reading + 1;

/* Print the reading on the screen */
  printf("\r%30cReading : %9.2f\n",space,reading);

  /* To reset the master interrupt controller */
outportb(MASTER_CONT,END_OF_INT);
}

main()
{
 int inum = 0xc;
 unsigned char ch, space = ' ';
 void interrupt (*old_vect)();
 float reading = 0;

/* Clear the screen and print message */
 clrscr();
 printf("\n%20cReset the computer to stop !\n\n\n\n\n",space);

/* Obtain the existing vector */
 old_vect = getvect(inum);

/* Install new vector */
 setvect(inum,*event);

/* Wait for the command to finish the measurement */
 do
 {
 }
 while (TRUE);

}
```

Ptype.c is a program to test the interrupt input to the computer

The structure of the program is as follow :
Include the header files:
dos.h
c:\program\c\prolib.h

Function event
Prototype : void interrupt event(float reading)

This function is an interrupt handler. When the interrupt, the number is given by the variable INUM, is invoked the function will increment the floating point varaible READING by one and displays the number on the screen. The last instruction of the function is to reset the interrupt controller of the computer by sending the EOI instruction to the controller control port.

Main body
main()
{
Declarevariables

Clear the screen

Display the message "Reset the computer to stop !"

The existing interrupt vector is assigned to the variable OLD_VECT. The interrupt vector number is given by the variable INUM.

The vector pointing to the function EVENT() is installed into the interrupt number given by the variable INUM.

Enable hardward interrupt.

The program runs in an endless loop

}

```
/* prpto2.c */
/* This is the program to form part of the trolley measuring system */
/* The program enable measurements to carry out ans\d has the option */
/* for the use to store the result in a file */

#include stdio.h
#include fcntl.h
#include conio.h
#include dos.h
#include  c:\program\c\prolib.h
#include  c:\program\c\prolib.c
#include  c:\program\c\proto2.h

void interrupt event()
{
 float reading;
 unsigned char space = ' ';

reading = Measure();

/* Print the reading on the screen */
 printf("\r%30cReading : %10.3f\n",space,reading);

 /* If a file is opened output the measurement to the file as well */
 if (decision == 'y') fprintf(stream,"%9.4f\n",reading);

 /* To reset the master interrupt controller */
outportb(MASTER_CONT,END_OF_INT);
}

int c_break()
{
 /* Restore the original vector */
 setvect(inum.old_vect);

/* If a file is opened close the file */
 if (decision == 'y') fclose(stream);

printf("finish !\n");
```

```
/* To reset the master interrupt controller */
outportb(MASTER_CONT,END_OF_INT);

return(0); /* Stop the program */
}

void set_range()
{/* Function to setup the operation mode of the range-finder */
unsigned char stat_error, mode, echo_type, measurement;

/* Set up the rangfinder for the measurement */
measurement = CONT;
stat_error  = S10;
mode        = QUALITY;
echo_type   = FREE;
bioscom(1,measurement,1);
bioscom(1,stat_error,1);
bioscom(1,mode,1);
bioscom(1,echo_type,1);
}

void open_file()
{
  unsigned char filename[20],full_name[35] = "c:\\program\\c\\results\\",

valid = 'n';

/* Clear the screen and print message */
clrscr();
printf("\nDo you want to save the data in a file ?");
cscanf("%c",&decision);

if (decision == 'Y') decision = 'y';
 printf("\n");

/* If the user wants to save the data in a file */
/* ask the user for the file name */
 if (decision == 'y')
  while (valid == 'n')
  {
```

```
  printf("Enter a file name for not more than 8 characters \n");
  scanf("%s",&filename);

  if ( 8 = strlen(filename))
  {
  strcat(filename,".dat");
  strcat(full_name,filename);
   stream = fopen(full_name,"a");

   clrscr();
  printf("The data is going to store in the file : %s\n",full_name);

/* If file cannot be opened try again */
   if (stream == 0)
   printf("File cannot be opened, try again !\n");

   else
    valid = 'y';
  } /* If */

  else
   printf("\n\nInvaild file name !\n\n");
 } /* while */
}

main()
{
 int handle;
 unsigned char ch, space = ' ';

/* Set up the rangefinder for measurement */
set_range();

/* Ask the user whether to open a file for output or not */
open_file();

/* Print the instruction on hoe to exit from the program */
 printf("\n%20cPress CLt-C or CLT-Break to stop\n\n\n\n\n",space);
```

```
/* Obtain the existing vector */
 old_vect = getvect(inum);

/* Install new vector */
 setvect(inum.*event);

/* Change the control break vector */
 ctrlbrk(c_break);

/* Enable hardward interrupt on the 80286 */
 enable();
bioscom(1,START,1);

/* Wait for the command to finish the measurement */
 do
  {
  }
 while (TRUE):

}
```

PROTO2.C is the program to drive the prototype profiling system.

The program consists of four functions and a main body. The name and function prototype of the function is given below:

VOIDINTERRUPTEVENT()

INTC_BREAK()

VOIDSET_RANGE()

VOIDOPEN_FILE()

The program enable the range-finder to carry out a measurement at the trolley has travelled for a fixed distance. The more information about the prototype system can be obtained in the report about the experiment. It also allows the user to store the measurement in a file.

The structure of the program is as follow :

Include the following header files:
stdio.h
fcntl.h
conio.h
dos.h
c:\program\c\prolib.h
c:\program\c\prolib.c
c:\program\c\proto2.h

FuctionINTERRUPT
Function prototype
VOIDINTERRUPTEVENT()
{
This function is an interrupt handler to carry out a measurement when it is invoked. The measurement is taken from the range-finder through the RS232 serial port.

The function BIOSCOM is called to send the comand to start a measurement down the RS232 serial port.

The function MEASURE() is called to take a measurement. This function is contented in the file prolib.c.

The measured value is displaced on the screen.

If the Boolean DECISION is equal to 'Y' then the measured value is also output to the output file.

Reset the interrupt master controller of the computer.
}

Function C_BREAK()
Function prototype
INTC_BREAK()
{
This function intersects the BREAK interrupt vector, see the reference guide of TURBO C for detail, of the computer. It restores the original interrupt vector, closes the opened file if there is and terminals the execution of the program.

The function SETVECT() is called to restore the original vector of interrupt vector.

If the variable DECISION is 'Y' then close the opened file.

The message "Finish !" is printed.

The value 0 is returned by the function to terminal the program.
}

FunctionSET_RANGE()
Function prototype
VOIDSET_RANGE()
{
This function sets the operation mode of the range-finder up for the measurement. The value of variables MEASUREMENT, STAT_ERROR, MODE, ECHO_TYPE can be changed. Detail of the operation is given by the operational manual of the range-finder.

The function BIOSCOM() is called four times to set up the range-finder.
}

FunctionOPEN_FILE()
Function prototype
VOIDOPEN_FILE()

{
This function opens a file to store the measured data from the range-finder.

Declare the variables FILENAME AND FULL_NAME.

The file is stored in the directory C:\PROGRAM\C\RESULTS\. The path of the directory is stored in front portion of the variable FULL_NAME.

Clear the screen.

The message "Do you want to save the data in a file ?" is printed.

If the answer is 'Y' then the variable DECISION is assigned the value 'y'.

If the variable DECISION is equal to 'y' then the following will be executed :
{
While the variable VALID equal to 'n' then
{
The message "Enter a file name for not more than 8 chacters" is print.

If the file name given is less than or equal to 8 long then
{
The file extension ".dat" is given to the file by concatenating it to the end of the variable FILENAMEby calling the function STRCAT().

The variable FILENAME is then concatenated with the varibale FULL_NAME by calling the function STRCAT() again.

Attended to open a file with the name given by the variable FULL_NAME.

If the file is not succefully opened, file handle STREAM equal to 0, then the message "File cannot be opened try again" is printed. Otherwise the variable VALID is assigned the value 'y'.
}

else
The message "Invaild file name !" is printed.
}

}

}

Main()
{
Declarevariables

The function SET_RANGE is called.

The function OPEN_FILE is called.

The message "Press CLT-C or CLT-Break to stop" is printed.

The function GETVECT() is called to obtain the original interrupt vector in the position given by the variable INUM.

The function SETVECT() is called to install the vector pointing to the interrupt handler EVENT in the position given by the variable INUM.

The function CTRLBRK() is called to intall the vector pointing to the interrupt handler C_BREAK into the position of the BREAK vector.

Enable the hardware interrupt of the computer.

A endless loop is set up
}

```
/* Prolib.c */

#include    c:\program\c\prolib.h

float Measure(void)
{ /* Make a measurement from the rangefinder */
 unsigned char meg[13];
 float reading;
 int loop;

/* Put a Null character into the array */
 meg[11] = NULL;

/* Read measurement for the rangefinder */
 for (loop = 0;loop = 10;loop++)
   meg[loop] = bioscom(2,1,1); /* From com2 */

/* Converts a string to a floating point number */
 reading = atof(meg);

/* Return the value of the measurement */
 return reading;
 }

/*======================================
=================================*/
```

{Prolib.doc}

Contents inforamtion about the routines that are developed

Read_RS232()
Read a byte from com
Function prototype: Unsigned char Read_com1(unsigned int com_num)
com_num : number of the serial port, 0 for com1

Measure()
Make a measurement from the rangfinder
Function portotype: double Measure(void)
Setting of the communication port

```
        Bit              Use
 7  6  5  4  3  2  1  0
 X  X  X             .....Baud-rate
          X  X.       .  Parity
                        ..Stop-bit
                     X  X Character-size
```

Bit 7	Bit 6	Bit 5	Baud Rate
0	0	0	110
0	0	1	150
0	1	0	300
0	1	1	600
1	0	0	1200
1	0	1	2400
1	1	0	4800
1	1	1	9600

Bit 4 3	Parity Bit
0 0	None
0 1	Odd parity
1 0	None
1 1	Even parity

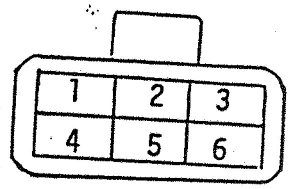
Stop Bits		Character size		
Bit	Meaning	Bit		Meaning
2		1	0	
0	One	0	0	Not used
1	Two	0	1	Not used
		1	0	7-bi
		1	1	8-bit

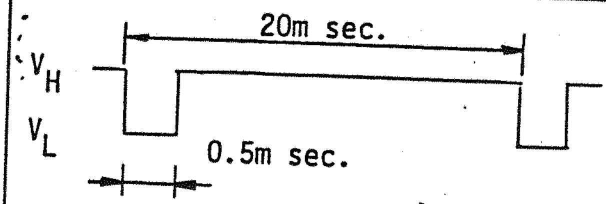
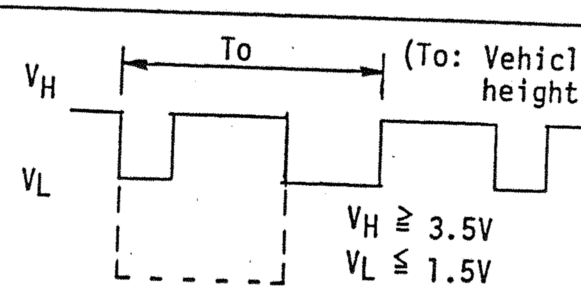
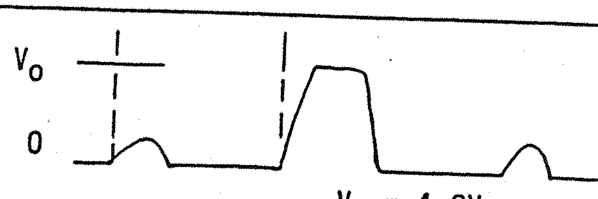
Appendix C
Data Sheets

INPUT/OUTPUT SIGNAL OF SENSOR TERMINAL

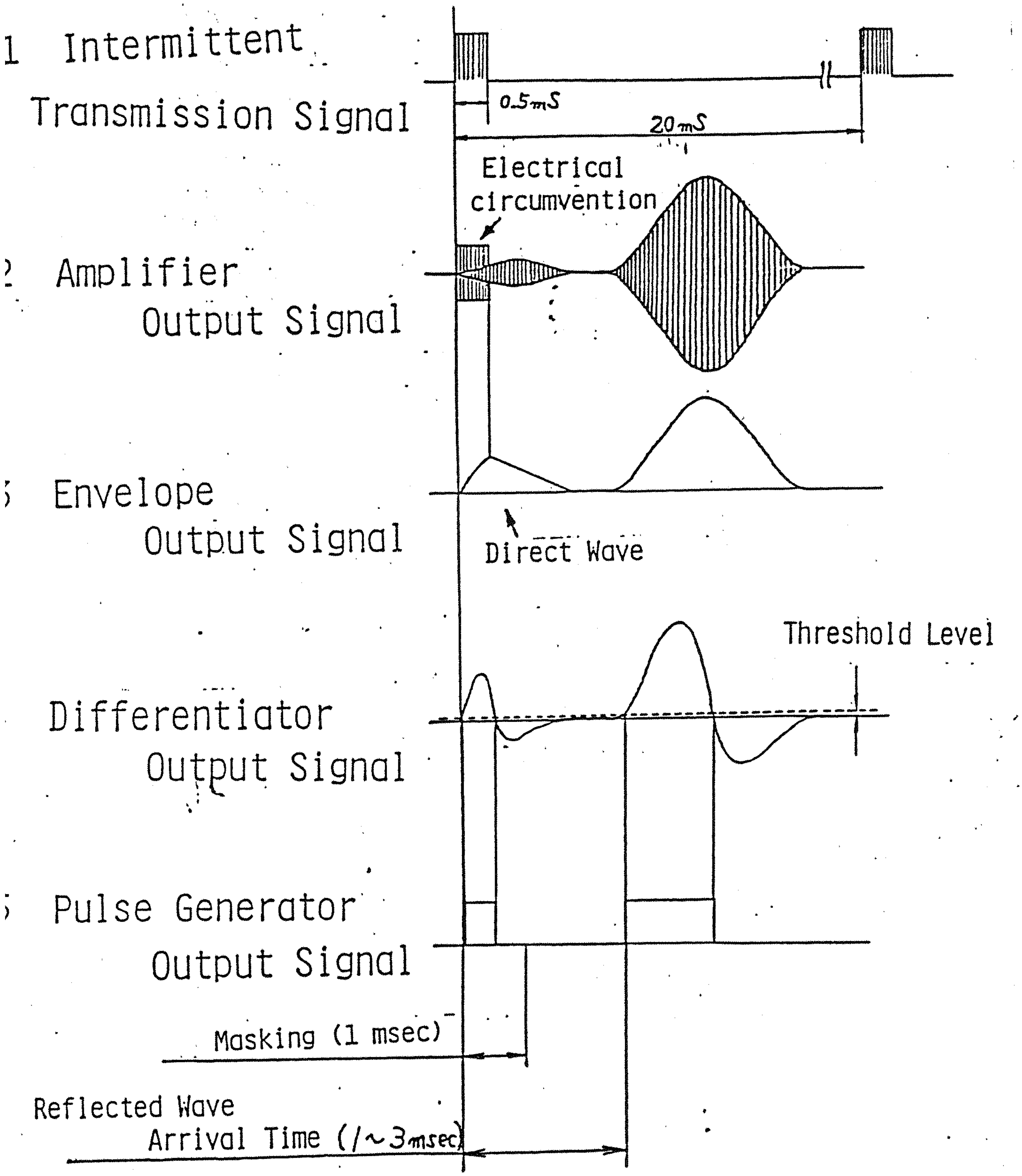
50Hz

Sensor Terminal

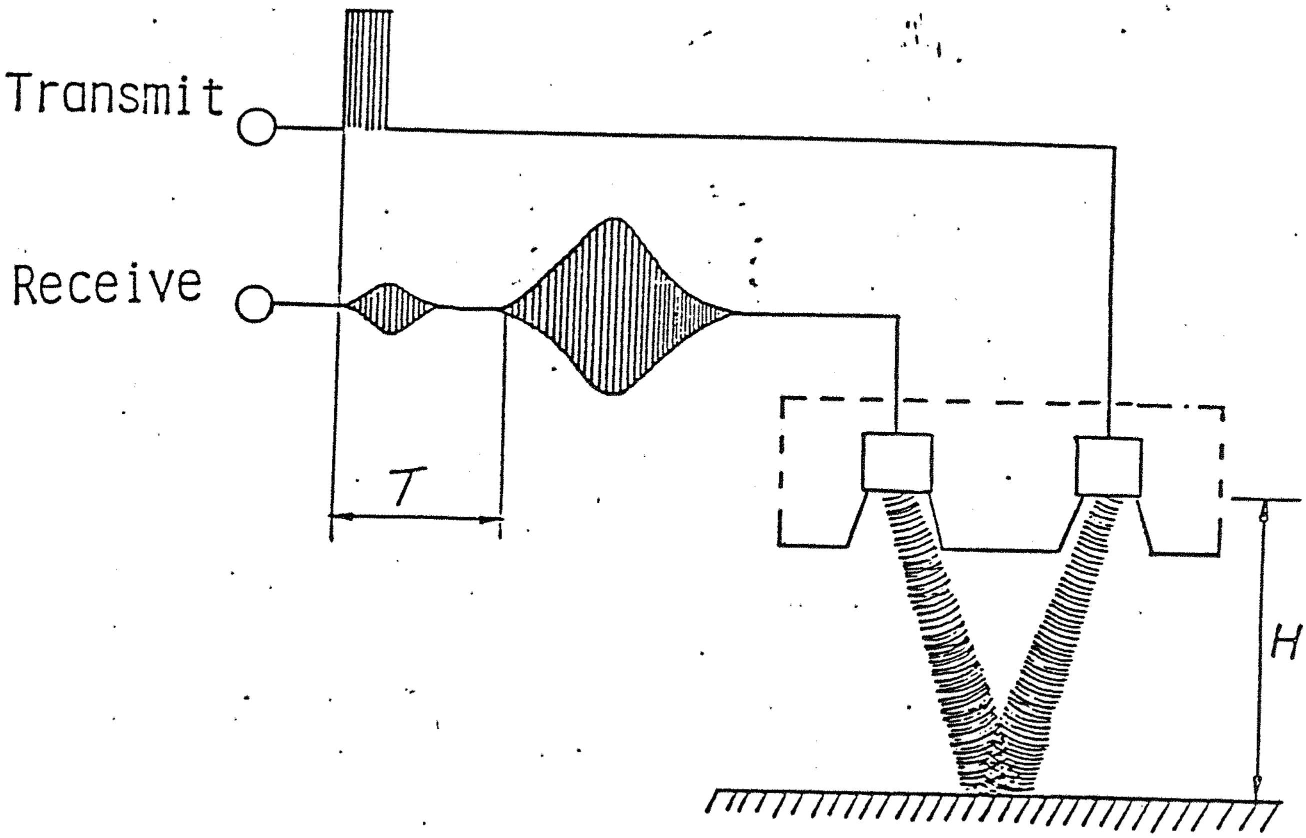


Terminal 1. (Red)	V.C.C.	Specification: DC15V Usable Range: DC14 16V
Terminal 2. (Yellow)	Terminal operating timing signal	 $V_H \geqq 4.5V$ $V_L \leqq 1.0V$
Terminal 3.	Suspended	----
Terminal 4. (Blue)	Wave pattern rectifier output (Vehicle height equivalent output)	 (To: Vehicle height) $V_H \geqq 3.5V$ $V_L \leqq 1.5V$
Terminal 5. (Green)	Envelope inspector output	 $V_o = 4.0V$
Terminal 6. (Black)	Earth	

Remarks: Terminal operating timing signal of the terminal 2 consists of a contorl circuit completely different from that of the sensor circuit. Therefore, in order to conduct an evaluatingtest of the sensor, separate signal which is equivalent to that of terminal 2 should be fabraicated using a transmitter.



Wave Forms of Each Component



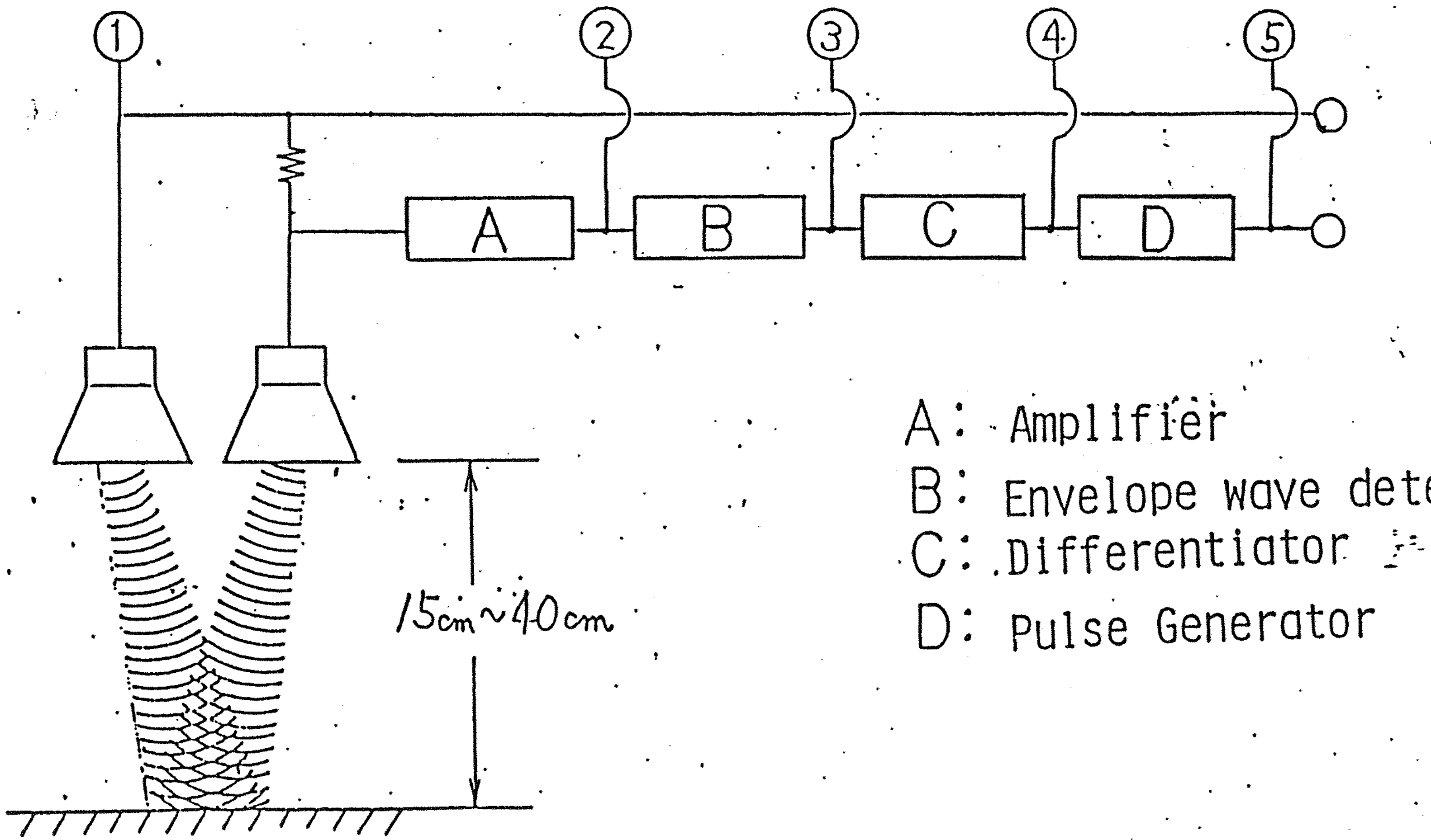
$$H = \frac{1}{2} \cdot C \cdot T$$

H: Vehicle-height

C: sound velocity

T: Reflected Wave Arrival Time

Principle

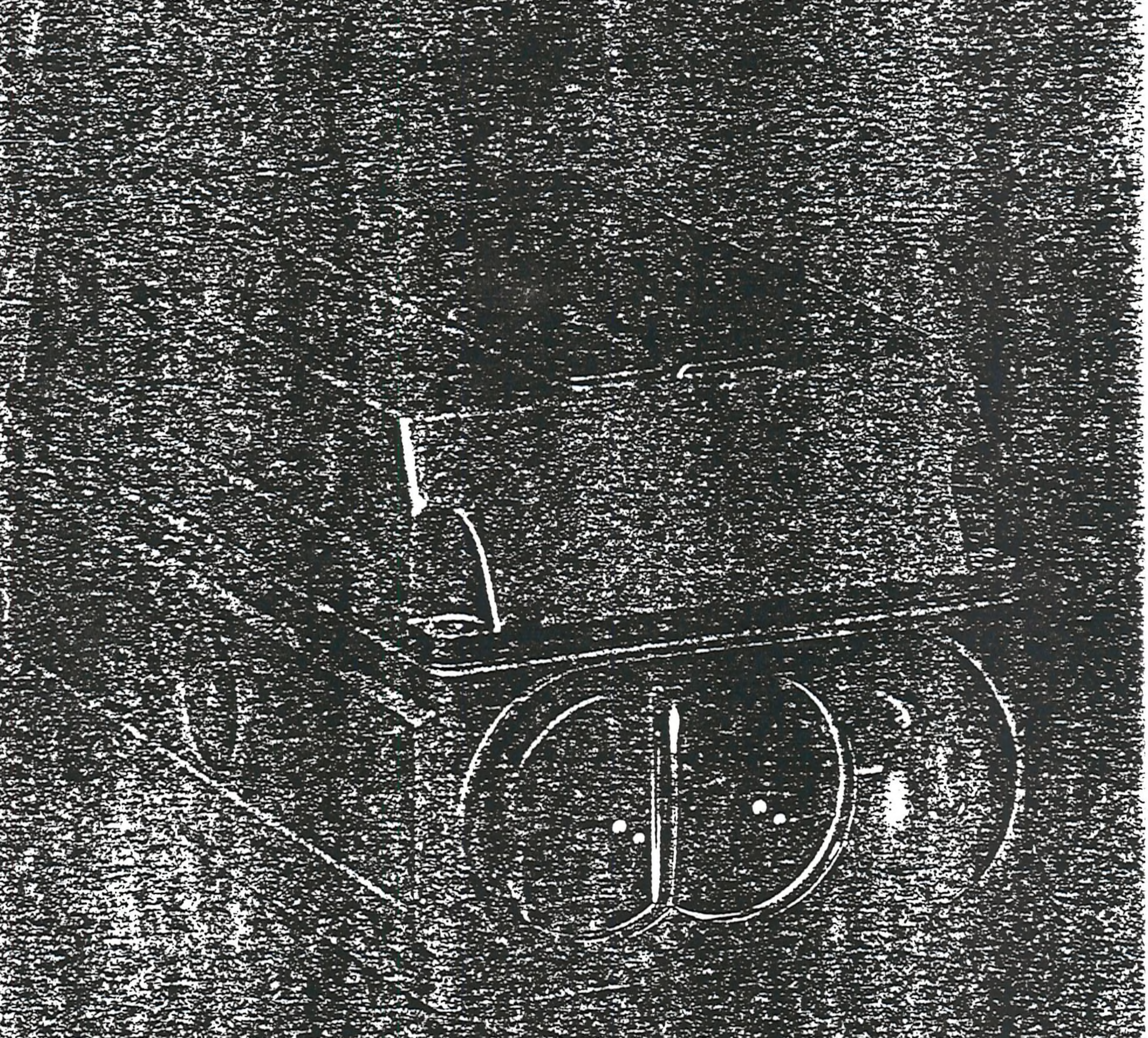


A: Amplifier
B: Envelope wave detector
C: Differentiator
D: Pulse Generator

IBEO

LASER DISTANCE SENSORS

PS 50
PS 100



Distance measurement to objects, materials or reflectors

Description PS 50 PS 100

PS 50 and **PS 100** are high resolution pulsed infrared laser range sensors for the range of 1m up to 200m (**PS100**) with 1 mm resolution, a beam divergence of 1mrad (**PS 50**) and 2.5 mrad (**PS100**) and a built-in 7x20 telescope. The integration of an **RLM** (Red laser marker) to indicate the target point is optional and replaces the telescope. The range of the SENSOR is increased when using co-operative reflectors; i.e. reflecting foil, plastic reflectors or corner cubes (prisms).

PS 50 and **PS 100** measure the reflection from virtually any surface including cloth, stone, metal etc. The reflection of short laser light pulses emitted by an internal semi conductor laser diode is detected and the time of flight from **SENSOR** to the target and back is converted into a distance.

PS 50 and **PS 100** are precision sensors of solid construction designed to withstand operation in rugged field and industrial environments.

Features

* Programmable measuring modes:
  - single or continuous measurement
  - 4 different speeds and accuracies
  - 2 modes for continuous measurement
* Programmable system configuration
  User-defined or standard configuration
* Measurement rate up to 120/s
* Accuracy up to 5 mm
* Measurement without reflectors
* Optional RLM or telescope 7x20
* Configurable RS232c interface
* Remote control of measurement and modes
* Water and impact resistant, sealed body
* Eye-safe operation, Class I

Application

* Intelligent light barrier with and without reflectors
* Position and distance measurement for crane control, industrial controls, robotics
* Long range measurement on reflectors
* Dynamic motion control of moving objects
* Profiling in combination with rotary tables for measurements in ships, tanks, rooms
* Speed measurement and speed control
* Approximation sensing and warning
* Height measurement and level control
* Landing and docking * Deformation testing
* Open pit mining * Quantity measurement

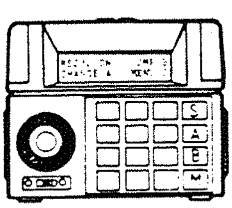
Specification

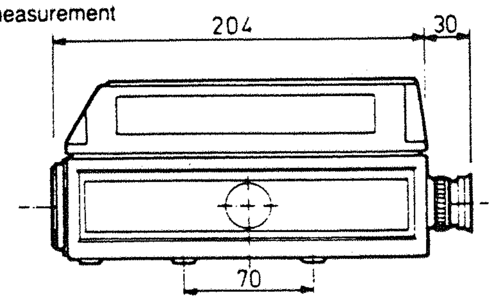
	PS 50	PS 100
Range on:		
grey concrete	>50m	>100m
white wall	>100m	>200m
Beam diameter at lens(100m)	40 (100)mm	40(250)mm
Resolution	1mm; 0.1 mm optional	
Best accuracy	< 5 mm; (1 sigma)	
Selection of statistical error	3, 5, 10, 20mm	
Measurements/s	up to 120/s	up to 50/s
Modes	single, continuous, User-, Standard-mode, Timer-, Quality- mode	
Timer-mode	Constant time frame with selectable surplus pulses of 25, 50, 100 or 200%	
Quality-mode	Arbitrary surplus pulses	
Units selectable	m/ft, C/F, mbar/PSI/Torr/hPa	
Input parameter	Temperature, pressure, scaling factor, offset	
Interface RS232c	configurable via keyboard	
Remote control	via RS232c	
Light source	Pulsed Laser diode, 905 nm	
Display	LCD dot matrix, 16 digits,	
Keyboard	16 keys, foil type	
Telescope	integrated, 7 X 20, opt.	
Supply voltage	5...7 Volt DC	
Supply current	1.30 A, 5 V DC; measurement 0.13 A, 5 V DC; stand-by 1.30 A, 5 V DC; marker on	
Laser marker opt.	HeNe Laser 638 nm, 0.5mW integrated incl. power module	
Weight	1.7 kg	
Temperature	working: -10°C to +50°C storage: -20°C to +70°C	
Rel. humidity	95% non-condensing	
Protection class	IP 64	

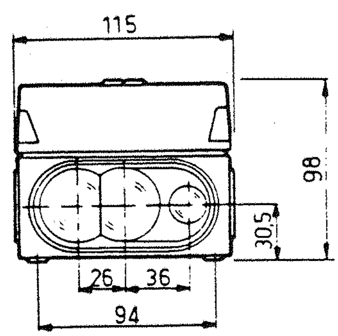
IBEO SENSORS AND INSTRUMENTS

SENSORS: **PS 2, PS 10, PS 50, PS 100**

SURVEY INSTRUMENTS: **PULSAR SURVEY, MINIFIX, PULSAR 50, 100, 500, 1000**
- comfortable survey software
- with and without reflectors
- angle input for XY- and relative co-ordinates
- tracking, slope and horizontal
- battery powered, long range capability







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FED. REP. of GERMANY
TEL. 40 / 645 10 41 **TX.** 216 49 47
FAX. 40 / 643 85 79

RS data

C-MOS 4000B series pin connections

The 4000B series of C-MOS integrated circuits all feature buffered ('B' specification) outputs which improve both the output drive and switching speed capabilities.

C-MOS circuitry offers very low power consumption at low switching speeds together with high noise immunity typically 45% of supply voltage making them ideal for battery powered equipment.

All devices operate from a supply voltage between 3 to 18V d.c.

Guaranteed Logic input thresholds for C-MOS are:—

'High' Logic 1	0.7 V_{DD} to V_{DD}
'Low' Logic 0	V_{SS} to 0.3 V_{DD}

Tie unused inputs to V_{DD} or V_{SS} as necessary.

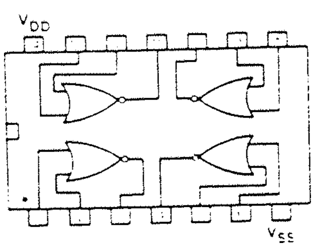
Connections shown are top view

A 'negation' circle at any output or input within the schematic indicates that the terminal is active low or at clocking inputs the device is negative edge triggered.

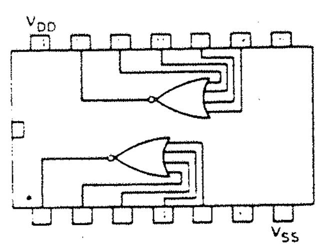
Abbreviations used through this data sheet

A,B,C,etc	Data inputs	R	Reset
a,b,c,etc	Segment outputs (decoder drivers)	RBI	Ripple blanking input
		RBO	Ripple blanking output
B.C.D.	Binary coded decimal	S	Preset
BI	Blanking input	S1,2,etc	Sum outputs
CE	Clock enable	S_{in}	Serial input of shift registers
CF	Cascade feedback		
CK	Clock input	S_{out}	Serial output of shift registers
CI	Carry input		
CY	Carry output	SF	Source follower output
D,JK	Data inputs to flip flops	ST	Strobe
DIS	Disable tri state output	T	Trigger
		U D	Up Down mode Control
EN	Enable		
F	Function outputs	VCO	Voltage controlled oscillator
INC	Increment		
INH	Inhibit	VI	Input to VCO
LE	Latch enable	VO	VCO output
LT	Lamp test	V_{CC}	+ Supply for buffers
MR	Master reset	V_{DD}	+ Supply
OF	Overflow	V_{EE}	– Supply
PE	Preset Enable	V_{SS}	0V
PH	Phase input for Liquid crystals	W	User selected +ve or –ve Logic
P/S	Parallel Serial Mode control	WE	Write enable
		X	Data inputs to selector
Q,$\bar{Q}$	Output and complement	⎎	Schmitt Device or function
QP	Phase Pulse Output		

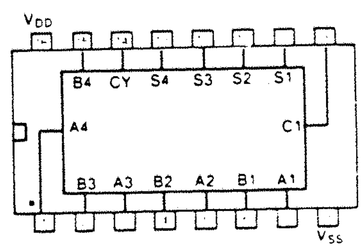
4001B Quad 2 input NOR



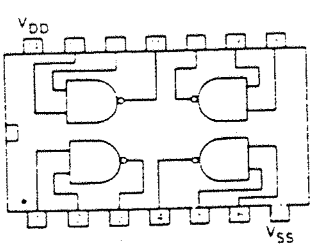
4002B Dual 4 input NOR



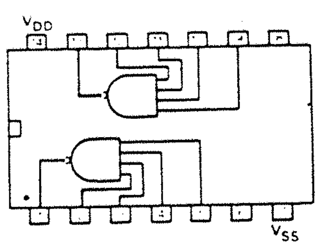
4008B 4 bit full adder



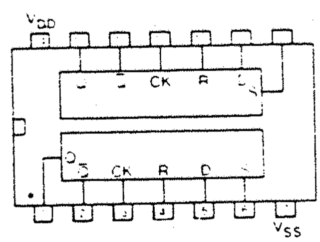
4011B Quad 2 input NAND



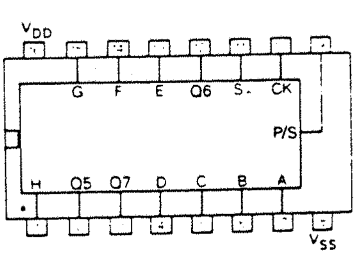
4012B Dual 4 input NAND



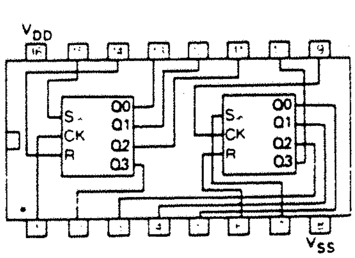
4013B Dual D type flip-flop



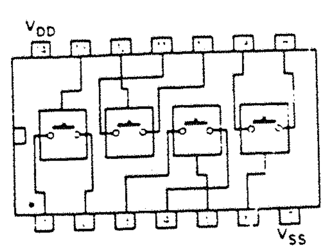
4014B 8 bit shift register



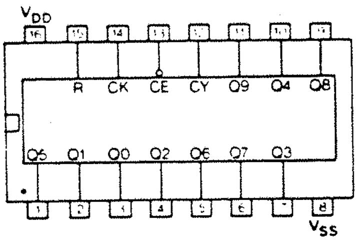
4015B Dual 4 bit shift register



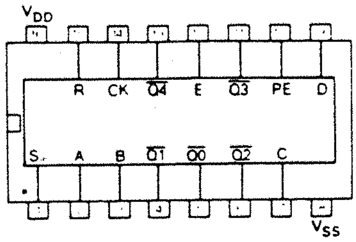
4016B Quad analogue switch



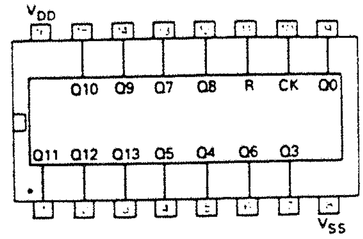
4017B Decade counter divider



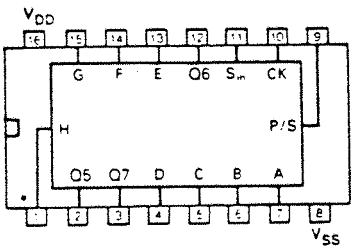
4018B ÷ by N counter



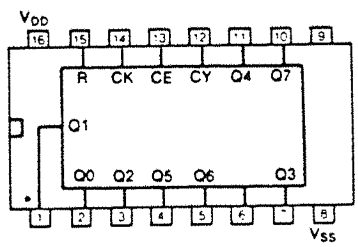
4020B 14 bit binary counter



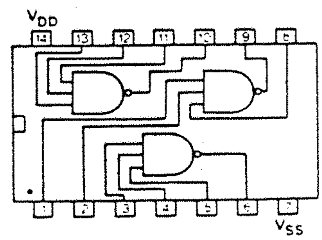
4021B 8 bit shift register



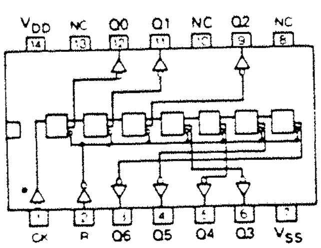
4022B Octal counter/divider



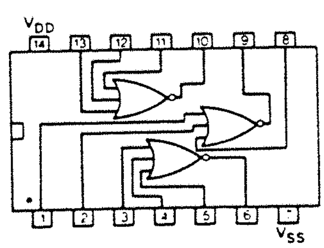
4023B Triple 3 input NAND



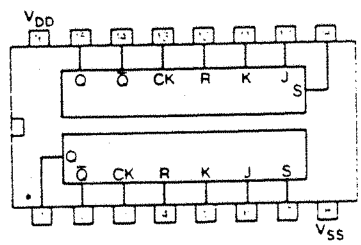
4024B Seven stage ripple counter



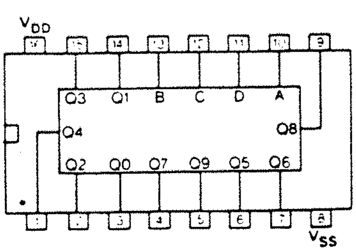
4025B Triple 3 input NOR



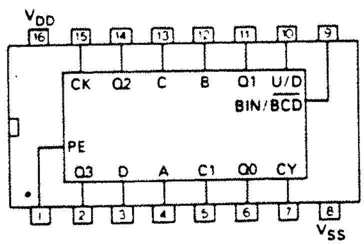
4027B Dual J.K. flip-flop



4028B BCD — decimal/binary-octal decoder

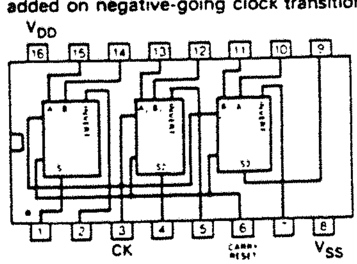


4029B Presettable binary/BCD up/down counter

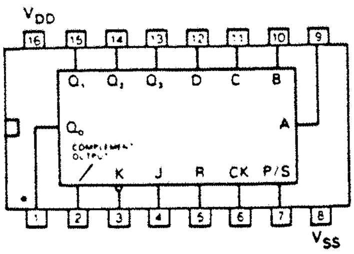


4032B Triple serial adder (carry is added on positive-going clock transition)

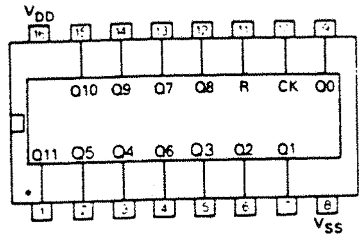
4038B Triple serial adder (carry is added on negative-going clock transition)



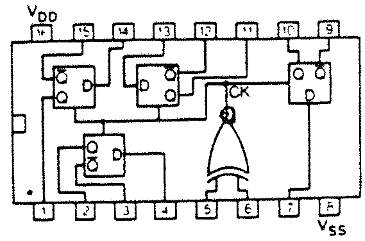
4035B 4 bit parallel — in/parallel — out shift register



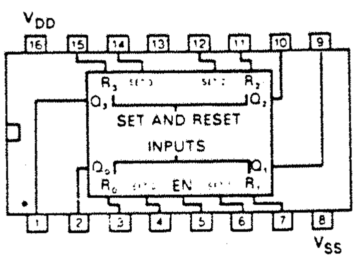
4040B 12 bit binary counter



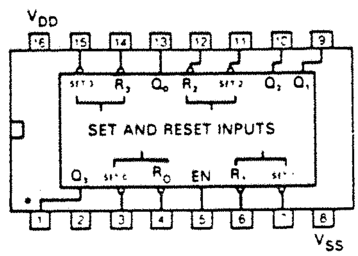
4042B Quad 'D' latch



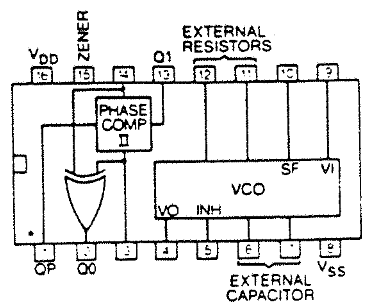
4043B Quad R/S latch with 3-state outputs "NOR"



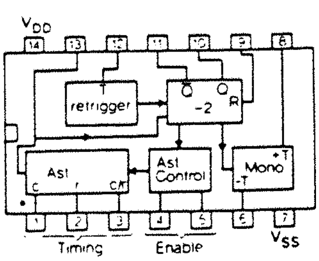
4044B Quad R/S latch with 3-state outputs "NAND"



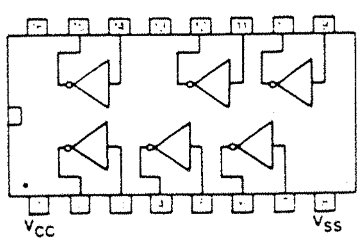
4046B Phase locked — loop



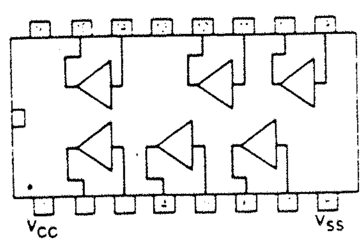
4047B Monostable/Astable multivibrator



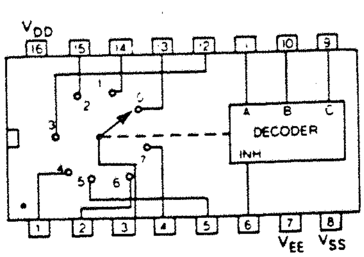
4049UB Hex inverter — buffer



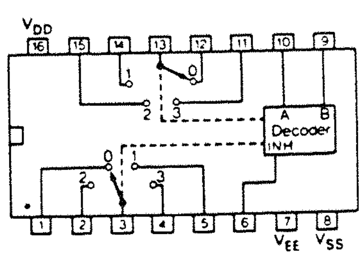
4050B Hex buffer



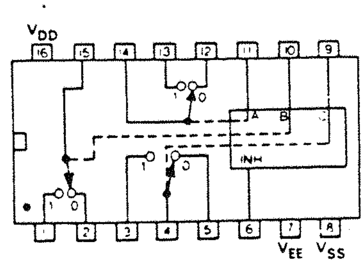
4051B 8 input analogue multiplexer



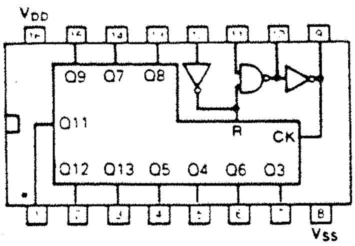
4052B Dual 4 input analogue multiplexer



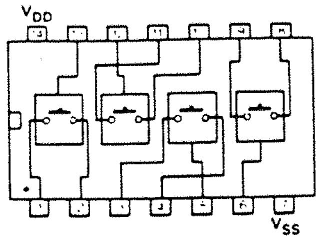
4053B Triple 2 input analogue multiplexer



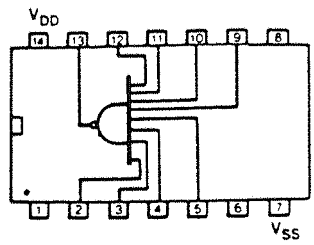
4060B 14 bit binary counter



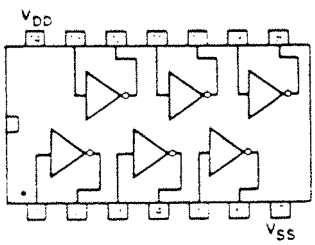
4066B Quad analogue switch



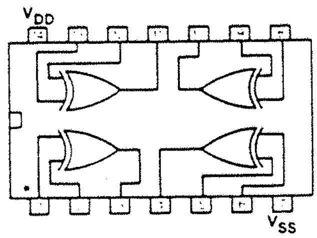
4068B 8-input NAND gate



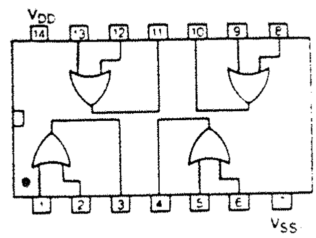
4069UB Hex inverter



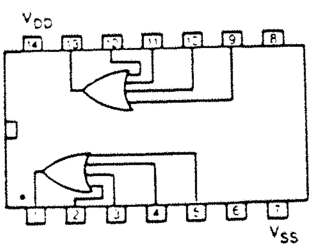
4070B Quad exclusive OR



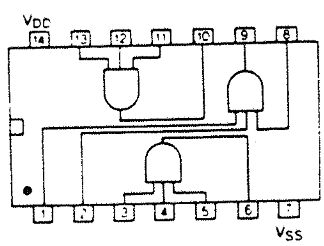
4071B Quad 2 input OR



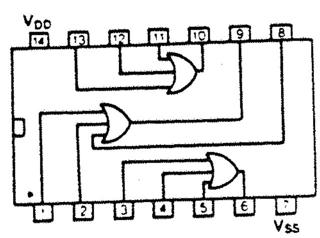
4072B Dual 4-input OR gate



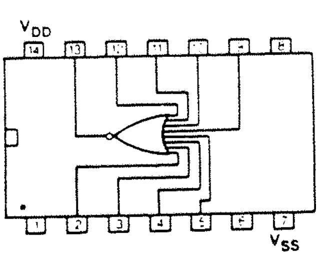
4073B Triple 3 input AND



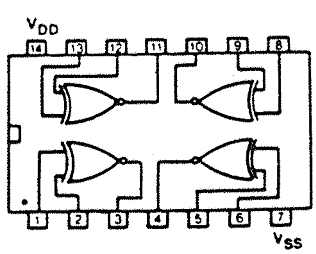
4075B Triple 3 input OR



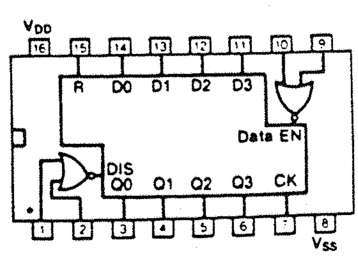
4078B 8 input NOR



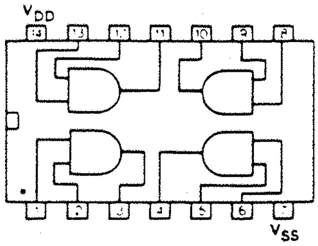
4077B Quad 2 input Exclusive "NOR" gate



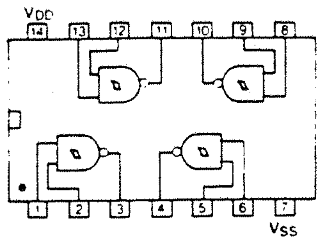
4076B Quad D type register



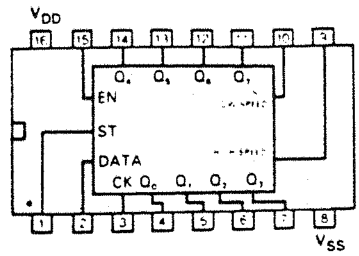
4081B Quad 2 input AND



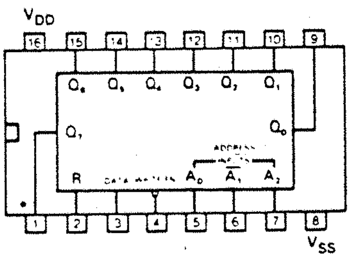
4093B Quad 2 input NAND schmitt



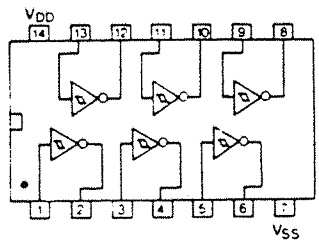
4094B 8-stage shift/store register with three-state outputs



4099B 8 bit addressable latch



40106B Hex inverting schmitt

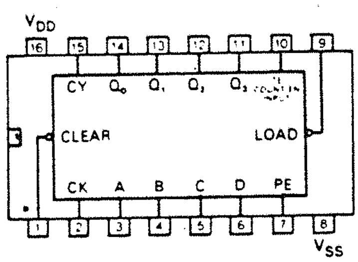


4160B Synchronous programmable 4 bit decade counter with asynchronous clear

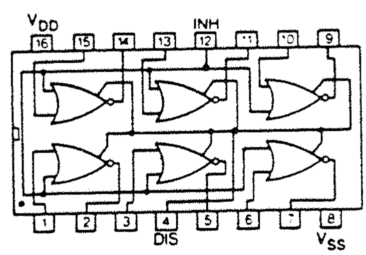
4161B Synchronous programmable 4 bit binary counter with asynchronous clear

4162B Synchronous programmable 4 bit decade counter with synchronous clear

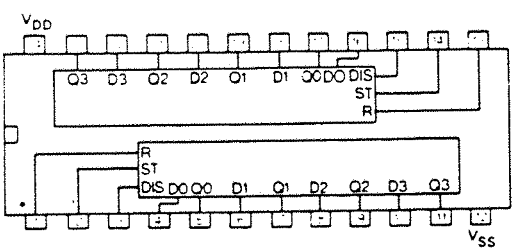
4163B Synchronous programmable 4 bit binary counter with synchronous clear



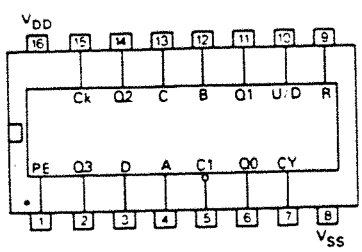
4502B Strobed Hex inverter buffer



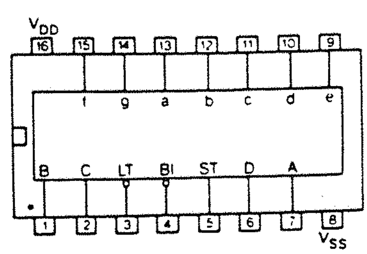
4508B Dual 4 Bit latch with tri-state outputs



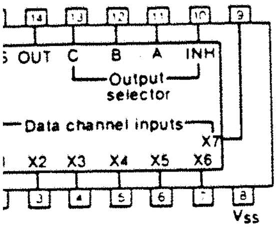
4510B BCD up/down counter



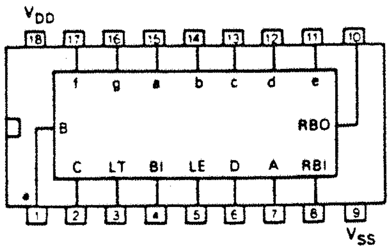
4511B BCD - 7 segment latch/decoder/driver



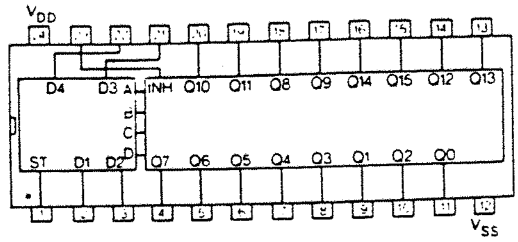
channel data selector



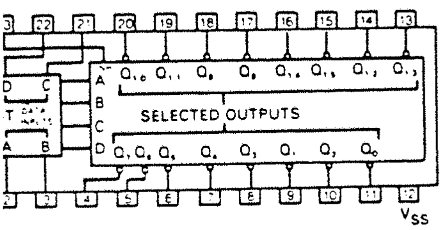
4513B BCD to seven segment latch/ decoder/driver



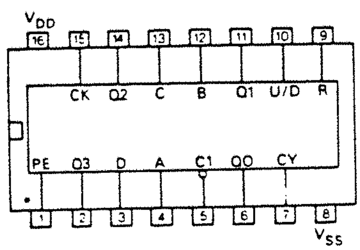
4514B 4 Bit latch to 1 of 16 decoder



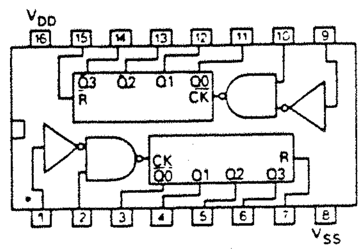
bit latch 4 to 16 line decoder



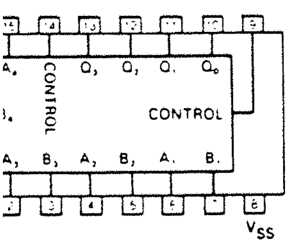
4516B Binary up/down counter



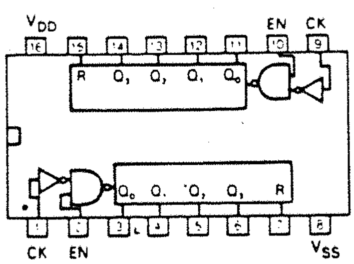
4518B Dual BCD up-counter



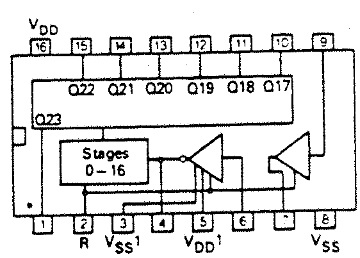
Quad 2 input multiplexer



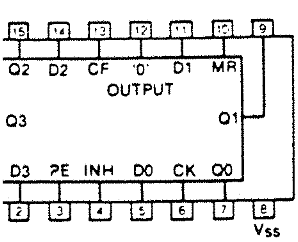
4520B Dual 4 bit binary counter



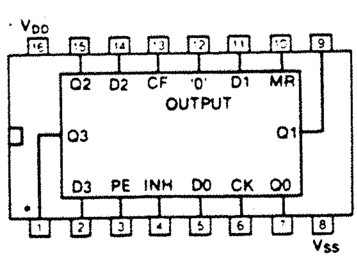
4521B 24 stage frequency divider



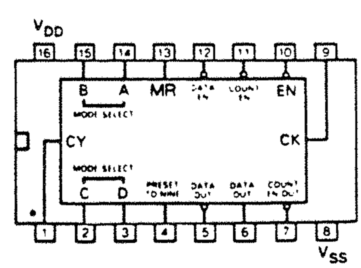
BCD – programmable divide by N



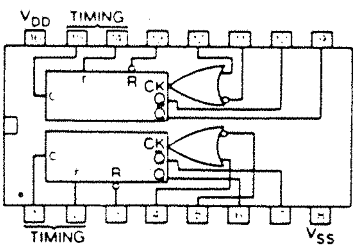
4526B Binary programmable divide by N



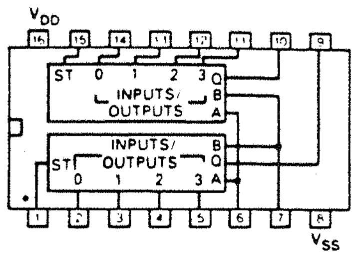
4527B BCD Rate multiplier



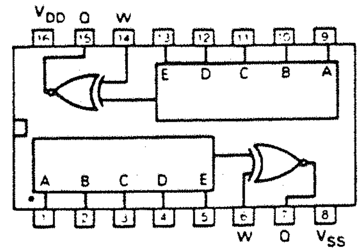
4528B Dual resettable monostable



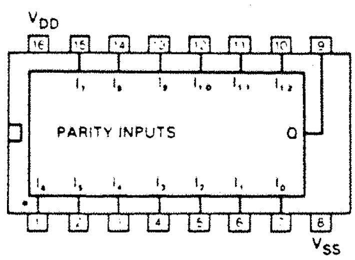
4529B Dual 4-channel analog data selector three state outputs



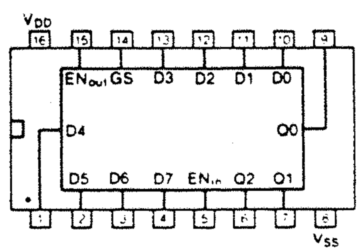
4530B Dual 5 input majority logic gate



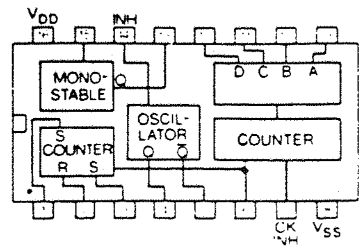
4531B 12 bit parity tree



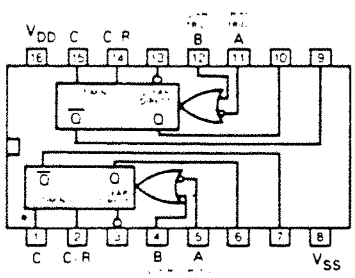
4532B 8 bit priority encoder



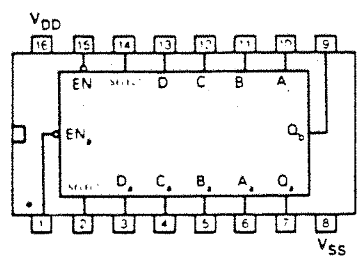
4536B Programmable timer



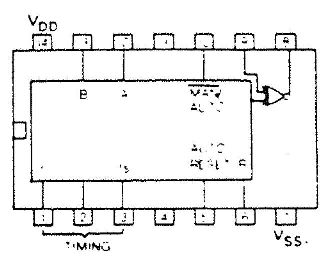
4538B Dual precision retriggerable/ resettable monostable multivibrator



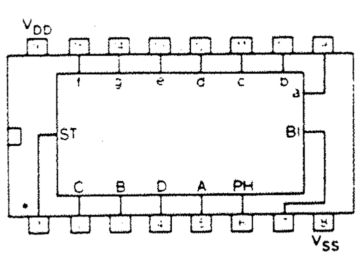
4539B Dual 4 channel data selector/ multiplexer



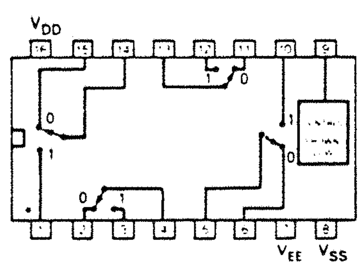
4541B Programmable timer



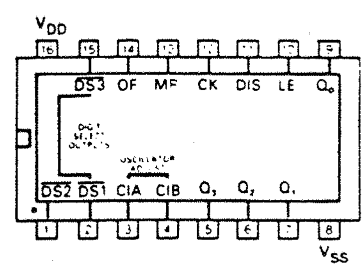
4543B BCD-to-seven segment latch/decoder/driver



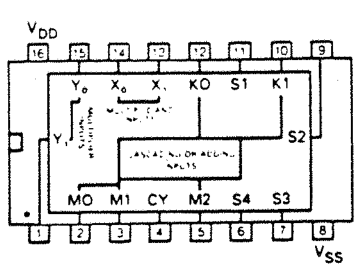
4551B Quad 2-input analog multiplexer/ demultiplexer



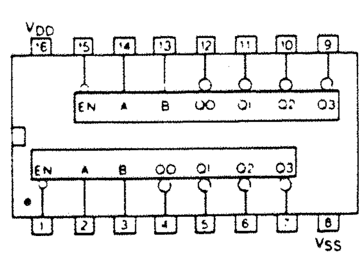
4553B Three-digit BCD counter



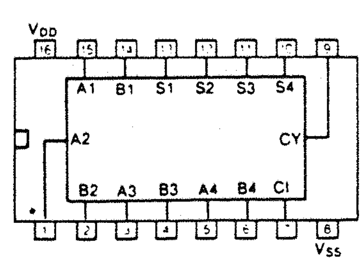
4554B 2 bit by 2 bit parallel binary multiplier



4556B Dual binary to 1 of 4 decoder

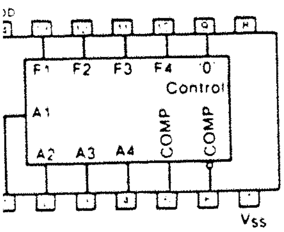


4560B Natural BCD adder

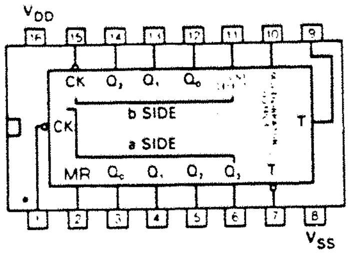


data

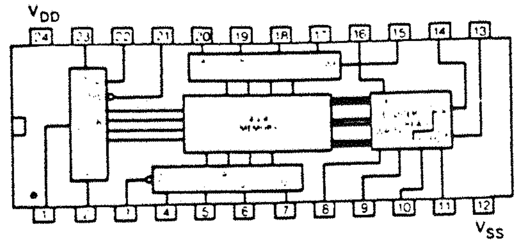
1B 9's Complementer



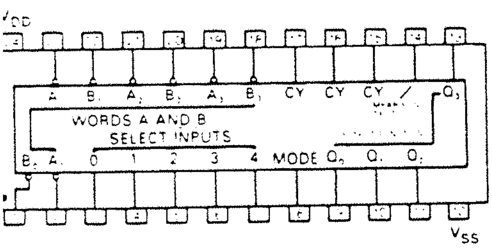
4566B Industrial time base generator



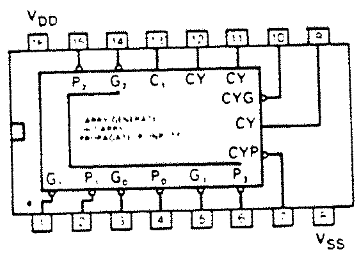
4580B 4 x 4 Multiport register



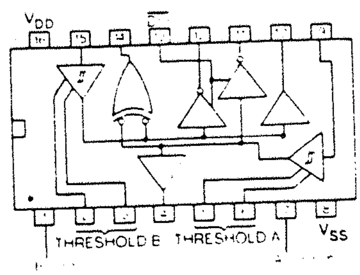
31B 4 bit Arithmetic logic unit



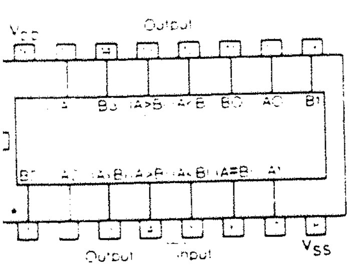
4582B Look-ahead carry block



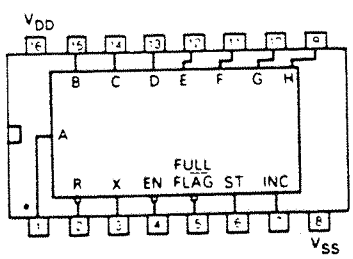
4583B Dual schmitt trigger



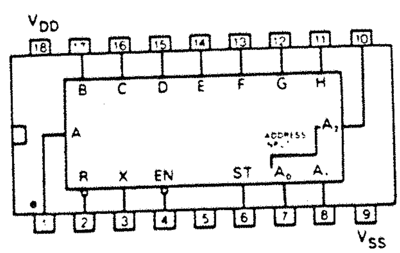
85B 4 bit magnitude comparator



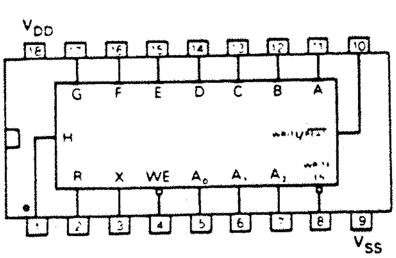
4597B 8 bit bus-compatible latches



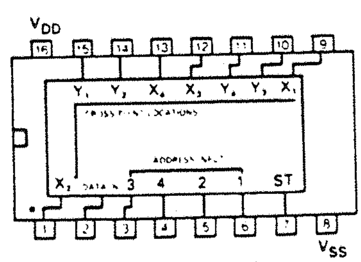
4598B 8 bit bus-compatible latches



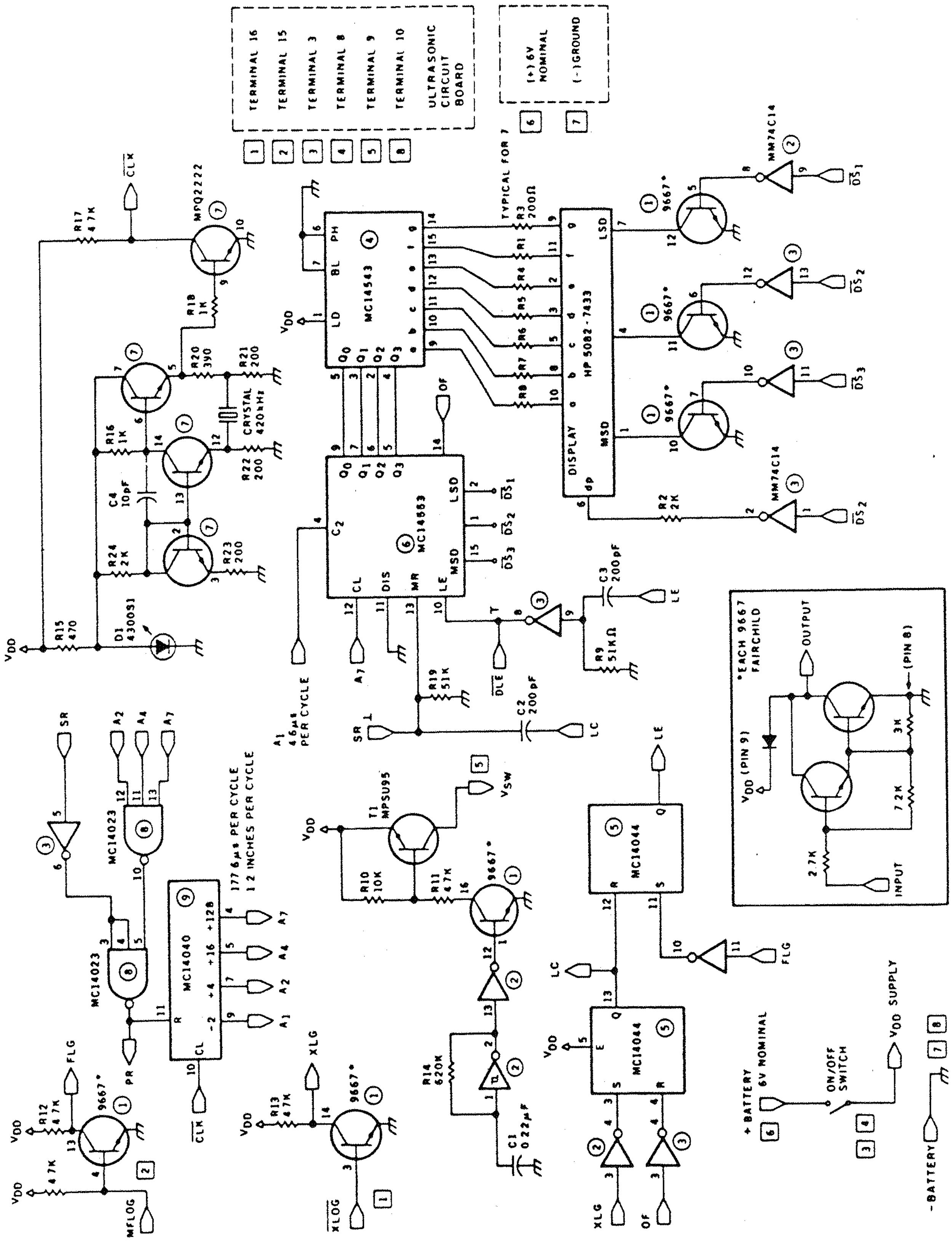
4599B 8 bit addressable latch



45100UB 4 x 4 Crosspoint switch with control memory



Components Ltd. PO Box 99, Corby, Northants, NN17 9RS
.n Electrocomponents Group Company
Telephone: 0536 201234



Schematic diagram of the EDB. This board contains all the necessary circuitry to convert the raw data of the sonar transmit/receive time interval into a numeric distance value and display it on a three-digit LED display.

HINTZE

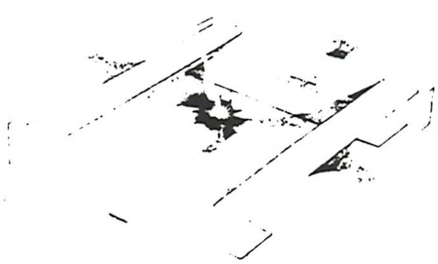
C R HINTZE AB, Vasavägen 78, S-181 41 Lidingö (Stockholm), Sweden, **phone +46-8-767 90 40**

HINTZE The Swedish Electro-Optics and Laser Specialist

Introduces SiTek

Position Sensitive Photodetectors PSD

A serie of very accurate and fast PSD-photodetectors ideal for non contact measurement of POSITION, DISTANCE and MOTION.



The PSD detector determines the position and movement of the light beam along the x- and y-axes.

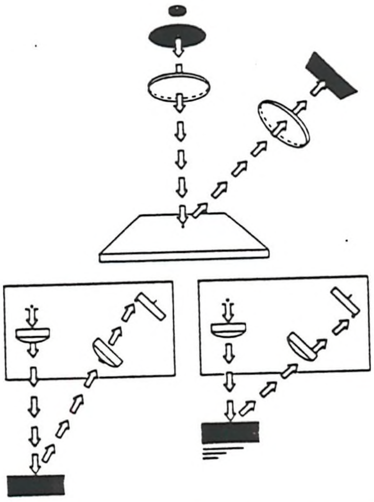
SiTek, the "spin-off company" from Chalmers University of Technology in Sweden developed a world unique position-sensitive photodetector PSD, for determinations of position, alignment, distance and motion.

In Partille close to Gothenburg the two science colleagues Lars-Erik Lindholm and Göran Petersson have created one of Europe's most modern facilities for development and production of advanced silicon based photodetectors.

These resources have made it possible for SiTek to offer their customers a broad range of SiTek's standard PSD-photodetectors as well as custom designed silicon photodetectors for special applications. With the ion implanting technique SiTek is able to meet almost all of our customers' unique needs.

Turn the page for applications!!

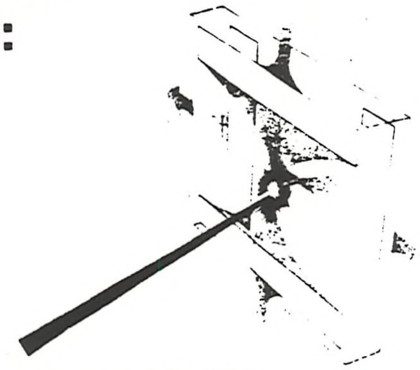
Examples of non contact measurements with the SiTek PSD:



DISTANCE MEASUREMENT

Distance measurement by SiTek's PSD is made by optical triangulation.

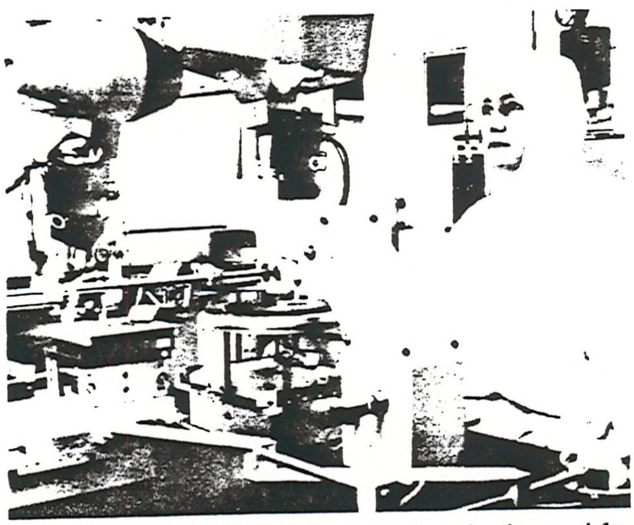
A beam of light hits a surface of an object. The light is reflected through a lens to a point on the surface of the PSD-photodetector. The light spot on the detector surface gives an indication of the distance to the object. If the distance is altered, the light spot on the photodetector surface will be displaced and thus indicating a change of the distance.



ALIGNMENT AND POSITION DETERMINATION

The same principle also applies to alignment and position determination. The light beam, e.g. from a laser, is centered on the photodetector and then a deviation of the location of the light spot along the x- or y-axis on the diode is instantly indicated as an analog signal with an outstanding linearity and accuracy.

> The outstanding feature of a system based on the SiTek PSD is that the measuring is made non contact and with an excellent precision and very high accuracy



In the advanced laboratory, a dye-bonder is used for packaging of detector chips.

How does the PSD work?

The SiTek PSD basically consists of a slice of silicon covered on both sides with very thin resistive layers. These layers are obtained by implanting ions of boron and phosphorus into the silicon surface. Two electrodes are then applied to each side of the detector.

When a light beam hits the detector, an electric current is created in the illuminated spot. The current then reaches the four electrodes and thus determines the exact position of the beam.

C R HINTZE AB is since ten years the exclusive distributor in Scandinavia for the EG&G Electro-Optics and Photon Devices groups. After acquiring the SiTek company, C R HINTZE AB has named the EG&G Photon Devices group in Salem, Massachusetts, USA, as the exclusive distributor in USA, Canada and Mexico for the SiTek PSD-photodetectors.

Here are some of the companies that already have discovered the SiTek PSD:

	TYPICAL APPLICATIONS:
AEROSPACE & RESEARCH SAAB Space, Lockheed, NASA, CERN, MBB, EG&G Photon Devices, Officino Galileo	*Positioning of objects in space with laser beams. E.g. docking and tracking.*
INDUSTRIAL MEASUREMENTS C-E Johansson, Fixturlaser, Remplir, Selcom, Deutsche Bundesbahn, Philips	*Alignment, centering, position, motion and distance determination.*
ROBOTICS ASEA, General Motors, Ford, Volvo, Selspot	*"Machine vision" – calibration of position and operation control in up to three dimensions.*
GEODETICAL ALIGNMENT SYSTEMS Kern, Wild, Fixturlaser	*Measurements of deformation and postition.*
ELECTROOPTIC COLLIMATORS Micro Radian	*Alignment and determination of tolerance.*

Another interesting field of application is in optical encoding. The SiTek PSD techonology will open up a new horizon where fast speed and high resolution together with non contact, non friction, non ware and independence of temperature are features that will make it possible for totally new solutions in the development of the new generation of optical encoders.

The SiTek PSD for measurements that need to be

NON CONTACT · NON FRICTION
NON WARE · INDEPENDENCE OF TEMPERATURE

C R HINTZE AB (Stockholm), Sweden, **phone +46-8-767 90 40,** facsimilie +46-8-767 53 02, telex 108 96 chintze s

HINTZE

C R HINTZE AB, Vasavägen 78, S-181 41 Lidingö (Stockholm), Sweden, **phone +46-8-767 90 40**

Position Sensitive Detectors PSD

ur SiTek® Standard PSD, UV-PSD and Nuclear PSD ome in many shapes and sizes.
Ve make them as standard 2-axis, 1-axis and 1-axis ircular.

Our standard production covers a wide size range.

2-axis PSD 20×20 mm, 10×10 mm, 4×4 mm
1-axis PSD 30 mm, 10 mm, 5 mm, 2.5 mm
1-axis circular PSD 10 mm diameter

Vhen we say size we mean a true effective size.
Vhen we specify a SiTek® PSD we give you the true minimum inearity over 80 % of the length of the detector chip.
Now you can forget the old story about all the large area PSD on he market where the specified linearity and useful measuring rea is only a "small" circular area in the middle of the detector hip.

The detectors have inherent, proven analog resolution of up to one part in ten million.

Outstanding Position Nonlinearity
The nonlinearity for a standard 1-axis PSD is typically ±0.1 % of detector length, with a maximum of ±0.2 %. For 2-axis PSD, a typical value is ±0.5 % and a maximum of ±1.0 %.
In addition, SiTek® can now produce a 2-axis special PSD with a *maximum* nonlinearity of ±0.5 %!

All SiTek® PSD-detectors can now, at a nominal extra cost, be supplied with a certificate of a computorized linearity calibration.

Extended Spectral Range – Another SiTek® "First".

SiTek® UV-PSD-detectors open up a world of new possibilities for applications as;

Wide Spectral Range Analytical Instruments
to
Three Dimensional Robotic Machine Vision.

SiTek® Nuclear PSD-detectors – One More SiTek® "First"

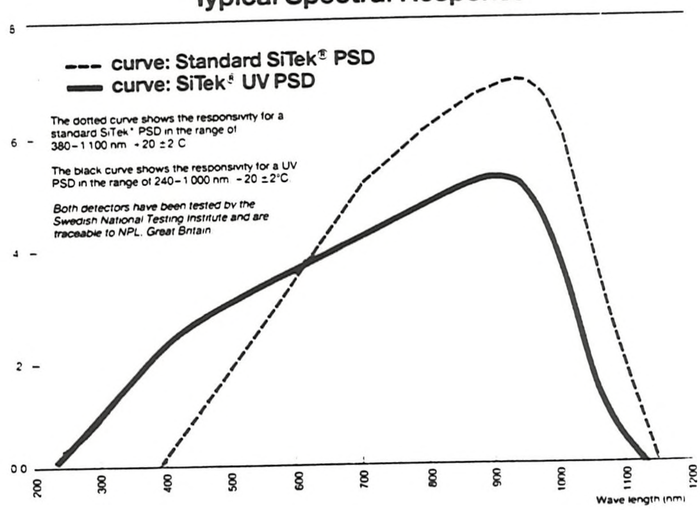
New SiTek® Nuclear PSD-detectors are now being field tested in particle accelerators in Sweden.
These are characterized by unusually high resolution at low energy levels – and promise to become a new valuable addition to the detectors used by scientists at all particle accelerator sites/laboratories.
New SiTek® Nuclear PSD-detectors have a dead layer on the chip of less than 500 angstrom – think about what that can mean for your next experiment . . .

Custom designed SiTek® PSD-detectors up to 45×45 mm

Being a small, lean and hungry company we understand and can meet the needs for fast, cost effective development and production of custom designed PSD.
A typical lead time for a custom designed SiTek® PSD is less than 8 weeks.
Ask any of our competitors if they can match that!!

We have over 10 years of experience of development and production of silicon-based PSD and other detectors. We know that most of our best customers achieve better performance of their PSD-based instruments and systems when we meet their needs with our skills.
Try us next time you need a silicon based detector that you cannot find in the catalogue of "the big guys".
We make them in any shape, size or configuration you may want.

Typical Spectral Response



When we at Hintze/SiTek® say

A Breakthrough for PSD-Technology

– we stand behind it!

Turn the page for a typical data sheet!

SiTek® Products

***Two dimensions** – examples of available sizes: 4×4 mm, 10×10 mm, 20×20 mm*

Active area = 10×10 mm
Chip area = 12.2×12.2 mm

Temp = 23° C, Bias = 15 V,
Wavelength = 940 nm

DATA	MIN.	TYP.	MAX.	
Position nonlinearity		0.5	1.0	% (+ −)
Detector resistance	7	10	16	kohm
Leakage current		200	800	nA
Noise current		1.3	2.4	pA/sqr(Hz)
Responsivity		0.7		A/W
Capacitance		90	110	pF
Risetime (10−90 %)		0.2	0.4	µs
Bias voltage	5	15	20	V
Max voltage			30	V
Thermal drift		40	200	ppm/°C(23−70°C)
Operating temp.			70	°C
Storage temp.			100	°C

***One dimension** – examples of available sizes: 2.5×0.6 mm, 10×2 mm, 30×4 mm*

Active area = 10×2 mm
Chip area = 12.2×3 mm

Temp. = 23° C, Bias = 15 V,
Wavelength = 940 nm

DATA	MIN.	TYP.	MAX.	
Position nonlinearity		0.1	0.2	% (+ −)
Detector resistance	40	50	80	kohm
Leakage current		100	400	nA
Noise current		0.6	1.0	pA/sqr(Hz)
Responsivity		0.7		A/W
Capacitance		15	20	pF
Risetime (10−90 %)		0.2	0.4	µs
Bias voltage	5	15	20	V
Max voltage			30	V
Thermal drift		40	100	ppm/°C(23−70°C)
Operating temp.			70	°C
Storage temp.			100	°C

Position nonlinearity and temp.drift are measured within 80 % of det. length
Thermal drift is measured from 23 C to 70 C.

HINTZE

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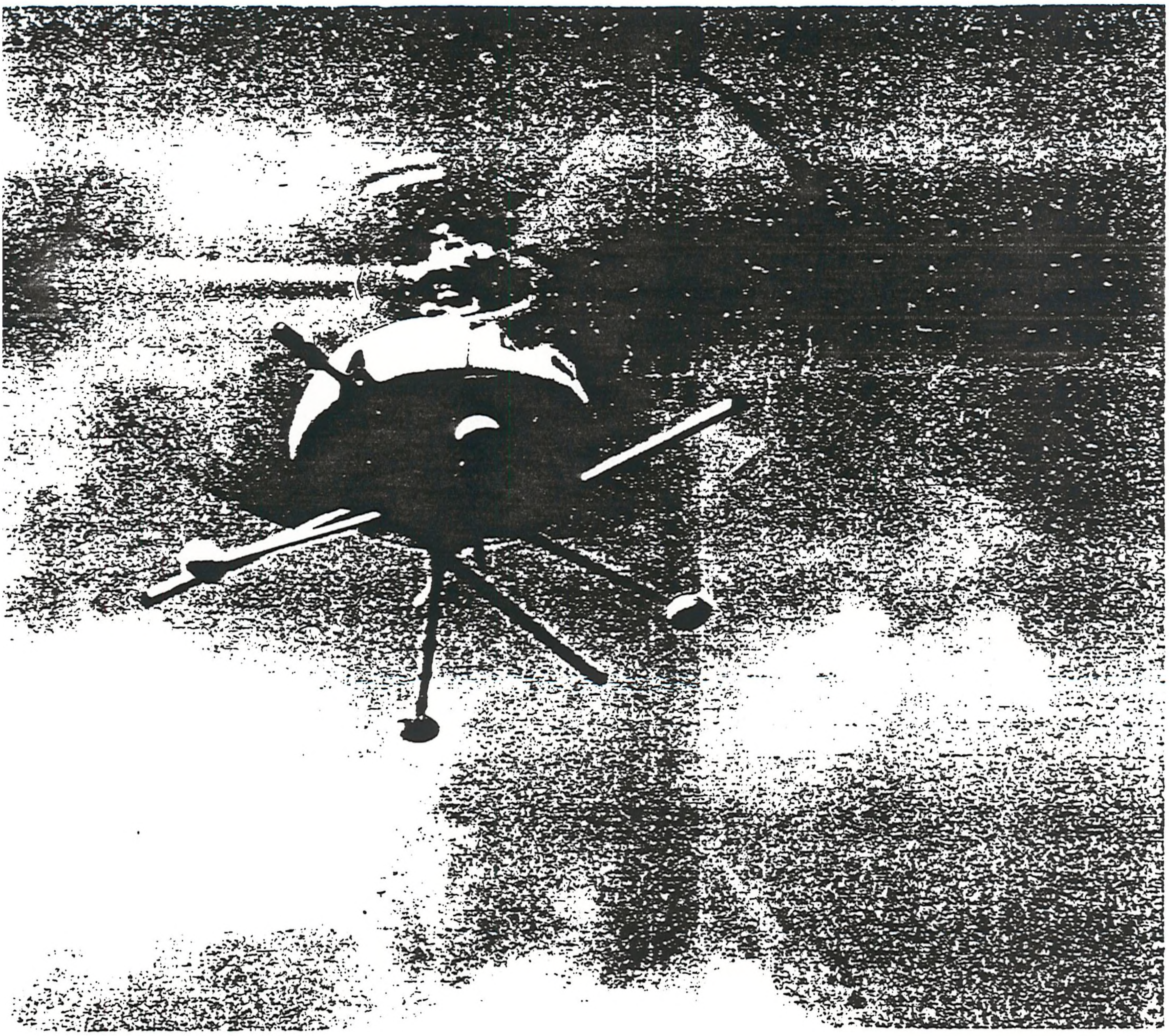
Laser Altimeter



;curate height
'ormation
low altitude

duction

ORN EMI Laser Altimeters are now
ble for use in Remotely Piloted
›pters (RHP) and Vehicles (RPV).
ә laser altimeters will provide accu-
ıformation to the control system for
otely piloted helicopter (or vehicle).
ate height information at low altitudes
icularly important as one of the pri-
functions of the device is as an aid
ıutomatic descent control system
ıding.

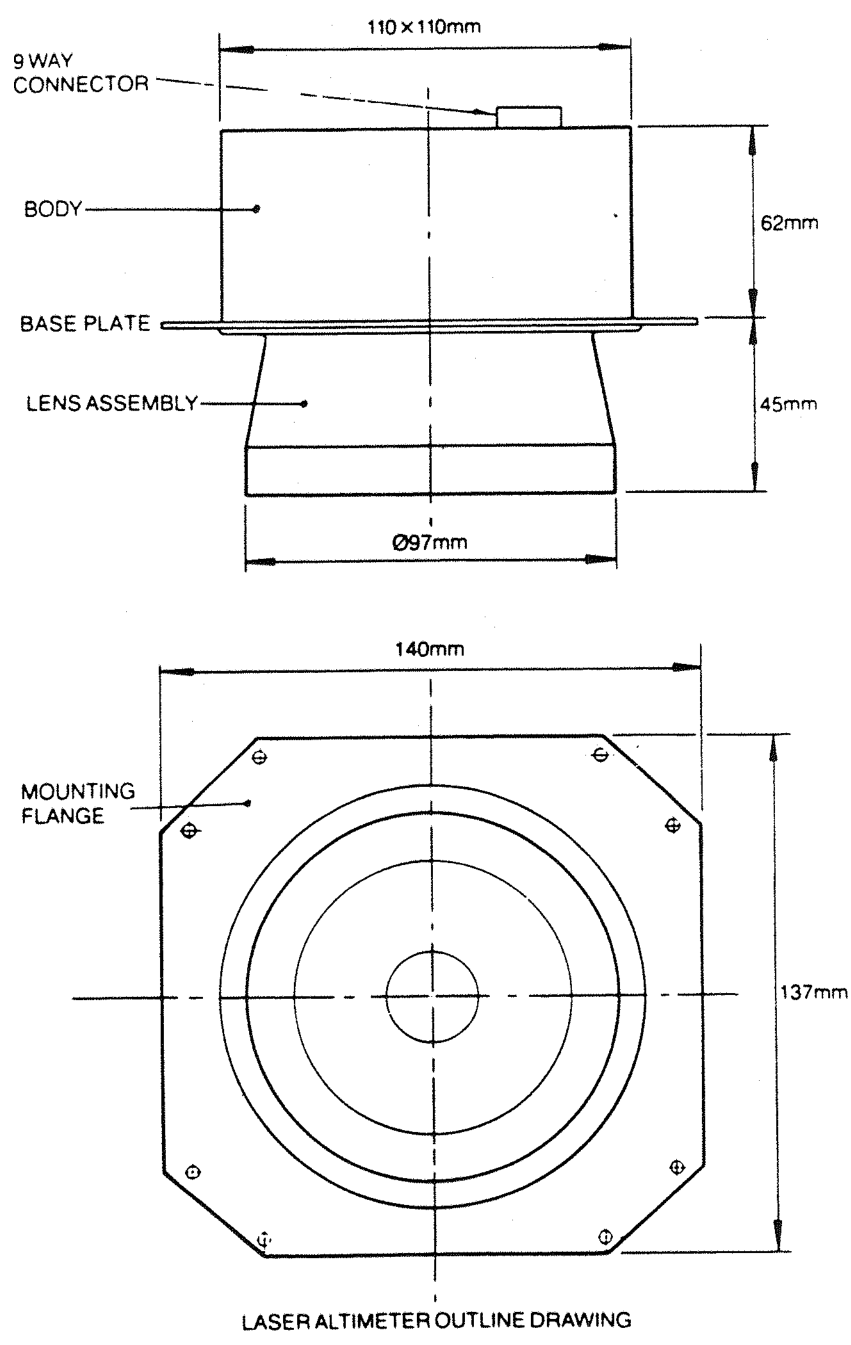
ɔiple of operation

rrow pulses of infra-red radiation
ınsmitted in a 1° beam; the received
ted pulses are focussed onto a sen-
detector. The received signals after
fication are processed to generate
ate range measurement using con-
›nal timing techniques. The range
›ration is from less than 0.5m to
ər than 50m.

hanical configuration

e mechanical construction and key
ısions are shown in the diagram.
ase plate provides the mounting
ɔe for the unit and the major support
ә optical assembly. The electronics
ıge which is housed in a cuboid
d the lens assembly can be repack-
to suit a given space envelope
ıgh the volume of optics would
in unchanged. The whole
ıge conforms to the mechanical
rements associated with MOD Air
100B Certificate.

DING EDGE TECHNOLOGY
)NT LINE APPLICATIONS



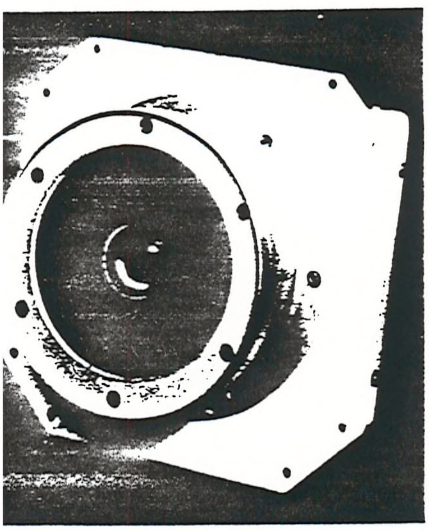
LASER ALTIMETER OUTLINE DRAWING

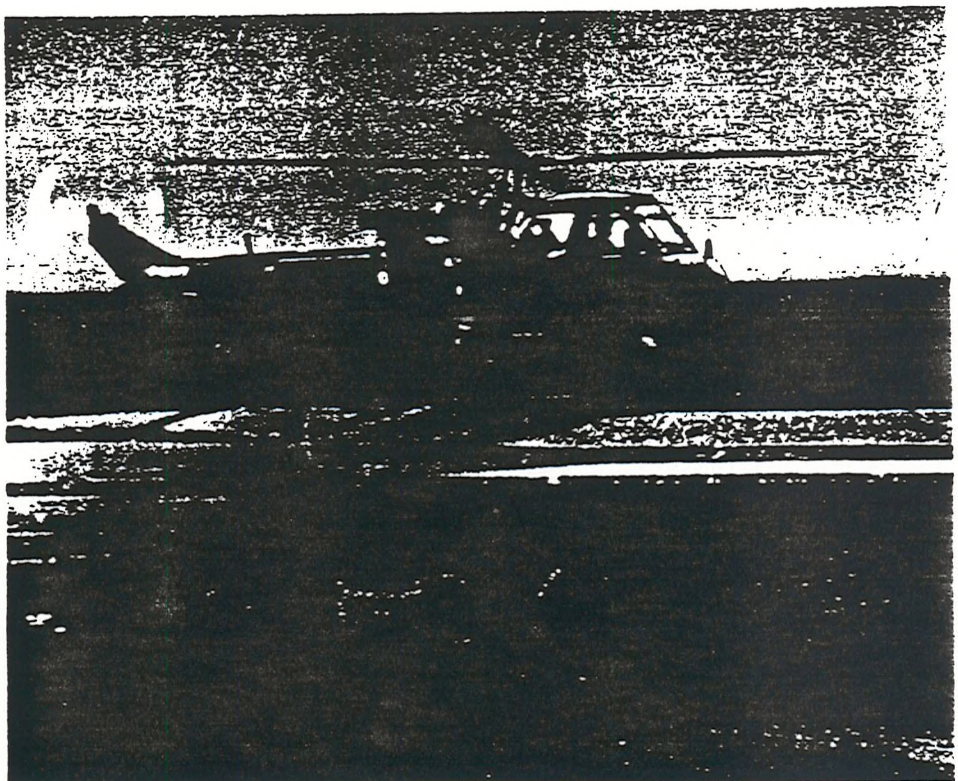
Cover
\viation's Sprite R.P.H.
ı with Laser Altimeter

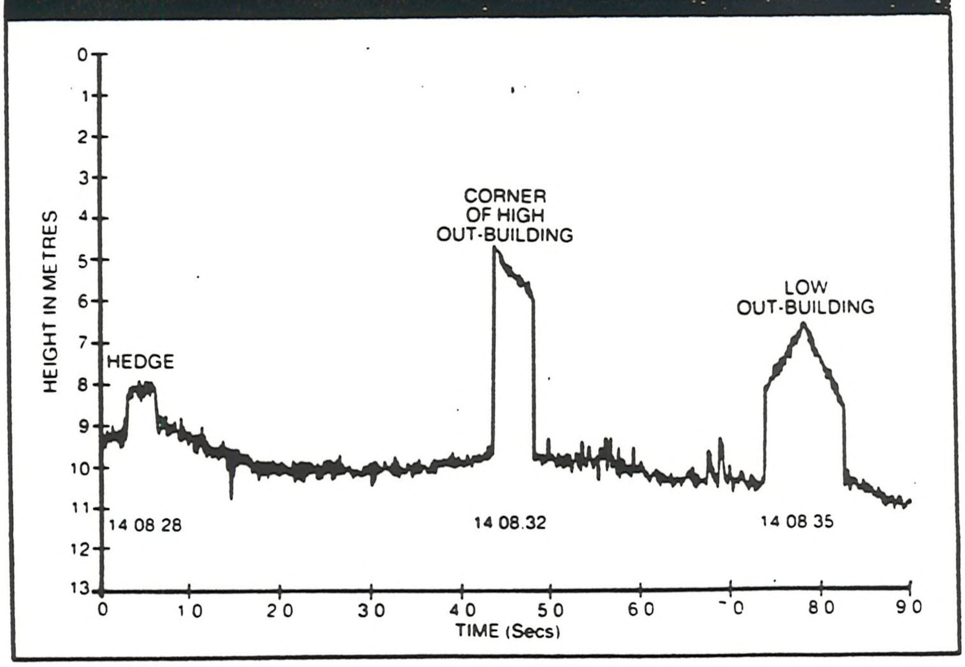
'HORN EMI .aser Altimeter

The photograph below shows the
monstrator model of the laser altimeter
signed and built for the Westland
'isp' remotely-piloted helicopter.

Accurate ranging
Compact and lightweight
Eye-safe

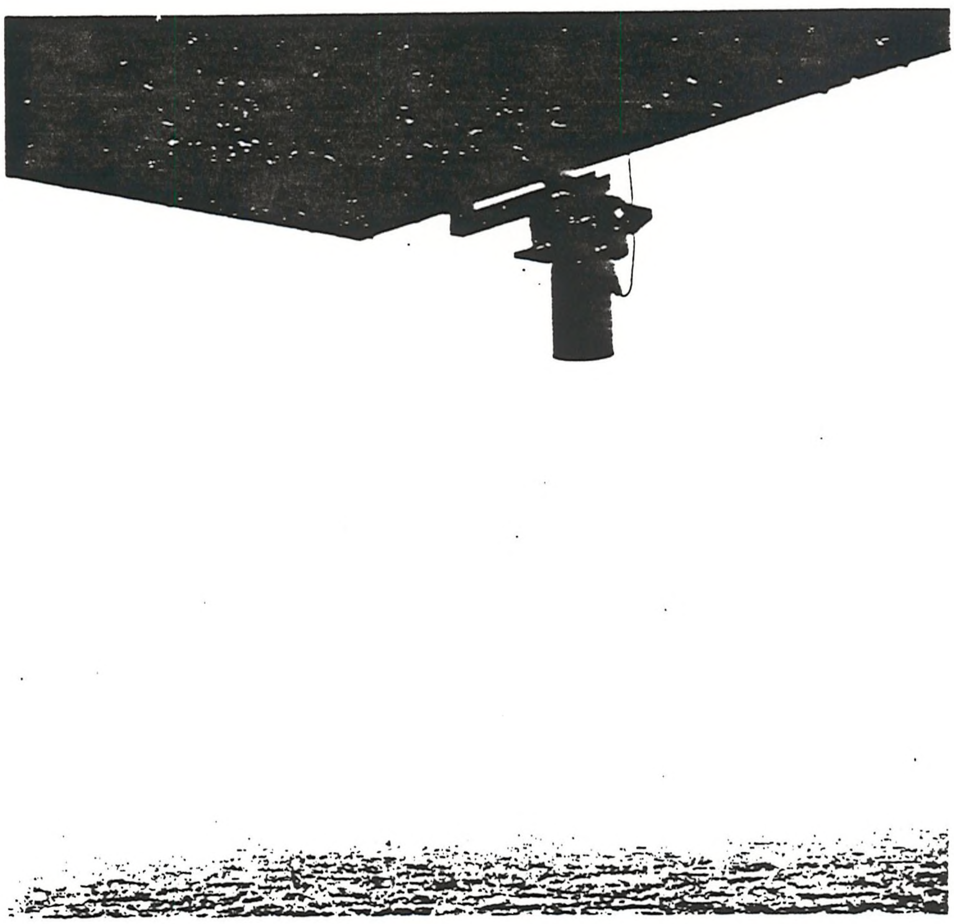






Ground profiling trials of the laser alti-
eter mounted on a conventional heli-
pter demonstrate its high degree of
solution. For instance, the key features
the deserted farm over which the heli-
pter has just flown can be clearly identi-
ed from sensor response.

aser Altimeter



formance

imum Range
n

ximum Range
)m

uracy
ı to 50m ± 1%
n to 10m ± 0.1m

ety
ally eye-safe
ss 1 laser product
lefined by BS 4803

e and weight
ce envelope
nm × 110mm × 107mm
ght – less than 1kg

ver requirements
)W (from a nominal 12 volt supply)

ironmental
copter vibration environment
)°C to +35°C
anding force

erational

ain
d – accurate operation
– accurate operation is limited above 5° to 10° of vehicle attitude over a glassy surface

ural Environment
y operational except in conditions of
‹ fog/cloud or thick dust and sand

tem processor/Design operation
following occurrences are indicated:
ude greater than a pre-set figure
s of IR signal
s of power
tain modes of equipment failure

Other applications for the device include

- ☐ Wave-height monitor (in full production)
- ☐ Aircraft landing aid
- ☐ Helicopter and VTOL operations

Note: Continuous review of product performance may result in the specifications in this brochure being changed without notice.

Other variants
Altimeters with ranges in excess of 300m are also available

THORN EMI Electronics
Defence Systems Division

THORN EMI Electronics Limited Defence Systems Division
Victoria Road Feltham Middlesex TW13 7DZ telephone 01-890 3600 telex 24325

Printed in UK Bridge 85 12/50

Helicopter Obstacle Warning Device

rt of a battlefield ionics package · attack helicopters.

duction

ORN EMI Electronics is developing em based on laser technology fully meets the requirement for an cle warning device for helicopters. ystem is ideally suited for night tions and is capable of detecting 'dead" cables (i.e. without power). e company has a contract with the Systems Department of RAE orough to develop this obstacle ng device as part of a battlefield cs package for attack helicopters. ackage was introduced at the orough International 82. The t has now reached a stage where rformance has been demonstrated hardware with an operational cable ion range already in excess of 400m rge targets such as buildings, trees, ylons can be clearly identified at s over 1km.

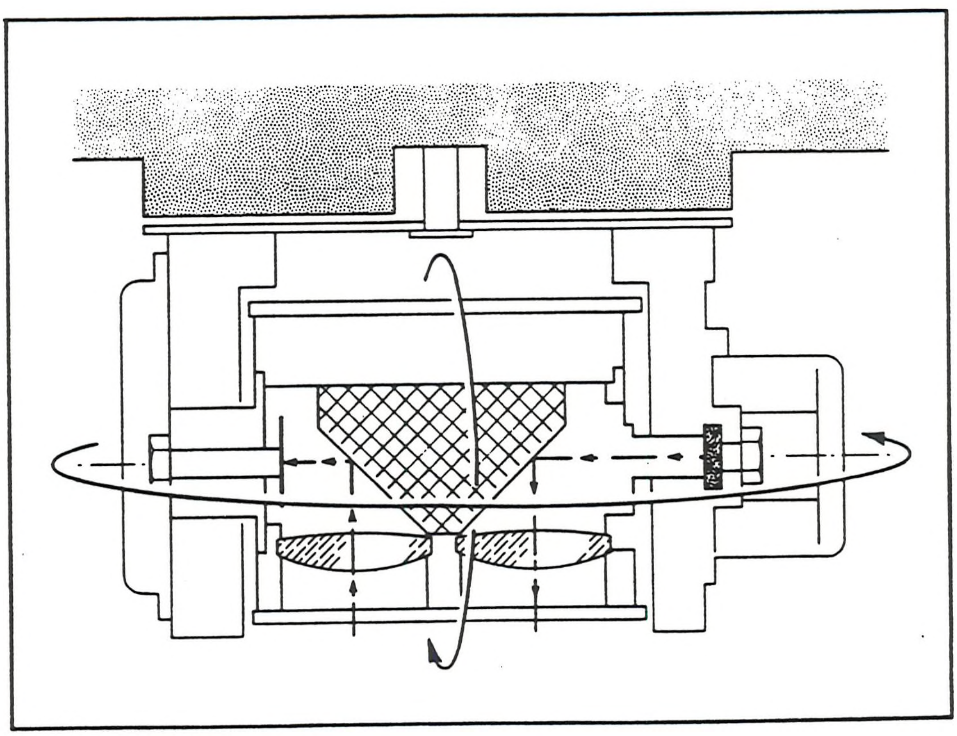
Applications

- ☐ Obstacle warning at night (including dead cable detection)
- ☐ Station-keeping under battle and adverse flying conditions
- ☐ Aid to formation flying

Principle of operation

Short pulses of infra-red radiation are transmitted in a narrow pencil-shaped beam. The pulses reflected from the target, such as a cable or tree, are received and focussed onto a sensitive detector. The received signals are processed to generate accurate range measurement.

The complete system is mounted below the nose of the helicopter (or other suitable vehicle) on a horizontally-rotating platform; a mirror is used to further rotate the laser beam in the vertical plane. This scanning arrangement allows the beam to be swept once every second over a complete hemisphere below the vehicle. In this way, a topographical "map" of the local air/ground environment can be produced. By suitable signal processing and using information concerning the flight path and vehicle attitude, information on obstacles to safe navigation can be presented to the pilot as a simple audio or visual warning or as a pictorial representation. Outputs from the system can also be fed to the Air Data Computer (ADC) to provide in-flight information and to the autopilot for automatic flight control.



uitable for wide ange of civil nd military uses.

ıer applications

)ther military and civil uses for the tacle warning device include:

)ff-shore operations

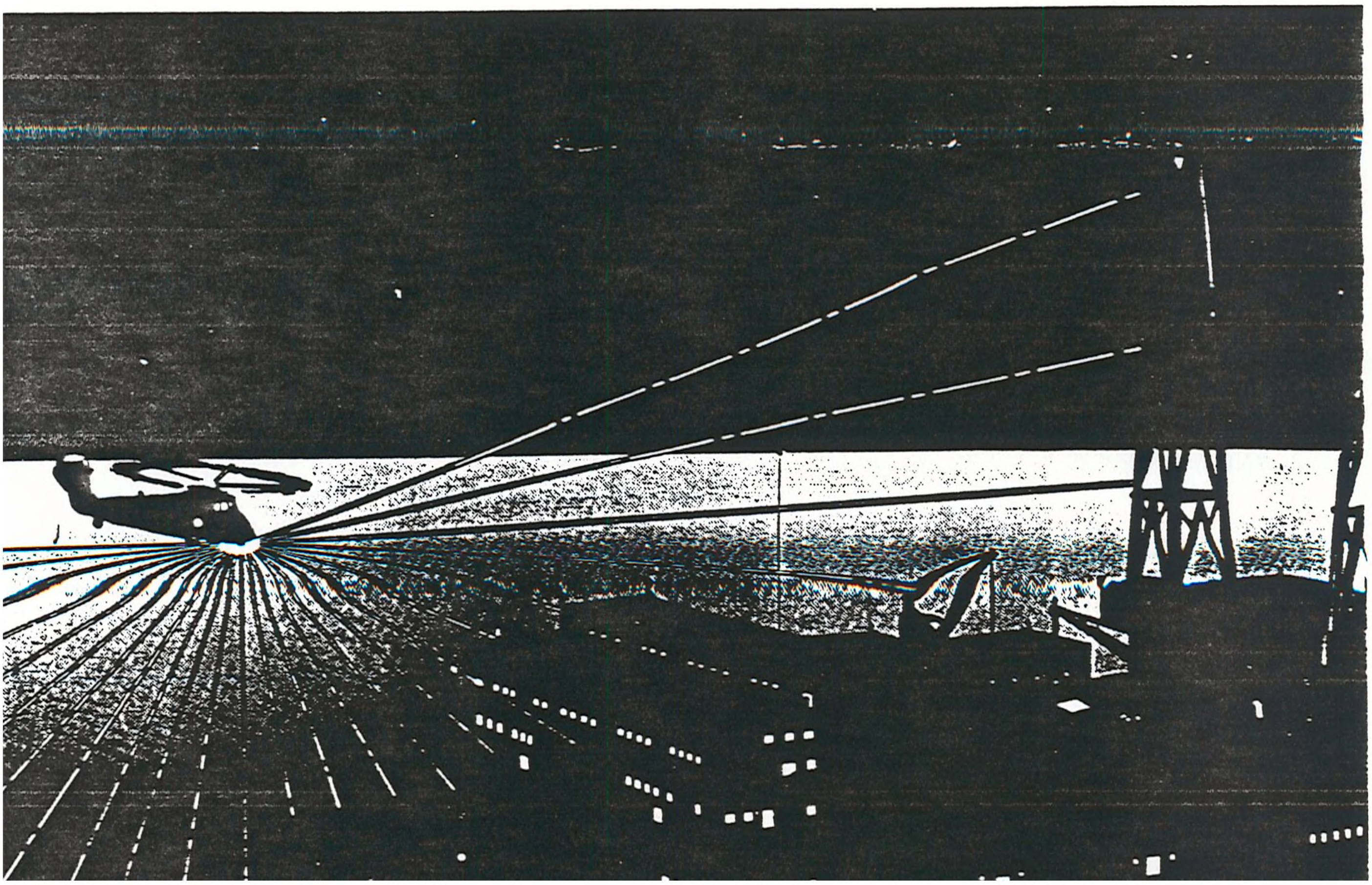
\ir-sea and cliff-face rescue operations

\aval small ship operations

?econnaissance data gathering

/STOL/VTOL operations in confined ;paces

The THORN EMI obstacle warning device has potential application to helicopters operating off-shore for automatic approach to and landing on platforms.



ɘlicopter Obstacle
arning Device

ɪrmance

um Range

ɪum Range
detection greater than 400m
targets beyond 1km in clear air

ar Resolution.
ing at less than 2° intervals

e Rate
ɜmisphere per second

afe Viewing Distance

nd Weight
n diameter x 450mm, 10kg
ional)

wer Requirements
n a nominal 28V DC supply
ional)

ɔnmental
pter vibration environment −20°C
°C

bility

ddition to the hemispherical general
ge of the system, there will be a
for electronically reducing the area
ch/coverage. It will also be possible
ignal processing techniques to
ɜ a station-keeping and formation-
apability with inputs to the autopilot
ɔC.

*ɔntinuous review of product performance
ult in the specifications in this brochure
anged without notice.*

THORN EMI Electronics

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