ROUGH-TERRAIN GROUNDSPEED MEASUREMENT: A RADAR-BASED COMMERCIAL SOLUTION.

VOLUME ONE OF TWO VOLUMES

A THESIS SUBMITTED TO THE
UNIVERSITY OF ASTON IN BIRMINGHAM
BY CHRIS WALLACE IN JULY 1985 FOR
CONSIDERATION FOR THE DEGREE OF PH.D

Interdisciplinary Higher Degree Scheme

THE UNIVERSITY
OF ASTON
IN BIRMINGHAM

SUMMARY OF THE THESIS PRESENTED BY CHRIS WALLACE

FOR THE DEGREE OF Ph.D IN 1985

Off-highway motive plant equipment is costly in capital outlay and maintenance. To reduce these overheads and increase site safety and workrate, a technique of assessing and limiting the velocity of such equipment is required. Due to the extreme environmental conditions met on such sites, conventional velocity measurement techniques are inappropriate.

Ogden Electronics Limited were formed specifically to manufacture a motive plant safety system incorporating a speed sensor and sanction unit; to date, the only such commercial unit available. However, problems plague the reliability, accuracy and mass production of this unit.

This project assesses the company's exisiting product, and in conjunction with an appreciation of the company history and structure, concludes that this unit is unsuited to its intended application. Means of improving the measurement accuracy and longevity of this unit, commensurate with the company's limited resources and experience, are proposed, both for immediate retrofit and for longer term use. This information is presented in the form of a number of internal reports for the company.

The off-highway environment is examined; and in conjunction with an evaluation of means of obtaining a returned signal, comparisons of processing techniques, and on-site gathering of previously unavailable data, preliminary designs for an alternative product are drafted. Theoretical aspects are covered by a literature review of ground-pointing radar, vehicular radar, and velocity measuring systems. This review establishes and collates the body of knowledge in areas previously considered unrelated.

Based upon this work, a new design is proposed which is suitable for incorporation into the existing company product range. Following production engineering of the design, five units were constructed, tested and evaluated on-site.

After extended field trials, this design has shown itself to possess greater accuracy, reliability and versatility than the existing sensor, at a lower unit cost.

KEYWORDS:

Microwave, Doppler, Velocity, Backscatter, Off-highway.

"Have you guessed the riddle yet?" the Hatter said.
"No. I give up" Alice replied. "What's the answer?"
"I haven't the slightest idea" said the Hatter.
"Nor I" said the Hare.

ACKNOWLEDGEMENTS

I thankfully acknowledge the invaluable assistance of my university tutor and supervisor, Dr A J Cochran; industrial supervisor, Mr A B Love; and associate supervisors, Mr G Jones and Mr A Montgomerie.

Thanks also to Mr Hickson, tutor for the early months of the project and Dr Van Rest, Head of the IHD Department; indeed to all the IHD staff.

May I thank the OEL staff, including Mr D Davey for the prolonged loan of laboratory equipment; and Lynne and Towney, who provided valuable assistance.

Note must also be made of the Aston University departments who willingly provided advice: mechanical engineering, electronic engineering, the microprocessor unit, physics, metallurgy and the management centre.

And not forgetting everyone, especially family and friends, who not only tolerated my jubilation at successful moments and despondency at setbacks, but offered advice and encouragement.

Financial support for this project was provided by the Ogden Group of Companies in conjunction with the Science Engineering Research council, award No. B81303497.

LIST OF CONTENTS.

PAGE

VOLUME ONE

CHAPTER FOUR PAGE

THE ASSESSMENT OF POSSIBLE UNIT FEATURES

CHAPTER FIVE

A REVIEW OF LITERATURE RELATING TO THE USE OF RADAR AND ELECTRONICS

PAGE

VOLUME TWO.

SUPPLEMENTARY MATERIAL SECTION.

CHAPTER TWELVE

LITERATURE REVIEW: DETAIL

SECTION ONE

DATA RECORDINGS

SECTION TWO

COMPANY REPORTS

PAGE

SECTION THREE

APPENDIXES

LIST OF TABLES, FIGURES AND PHOTOGRAPHS

INTRODUCTION TO THE FORMAT OF THIS THESIS.

SECTIONING AND STYLE.

It is pertinent at the outset to introduce the format of this thesis, and to illustrate the benefits of the approach adopted.
The thesis is divided into three distinct parts collated into two volumes (refer to fig Pref 0A). These are:

1 The main body of the thesis, constituting the 'story' of the project undertaken,
2 Supplementary material, consisting of reports written during the course of the work; graphical data and the bulk of the literature review work.
3 Appendixes: material of use in further understanding the project.

This format has three major advantages.
Firstly, volume one, containing part one, can stand alone. Hence if an overview of the project is required, volume two can be dispensed-with. Where greater detail is required, reference is made throughout volume one to the relevant sections in volume two.
Secondly, the reports compiled throughout the project can appear in their original (re-typed) form,
And finally, the appropriate section of the main body of the thesis can be read whilst simultaneously referring to the appropriate backup data in volume two.

Inevitably therefore, the supplementary material sections contain much that might usually be incorporated into the main body of a more conventional thesis format.

The general style is semi-chronological, allowing, in the writer's opinion, problems encountered throughout the course of the work (and, hopefully, their solutions) to be presented in the most comprehensible manner. But such a style is necessarily a compromise. Consequently, often work performed over an extended period of time is collated into one section: chapters five and six, for example, describe work carried out over two years.

The achievement of objectives throughout the work is very much 'continuous', with few defined landmarks. Hence the writer apologises for the lack of either an identifiable 'common thread' or a sequence of fulfilled tasks with which to guide the reader through the work.

RESUMÉ OF THE CONTENTS.

PART ONE.

Chapter one provides background information on the scheme under which the project was organised; introduces the participants; and presents a brief history of the formation of the sponsoring company. The early stages of project selection are also documented. The process of final project selection is continued in chapter two, which outlines work performed by the company on development of the speed sensor unit in a historical context. Having established the background to both the company and product, chapter three presents the project format and methodology, and continues with the writer's technical evaluation of the speed sensor.

The next five chapters document the process of acquisition and collation of information required to fulfill the project brief. Chapter four examines possible unit modifications and features for both the present unit and a prototype new unit, and discusses the basis of on-site data gathering. Chapter five reviews all areas of literature pertinent to the project brief including radar-terrain interaction, radar parameters, electronics in vehicular applications etc. Chapter six discusses the interpretation of graphical data derived from laboratory, road and site trials using the existing unit, and several forms of prototype unit. A definition of the off-highway environment and its effect on radar and electronics forms chapter seven, which proposes a full environmental test schedule based on this information. Chapter eight provides an insight into the effect of commercial factors, company structure and attitude on the project progress.

The development, construction and test of a production prototype sensor unit forms chapter nine.

The project progress and outcome is discussed in chapter ten, with chapter eleven providing details of further work, recommendations and a recapitulation.

The final section of volume one, the suffixes, contain references and a bibliography.

PART TWO.

Chapter twelve presents an extended review of the work covered in resume form (chapter five) concerning pertinent literature. Section one of volume two contains all graphical and spectrum data collected on the 'returned signal' investigation, discussed in chapter six.

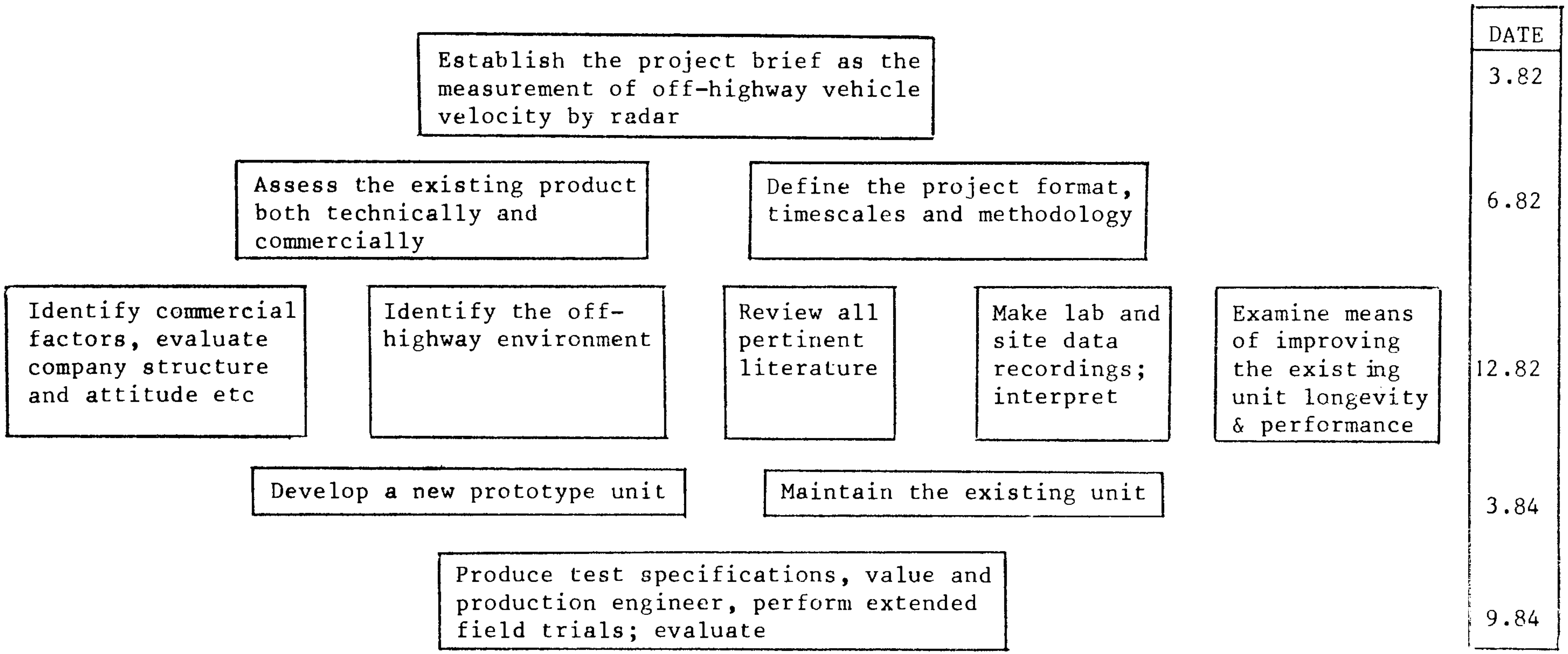
Section two comprises a collection of the reports produced during the course of the project. Page numbers reflect the report number.

PART THREE.

This section contains the appendixes to the thesis.

1 The project scenario; 2 Definition of the project and early history of the speed sensor	GENERAL PROJECT BACKGROUND	SECTION ONE	VOLUME ONE
3 Evaluation of the existing speed sensor unit	TECHNICAL EVALUATION		
4 Assessment of possible unit features; 5 Literature reviews; 6 Data recordings and analysis; 7 Environmental assessment and specifications; 8 Commercial factors and company structure	DATA GETHERING		
9 Production prototypes: construction and test	TECHNICAL RESULTS		
10 Discussion and conclusions; 11 Proposals, further work and resume	EVALUATION OF PROJECT		
References and bibliography			
12 Literature review: detail; 2.1 Data recordings: graphical output; 2.2 Reports produced during project	SUPPLEMENTARY MATERIAL	SECTION TWO	VOLUME TWO
2.3 Appendixes	APPENDIXES	SECTION THREE	

THE STRUCTURE OF THIS THESIS. FIG PREF 0A



This diagram illustrates the 'parallel' nature of the tasks undertaken during the project, and gives an indication of the timescales involved. A full chronology appears in appendix 3.3 (volume two).

A DIAGRAM OF THE PROJECT LANDMARKS. FIG PREF OB

OBJECTIVES

- To document the problems met in the measurement of off-highway vehicle velocity by Doppler radar, in terms of technical, resource and management factors,

- To maintain the existing product until any new product can be substituted,

- To design, develop and test to production stage, a new sensor unit.

METHOD

- A literature review of the theory and practice of irradiation of terrain by X band radar, radar and electroncs in vehicular and off-highway applications etc,

- An assessment of existing products and designs,

- An examination of the sponsoring company's structure and pertinent commercial factors,

- An examination of practical difficulties and alternative approaches in areas of design, evaluation etc,

- Development of test systems and experimental procedures,

- Design, development and evaluation of suitable circuitry

- Collection, interpretation and utilisation of data recordings from laboratory, road and site,

OUTCOME

- A new, accurate and reliable speed sensor,

- An increased facility system costing less than the present unit,

- New data on off-highway terrain and on the applications of low-cost Doppler systems to vehicular velocity measurement.

PROJECT OBJECTIVES, METHOD AND OUTCOME

FIG Pref OC

SECTION ONE

MAIN BODY OF THESIS

CHAPTERS ONE TO ELEVEN INCLUSIVE

CHAPTER ONE

THE PROJECT SCENARIO

"Such a number of wrong paths present
themselves in the investigation of
the sciences. Through how many errors,
each more perilous than truth itself,
must we not pass to arrive at it ? "

Jean Jacques Rousseau.
A discourse on the arts and sciences.

CONTENTS

SECTION

FIGURES AND TABLES

1.1 INTRODUCTION TO THE PARTICIPANTS

1.1.1 The Interdisciplinary Higher Degree Scheme.

The University of Aston in Birmingham Interdisciplinary Higher Degree Scheme (UoA IHD) was established in 1968 following the Swann report (HMSO 1968) which recommended closer cooperation between universities and industry. Consequently the IHD department establishes and coordintes a wide range of projects sponsored by industrial and commercial organisations.

It is pertinent to outline the specific aims of the scheme, such that a contrast with the more traditional Ph.D approach can be appreciated from the outset. The intention is to broaden the student's experience by means of 'interdisciplinary research training' (Van Rest 1980): the philosophy behind this approach is discussed in depth by Cochran (1981) who states that the scheme intends to:

".. equip postgraduate students for positions of responsibility in industry by providing training in practical, real-world problem-solving in the: application of existing knowledge, generation of new knowledge needed, appreciation of different academic disciplines, appreciation of practical constraints, and the implementation of solutions in the real world."

Chang (1973) quotes the Joint Science and Social Science Research Council as stating that:

"...research in breadth is as challenging and demanding as specialist research: it is in no way superficial or shallow, and requires able people to pursue its aims; and is a proper activity for a university to undertake..."

The breadth of research within the IHD scheme stems from the project structure, which is based on a three year period of research intended to solve a real-life industry-based problem. The student is guided by a committee consisting of academic disciplines, industrial supervisors from the sponsoring organisation, and an IHD tutor who co-ordinates the research as a whole. Each student spends the majority of his time working with the sponsoring organisation on the project: the remainder being at the university, where both specialised IHD coursework on complementary topics, and formal courses on related topics, augment the project work and further realise the objectives of the scheme. IHD project methodology also differs from more 'conventional' research: one feature of this type of project is the gradual (indeed often painful) emergence of the true basis of the research and of the real beliefs and expectations of the project's participants. Van Rest (1980) states:

"The first year is a time for exploration, a time when there is room for the occasional blind alley; and also for examining what has been done elsewhere that might throw light on the path to take. Long shots can be tried and the whole area can be thought around so that by early summer, focusing can begin in earnest."

But even when the research area has been identified, the emphasis can shift. Indeed, this 'dynamic' aspect of the project provides the basis of the scheme's value: the student can, and is encouraged to, view problems from various angles and viewpoints; and to adapt accordingly. The final objective is that (Van Rest 1980):

"...at the end of the day the firm should have a series of manuals and drawings on how to do things, and if possible, a new product. The university will have some general lessons on how things work in practice, and authentic case-study material."

This ideal project progress is illustrated in fig 1.1. It is unlikely, however, that any real project will conform to this pattern. Hence, although the IHD philosophy has a significant bearing on the formation and progress of the project, deviations can be expected. This thesis to some extent is such a deviation; and thus an effort is made in the following material to explain the cause, and effect, of this project's peculiarities.

1.1.2 Introduction To The Sponsoring Organisation.

The Ogden Group of Companies (OGC) was formed in 1957 by Mr A Ogden, and presently consists of thirty-seven companies; employing several hundred people and producing an annual turnover of approximately ten million pounds. The present chairman and joint owner is Mr R Ogden, one of four brothers who comprise the main board. The group headquarters are located in Otley (near Leeds, West Yorkshire) where several divisions are based, including, at the time of writing, the writer's sponsoring company: Ogden Electronics Limited (OEL).

The mainstay of the group has been until recently, the use of plant equipment in construction work, mining, quarrying and demolition etc, although the rapid expansion also allowed the encompassing of a greater range of associated industries: coal recovery, stone crushing, etc, and an interest in the manufacture of off-highway trucks (DBJ Engineering Ltd, who have won a Queens award for technological achievement in 1979 and a design council award). One division of OGC alone trades with seventy-two countries, and has been awarded the Queens award for both industry and for export. The youngest division, OEL, was visited in 1983 by the Prime Minister, who had expressed an interest in DJB vehicles and in the OEL vehicular safety system. In 1984 Mr R Ogden was awarded the CBE.

1.1.3 Formation And Early History Of Ogden Electronics Ltd.

The circumstances surrounding the birth and early development of OEL had a great bearing, both directly and indirectly, on the course of this project; due partially to the age of the company: the writer joined ten months after its formation and four months before the full complement of staff had been appointed; and partially due to the company management, product and market position etc: factors assessed in later chapters. Thus the early history of OEL is described in sufficient depth to provide a background from which the factors affecting the course of this project can be identified.

The involvement of OGC in the area of plant equipment allowed the group to easily and quickly identify present and possible future needs of the industry. One such need was that of site safety: sites such as open quarry workings have poor accident records (65 fatal and 173 serious accidents in 8 years: HMSO 1980). But although OGC appreciated the potential market for site safety equipment, they possessed no experience in electronics. In late 1980, OGC was introduced by the Department of Trade and Industry to JMS Ltd, an electronics consultancy based at Dalton (west of Newcastle). JMS has previously collaborated with Taylor-Woodrow Ltd on their open-cast mining site at Butterwell (some thirty miles north of Newcastle) to develop a safety system termed ALBERT (acronym for Analogue Linear Bipolar Ranging Transducer), as a result of two recent site deaths.

Thus, OEL was formed by OGC specifically to manufacture ALBERT, with the management comprising a combination of JMS staff and caretaking directors from OGC until suitable production, sales and marketing personnel could be recruited; although a production workforce had been appointed. The production facilities were installed at Bowburn (near Durham), and production proper commenced within five months with a capacity of forty complete systems per week.

Believing the system to be fully developed, active marketing took place both in Britain and abroad. Discussions took place with, for example, the Bureau of Mines and the National Transportation Safety Board in July 1981 (OGC 1982). In October 1981 the writer joined the company as a research and development associate: a temporary post.

By late 1981, by which time OEL management had taken over production (although no personnel with any experience in electronics were yet employed), it became apparent that the system had severe failings, and production was postponed pending a full technical reassessment. Several reasons for the malfunctions were found to be fundamental: development and testing had all been conducted under favourable circumstances, and provided no indication of performance in the harsh environment for which the system was intended. Much of this thesis is dedicated to the reasons why such systems work in 'controlled' tests, and yet fail, or work unreliably, in real conditions.

OEL thought that by collaborating with Marconi Radar Systems Ltd, alternative man-detect and tip-edge sensors could be developed quickly, whilst OEL concentrated on the remaining seemingly minor problems. In the event, the development of suitable sensors took several years, and other aspects of the system were found to require rather more fundamental re-engineering than first thought.

In the light of these delays, production at Bowburn ceased, and in October the production unit was moved to Otley, where a skeleton workforce was maintained to provide servicing facilities. The difficulties met by MRS prompted JMS to commence the design of alternative units, but these were also found to suffer from apparently insurmountable problems. Thus, the remaining OEL servicing personnel were laid-off, and research links with JMS were severed.

Thus, OEL found itself, whilst waiting for the MRS sensors, playing the role of a development unit: a role for which it was not intended.

An employee and location chart is given in fig 1.2: this illustrates the short, but dramatic lifespan of OEL. The detailed history of OEL is of course, more complex. If greater depth is required, this will appear in later text.

1.2 BACKGROUND TO THE PROJECT SELECTION

1.2.1 Project Selection

This section presents an overview of the reasons for selection, and reselection of the writer's original project. As the writer joined when ALBERT was seen as a fully developed product, the original project was concerned with a radically different topic: the examination of the means by which the copyright laws pertaining to cassette and video tapes could be enforced. To this end, several months were spent performing a feasibility study, literature review, and an appreciation of copyright laws and the viewpoint of all associated bodies. Whilst it was clear at the outset that the 'invention' of a system capable of preventing illegal home-taping was most unlikely, the possibility of patenting and licensing 'conceptual' solutions was considered. It soon became clear that no solution, practical or conceptual, could be proposed. The feasibility study, some sixty pages long, is not included in this thesis.

Thus, in December 1981 alternative products were being considered. By now OEL was based solely at Otley, and the limited research facilities (see fig 3.1) meant a project concerned, or at least linked, with plant and off-highway equipment with which, by virtue of the development work performed to date on the ALBERT system, OEL had some previous experience.

After much discussion, the new project, as initially conceived, was of a vehicular monitoring and diagnosis system specifically for heavy plant (OEL 11.81). Such a project was a logical choice: ALBERT by now was seen to suffer from 'minor preproduction teething troubles' and OEL had been contacted by Euclid Inc, themselves engaged in the development of an engine monitoring and safety system for off-highway applications (including several features similar to ALBERT: EUC 1981). In July 1981, JMS advised OGC that the ALBERT system could be modified to incorporate the Euclid concept (OGC 7.81, OGC 1982). Other manufacturers had also expressed an interest in such systems (OGC 10.81). However, there was some confusion about the design basis of ALBERT. The OEL caretaking directors believed the system to be microprocessor based, and hence capable of significant modification and upgrading. In fact this was not the case. To clarify this point, a brief report was compiled by the writer highlighting the design factors of the system (report INT P10). The confusion was compounded by the sales brochure (see appendix 3.6a) which refers to microprocessors, and illustrates the system as required. Fig 1.4 indicates the factual state of the unit. Observers within the industry thus also referred to a 'microprocessor-based' system (Little, V9; HMSO 1980; HMSO 1981).

It was realised that the plans to incorporate the Euclid system into ALBERT were unworkable; and meanwhile other products performing similar tasks were being announced (Masai 1981; Gruben 1980; Gradline; Hopson 1981).

The writer thus conceived a project to update the ALBERT system and thence to incorporate the more relevant diagnostic and engine monitoring facilities as discussed with Euclid. The project title was provisionally defined as 'vehicular information management', with the intention being to produce a unit capable of monitoring all important truck functions such as engine, hydraulics etc, warning of pending unit failure and overriding the operator if necessary. The system would also assess optimum service intervals and provide hard-copy diagnostic analyses of truck reliability. Some weeks into this project it became apparent that its success would depend upon an extended, and possibly fruitless, search for suitable transducers. Contact with acknowledged experts within the industry confirmed that the project would indeed hinge upon the design of suitable transducers and sensors. Therefore the project brief was rejected.

Whilst this study was being undertaken, the OGC caretaking directors handed over to the newly-appointed OEL staff. It was now fully appreciated that the ALBERT system required much work: a review by OEL (OEL 1982) listed twenty aspects of the system requiring further action in order that the system be "totally reliable before production and sales can start". So, complementary to the work being performed by MRS, a project was conceived whereby the writer would examine exactly why the present radar system sometimes malfunctioned inexplicably, and examine the feasibility of low-cost signal discriminators.

The ALBERT system had by now been fitted to trucks at Butterwell for several months on a free loan basis in exchange for access to the site for modifications, repair and testing. It was this customer who required roadspeed sensing, so the poor performance of this aspect of the system was of major concern. The project brief was to examine the selection criterion and design methodology involved in low-cost signal processing, and to develop a procedure which would assist in defining techniques involved in the processing of signals derived from suitable transducers. The speed sensor was seen as a suitable case-study within this design brief.

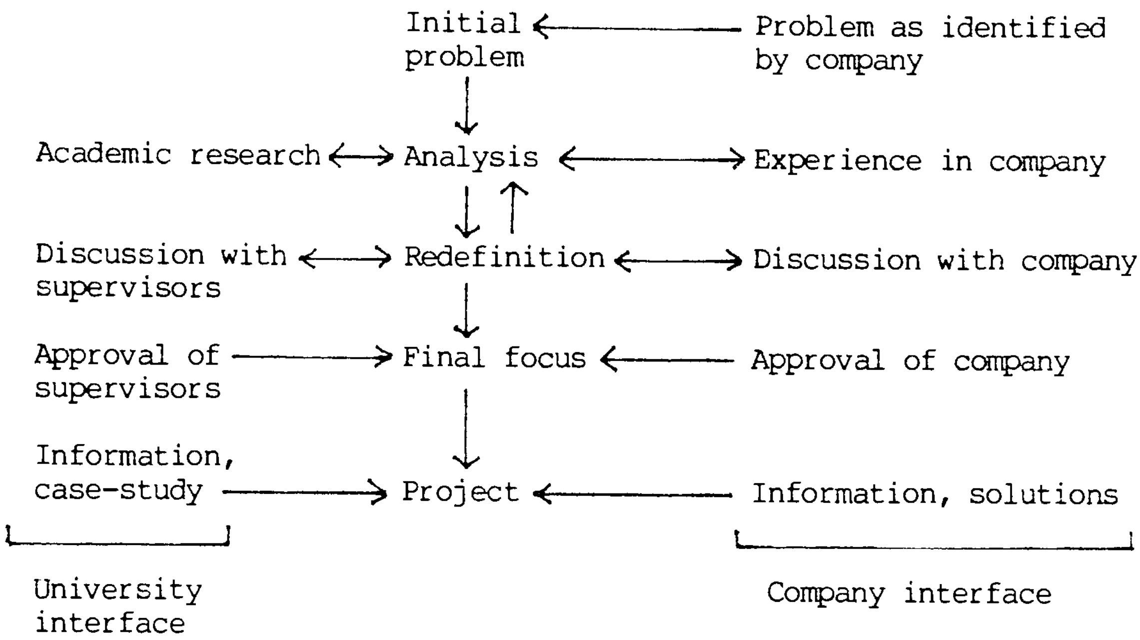
Thus, to reflect this change in project emphasis, the project title was redefined as (UOA 82): 'Low cost signal discriminators: their design, development and evaluation'.

1.2.2 ALBERT System: Overview

This section outlines the system's basic function modules. Fig 1.3 illustrates the method by which the modules described are linked.

Sensors:	Roadspeed:	measures truck speed. Includes electronic signal processing circuitry (see fig 2.2)
	Engine speed:	measures engine RPM. Includes an interface to suit the truck type
	Object scanner:	detects the presence of objects within a defined area behind the vehicle
	Tip edge scanner:	detects a lack of ground within a defined range behind the vehicle
Control box:		Contains the pneumatic components and truck interfaces: pneumatic (skip, lock, retard, brakes and air) and electrical (pressure, footswitches, skip position, vehicle gears)
Cab panel:		Mounted in front of driver. Informs and prompts visually & audibly of alarm states and includes a system test facility.

A brief review of likely competition to the system and an assessment of market potential is included as report INT P12A (volume 2, section 2).



AN ILLUSTRATION OF 'MODEL' IHD PROJECT DEVELOPMENT.
Adapted from IHD (1978). FIG 1.1

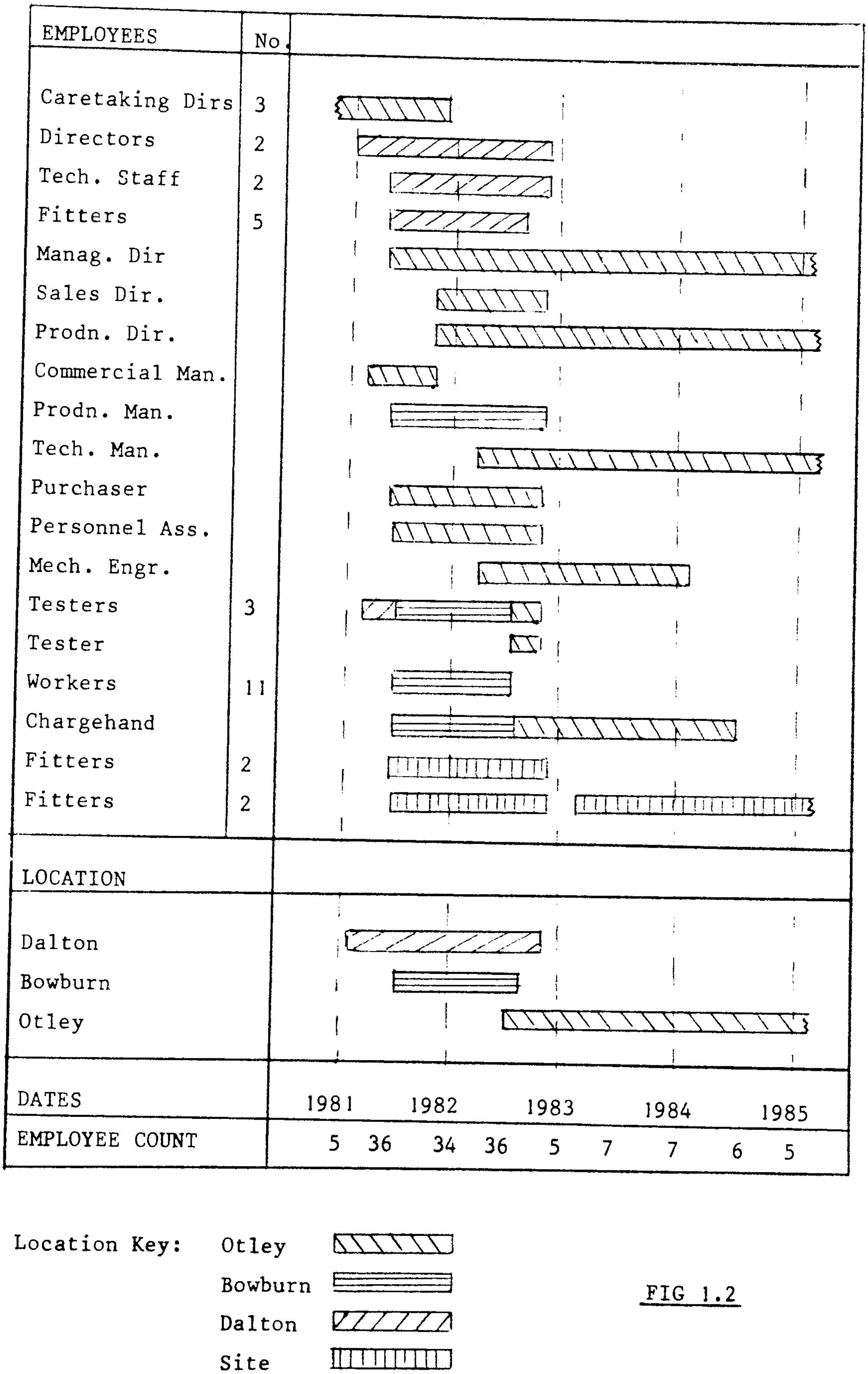
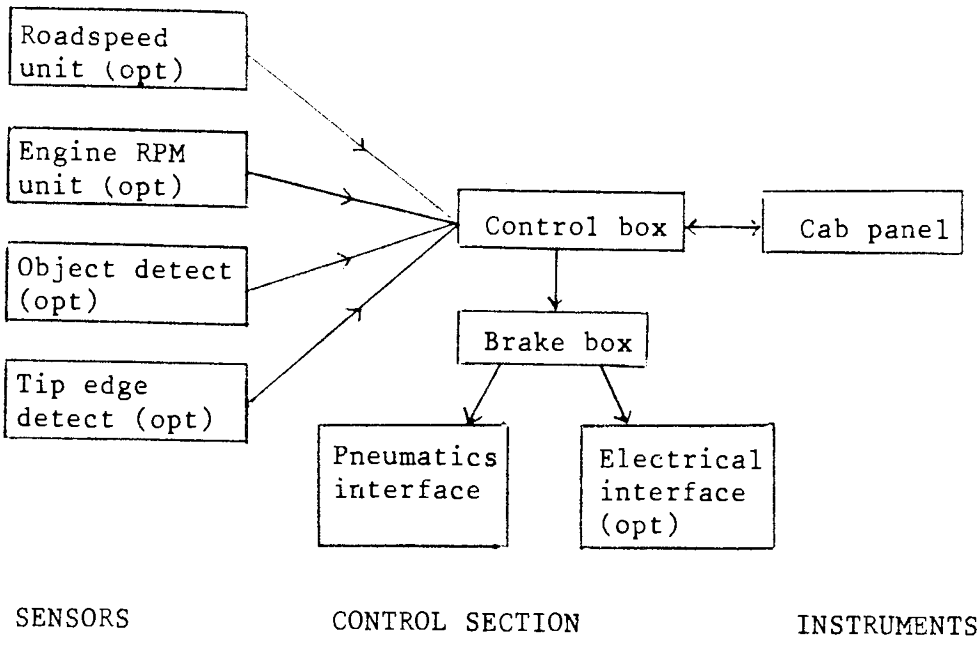


FIG 1.2

EMPLOYEE AND LOCATION HISTORY OF OGDEN ELECTRONICS Ltd.



A schematic of the control box appears as appendix 3.6B; the road speed unit and cab panel as Fig 2.2.
Each box represents a physically separate unit. 'opt' represents optional features.

ALBERT SYSTEM: MODULAR DIAGRAM FIG 1.3

FEATURE	INCORPORATED	FUNCTIONING CORRECTLY ?
STANDARD		
Personnel detect (IR) unit	no	-
Collision prevention	yes	partial
'Skip up' movement halt	yes	yes
Site speed restriction	yes	partial
Front brake switch bypass	yes	partial
OPTIONAL		
Forward collision warning	no	-
Tip-edge protection	yes	no
Localised speed enforcement	no	-
Lateral slope warning	no	-
Drivers seat and handbrake warn	no	-

The above features are derived from the sales brochure, given in appendix 3.6A. This table was compiled in Jan 1984.

ALBERT SYSTEM: CLAIMED FEATURES AND THE TRUE SITUATION

FIG 1.4

CHAPTER TWO

DEFINITION OF THE PROJECT AND EARLY (PRE-PROJECT) SPEED SENSOR HISTORY

" Science always begins with simplifications: it endeavours to combine simplified approaches gradually in order to recreate the complex reality. "

Vilfredo Pareto
Trattato de sociologica generale.

CONTENTS

SECTION

FIGURES AND TABLES

PHOTOGRAPHS

2.1 INTRODUCTION

It is important to ascertain the exact sequence of events leading to the final project definition. The company history and early project titles were described in chapter one. This chapter examines work performed on the general topic of 'signal discriminators', illustrates how this led to the final project definition, and reviews the pre-project history of the speed sensor.

2.2 INITIAL WORK: SIGNAL DISCRIMINATORS.

Although the case study within the project definition referred to the speed sensor, which used a microwave transducer, the span of work was in no way restricted to such transducers. Appendix 3.8 lists the topologies considered. Several options, however, were discarded. Ultrasonics or CCTV fare badly in the off-highway environment (Butterworth: report INT P17) and light techniques are inappropriate within the context of available resources. Hence an evaluation of radar and magnetic transducers was undertaken, commencing in February 1982.

2.2.1 Radar.

The original ALBERT system utilised three unmodulated continuous wave (CW) radar. The evaluation brief was extended to cover alternative radar and system types, including direction sense, diplex, biststic, frequency modulated, pulse, binaural and Janus configurations. The above terms are defined in appendix 3.7B.

Work traced on systematic means of assessing the suitability of radar configurations for projects primarily intended to measure velocity is summarised in appendix 3.8B. It is apparent that the monostatic CW configuration is cheap and practical, but inaccurate. If the processing circuitry is optimised, however, this would seem to be a worthwhile topology, allowing reasonable measurement accuracy and minimal environmental interference, yet incur no significant cost penalty. The Janus technique is also of interest, but due to the duplication of transceivers, falls outside the project definition of 'cheap'. The technique does possess, though, the potentially significant advantage of immunity to vertical platform travel and both static and dynamic tilt.

2.2.2. Magnetic Transducer.

The evaluation of this type of transducer took the form of a short internal report to the company (report INT P21A). This concluded that such transducers would be too inaccurate and unreliable. And further, it would be necessary to note the make, serial number and tyre size of every truck individually, and fit a specific interface box. The transducers also have an intrinsic reading inaccuracy, measured as up to ten percent; and wheelspin or wheellock cannot be compensated for. This type of transducer is also notoriously unreliable, with a typical life of several hundred hours.

It is believed that magnetic transducers were assessed by JMS. Exactly why they were rejected is difficult to establish as none of the staff involved are currently employed by OEL, and no written material exists. Word of mouth seems to indicate that they too found measurement of rear axle rotation to be prone to inherent errors, and that available transducers suffer from severe reliability problems.

2.3 EVALUATION OF THE EXISTING RADAR SYSTEM

In March 1982 the design brief was modified to solely consider radar transducers, specifically unmodulated CW transceivers. This decision was ratified by an examination of the existing ALBERT system: although the radar fitted had fundamental problems, some data had been gathered on the use of such units in the field. In order to place this data within a more 'scientific' context, OEL commissioned a report from the National Engineering Laboratory (NEL) on the effects of vibration on the object-detect sensor. This sensor used the same microwave unit as the speed sensor. Although a copy was not available unit early July 1982, verbal findings from NEL were available; notably:

- The Doppler signal produced by truck vibration is often indistinguishable from Doppler frequencies derived from valid targets viewed from a stationary platform

- the antivibration mounts reduce vibration amplitude above 50Hz but below this frequency some amplification occurs
- no rubber-based antivibration mount can successfully damp the vibration met on off-highway trucks,

To establish the state of the system from a technical standpoint, the writer and OEL held several meetings in early April 1982. Points minuted were:

- the microwave unit is known to have a limited working lifespan
- a significant stock of such units is held. Spares rescued from failed units are also in good supply
- for speed sensing, the units require conversion from 40 degree to, say 25 degrees beamwidth, measured at half-power.

So, although OEL appreciated that these microwave units (referred-to as Aro, after their manufacturer) had an unacceptable reliability and performance record, the failure modes had not beeen statistically analysed; indeed no unit history records were kept. Thus the writer sifted fitter reports to extract pertinent data. This survey, carried out over a period of several months, is documented in report INT P19. The most common fault as reported by fitters was 'not working'. Upon examination a decrease in Gunn and mixer diode sensitivity was found to be the single most common reason. Other faults noted, in order of frequency, were: vibration damage, potting compound leaks, breakage beyond repair due to accident damage, broken wires and PCB or component damage. Only the last two failures are easily repairable. Power output from the returned units was measured as an even distribution between 0 and 3mW for a nominal power of 1.4mW. When the unit field records were analysed it was found that only a few units survive over six months, and many failed within several weeks.

It was not known by OEL whether the signal produced by platform vibration (as examined by NEL) was a true Doppler signal produced by the relative movement between radar and target, including undesirable truck vibration; or due to physical vibration of the microwave assembly causing a piezo-like effect, reflection or internal resonances. Tests carried out by the writer using radar absorptive foam indicated the presence of both causes, producing returned signal modulation. However, this aspect was not examined further until a recording system and bench vibrator were constructed some months later.

In early April 1982 it was believed that the Aro roadspeed head performed inconsistently for four reasons:

- truck vibration producing unwanted doppler signal
- internal head resonance producing unwanted signal
- unit beamwidth: the large elevation angle allowing a wide range of 'true' Doppler signal frequencies to be received.
- loss or overload of returned signal due to changes in terrain type and covering. For example dry sand and wet mud produce too great a range of returned signal amplitudes,

and the head failed for four reasons:

- antivibration mount damage and failure
- vibration damage to the internal components of the head
- a decrease in microwave sensitivity over several weeks
- cumulative errors (eg vibration & overload) preventing alarms.

Factors known about by OEL, but not completely understood, were:

- qualitative values of backscatter amplitude for different terrain types and surface wetness
- repeatable differences in alarm speed for road and site. Typical values are 24 and 22 mph respectively
- difference between the theoretical alarm speed (19.5mph) and those measured on road and site (21 to 25mph)
- frequency-to-voltage converter reset below its designed frequency
- the system works well on trucks up to 20mph but erratically above
- successful car tests are no indication of truck performance. On

DATE	MAJOR TITLE AND DEFINITION
Sept 1981	THE SAFEGUARDING OF COPYRIGHT ON VIDEO TAPES not included
Nov 1981	VEHICULAR INFORMATION MANAGEMENT Techniques of vehicluar information management reported in the literature pertain specifically to automotive use. Such systems are only partially applicable to motive plant. This project will review the specifications necessary for a microprocessor-based system, including sensors and transducers; and design and develop such a system that: - existing safety features are incorporated and expanded - engine functions, hydraulic and pneumatic systems are monitored, reported and controlled - optimum choice of servicing intervals is indicated - potential unit failure is reported and prevented - diagnostic output of individual truck conditions and performance is available.
Dec 1981	(as above, but with the emphasis on upgrading the present system; specifically the sensors)
Feb 1982	LOW-COST SIGNAL DISCRIMINATORS:DESIGN, DEVELOPMENT AND EVALUATION. Complex electronic safety systems for off-road vehicle applications need improving in respect of signal discrimination so that these signals, important from the safety point of view, can be separated reliably from noise and interference. Such systems utilise sensors which receive electromagnetic waves including microwaves. The signals from these sensors control vehicle movement to preclude accidents. The project will examine the whole situation with the aim of producing a low-cost device which is expected to be digital, which the company can sell. Some of the technology already exists, but is too expensive for use in areas readily accessible from the marketing point of view to the particular company.
March 1982	(as above, but to solely consider unmodulated continuous wave radar sensors)
June 1982	ROUGH-TERRAIN GROUNDSPEED MEASUREMENT: A RADAR-BASED COMMERCIAL SOLUTION Off-highway motive plant equipment is costly in capital outlay and maintenance. To reduce these costs, and increase site safety, a technique of assessing and limiting vehicle speed is required. Conventional speedometers have shown themselves to be inappropriate. This project will examine the whole field of off-highway velocity measurement, and aim to produce a commercial unit suitable for incorporation into the existing company product range.

PROJECT DEFINITIONS WITH MODIFICATION DATES.

Changes in emphasis are indicated by parentheses. This figure illustrates the emergence of the common theme of speed sensors, starting as a minor aspect of a project, and ending as the sole topic.

FIG 2.1

site a tested unit may fail to work completely

- some units work satisfactorily with some trucks, but not others
- an apparent change in power output after several hours of use when fitted to trucks: a change not noted on car tests.

Thus it was clear at this stage that a significant quantity of work was required to develop this or a similar unit, including original research on the environment in which the truck must operate. These findings prompted a modification to the project brief in June 1982: the project would concentrate on the speed sensor, with the general field of 'signal discriminators' taking a supplementary role.

2.4 FINAL PROJECT BRIEF: THE SPEED SENSOR

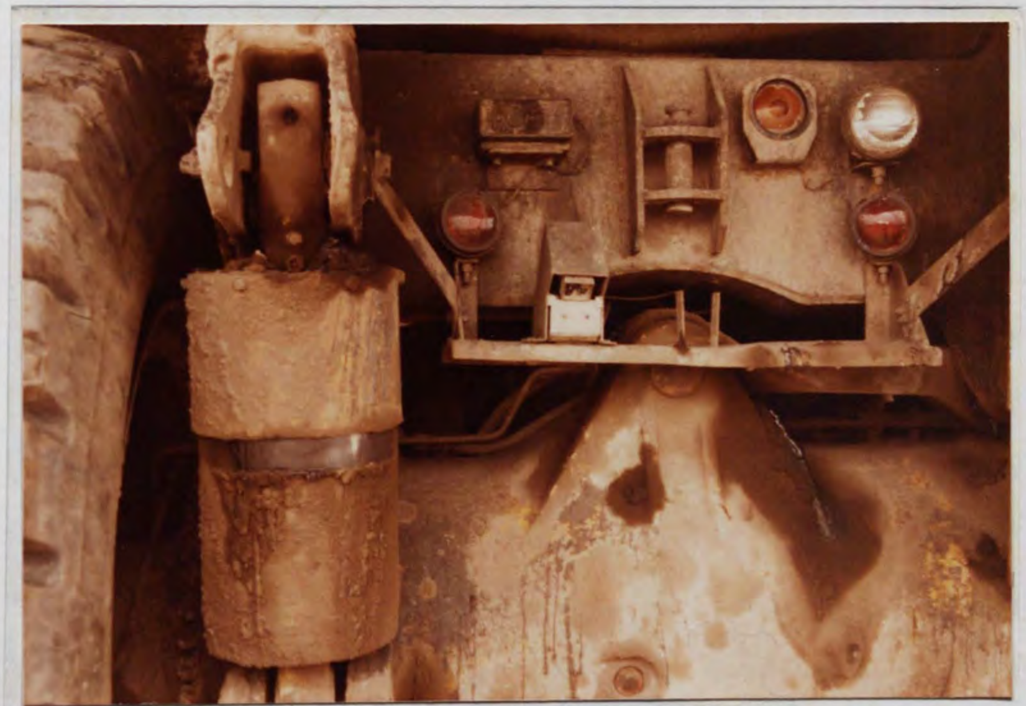
This section will establish the exact state of the sensor when the writer's project was defined as the development of this unit. Such a review is crucial for two main reasons. First, to establish previous findings of OEL in this field: as no work is documented, the following history was traced from oral reports and fitter worksheets. And second, to highlight a further requirement of the project brief: the maintenance and improvement of the existing sensor whilst a new unit is being developed.

2.4.1 Early History Of The Speed Sensor

The basic sensor module is illustrated in fig 2.2 and Pic 2. The complete system is shown in fig 1.3. These diagrams provide adequate information for the discussion in this section.

The concept of sanctioning a vehicle for exceeding a preset speed limit is certainly not radical: it has appeared in many guises over many years. Scant literature exists, however, on the application of speed limiting devices to off-highway vehicles. Chapter five summarises all research traced on this topic; but as the original design concept of the ALBERT system is not available to the writer, comparison with previously proposed systems is difficult. This section therefore, simply assumes the existence of the ALBERT system, at least in concept,

PIC 1



PIC 2

PIC 1: Rear view of a Cat 777, of eighty-five ton capacity, as used for system testing at Butterwell open-cast site. The fitter is mounting an old-style speed sensor.

PIC 2: Close view of the scanner mounting bracket and speed sensor:rockfall damage, grease, oil and dirt are apparent. The limited suspension travel of five centimetres can also be appreciated: the cylinder to the left is a rear shock-absorber.

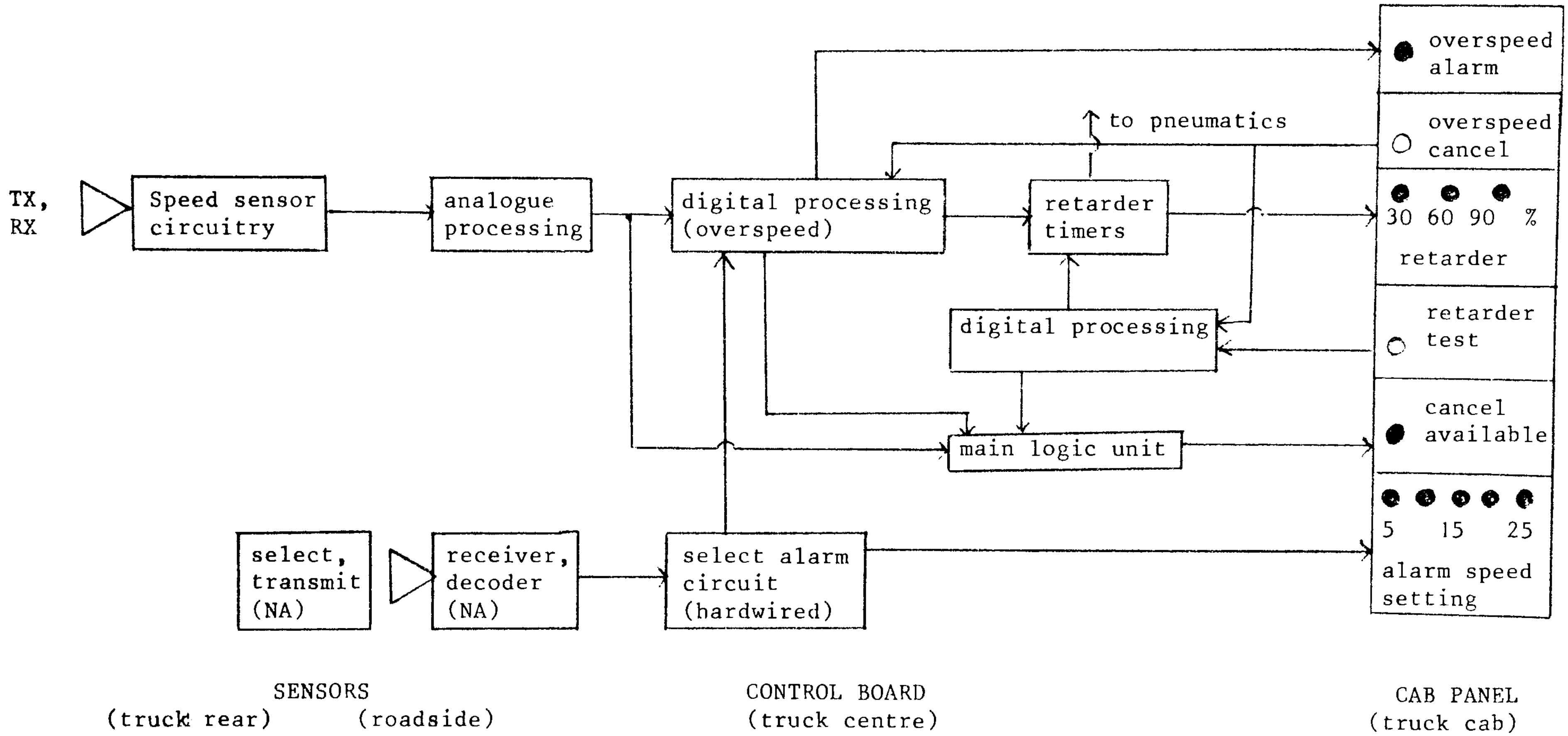
and laboratory prototype.

In summer 1981 the ALBERT control board possessed, in addition to the object and tip-edge detect scanner facility, two further inputs to measure vehicular speed and engine speed. Both speed measuring inputs were intended to be squarewave frequency-proportional pulses derived from magnetic transducers located at the vehicle driveshaft and crank-shaft respectively. The processing circuitry contained on the control board reflected this choice of sensor. At an unknown date, the speed input was fed with a replacement microwave unit. In order to consolidate the state of the system, OEL summarised its known failings in the form of a resumé of 'outstanding areas requiring consideration' (OEL 1982). Extracts of this list are given in appendix 3.13. In response to these requirements, OEL commenced three courses of action: the maintenance of units already sold and fitted, the initiation of a development programme, and the closure of the Bowburn plant.

So, in February 1982, the newly-appointed technical manager found himself responsible for a partially developed speed sensor unit using a Doppler transceiver originally designed to partner the rear object detector, by now found to be unreliable, and fed into electronics designed for a magnetic transducer. The circuitry used was a design by Holford (1981) intended for use in conjunction with a Mullard intruder detector unit, with an additional Veroboard circuit containing a filter and Schmitt trigger. These items were encased in a die-cast box originally intended to house the tip-edge unit; the microwave transceiver being mounted rigidly on top by an angled bracket. This angle was set initially to that predicted by basic Doppler theory as producting the correct speed-frequency ratio. The microwave unit as fitted to the object detect system had a 40 degree beamwidth producing a 3 metre deep footprint: too wide for its new application. One batch was returned to the manufacturer for modification to 25 degree beamwidth, but over half the heads so modified ceased to function.

This unit performed inadequately: in retrospect, hardly surprising as it was very much a 'Frankenstein'. OEL thus took a series of measures to rectify its failings. The circuitry was evaluated and several modifications were made, including the alteration of several component values both on the sensor board and control board. The microwave and outer case was redesigned in April 1982 after the unit was found to respond to engine vibration, and now incorporated the head tilt-angle and provision for the processing circuitry case. Subsequent tests in April and May 1982 involved the alteration of the tilt angle from 36 to 40 degrees, and changing circuit gain settings. Recalibration of the control board was also carried out, but the unit accuracy was not improved: for a nominal 25mph setting, alarms occurred between 18 and 34 mph (Davey, 7.82).

In late April 1982 the alarm speed selection circuit was found to be unreliable due to a circuit design fault, so of the five intended alarm speed settings, one was hardwired. The setting chosen was the 25mph setting which produced an alarm near 20mph. The correct alarm speed of 25mph could not be obtained as the unit performed inaccurately at such speeds. Thus OEL recommended a reduction of site alarm speed to Taylor Woodrow, on the grounds of site safety. Fortunately the site operators agreed to a trial period, during which a reduction in vehicle breakdowns with no decrease in workrate was reported. The slower maximum truck speed reduced queues at load collection and dump points, thus improving operating efficiency, site safety, and reducing truck wear. This event was crucial: OEL's credibility was re-established and the site operators continued to allow the development and testing of the whole ALBERT system in-situ. Two further outcomes of this trial period were the modification of the retarder sanction to prevent the truck being sent into an enforced skid (during the course of this project, twelve trucks overturned as a result of skidding), and the realisation that the actual alarm speed differed significantly from



This chart incorporates the speed sensor system as claimed by OEL in their advertising literature. However, 'NA' indicates Not Available, and the alarm select circuit was hardwired to one of its possible five speed selections. The control board is illustrated in more detail in appendix 3.6B

Key: LED: ● button: ○

THE EXISTING SPEED SENSOR: BLOCK-DIAGRAM. FIG 2.2

that predicted by theory. It was also noted that the Gunn diode was set to an incorrect operating voltage, although adjustment to the correct value did not significantly improve unit performance.

In May 1983 the units were reported "working in a generally satisfactory manner" (OGC 5.82). The writer's examination of the fitting and service history, however, (OGC 4.82) carried out as part of report INT P19, concluded that the failure rate was unsatisfactory: the average field life of a unit was a few weeks.

Engine vibration was known to present problems, and two courses of action were taken: the redesign of the outer case, and the application of antivibration mounts. OEL attempted to design the case three times; the final design being adequate. Vibration effects had been reduced on the object-detect unit by the use of rubber mounts. Although the speed sensor application is different (for object-detect in reverse gear, truck vibrations exceed the frequency of the relative speed-related frequency of the rear object. This is not so for speed sensing), the mounts seemed to perform reasonably well. Difficulty in the assessment of such an antivibration-mounted system, however, prompted OEL to commission NEL to examine the effect of such mounting in a scientific manner (NEL 1982). The report dealt specifically with the accelerations measured on an object-detect unit, both rubber and chassis mounted. Thus the findings are not directly applicable to the speed sensor unit, where truck velocities are five or six times greater.

Problems with truck bounce still occurred, so in late June 1982 the Butterwell site management were persuaded to accept a permanent 22mph nominal site alarm speed. They indicated a general satisfaction with the unit's performance, although they were not aware, at least officially, of the extensive labour involved in maintaining and replacing the units.

2.5 RESUMÉ

Thus although the unit was being improved over an extended period of time, it was clear that significant problems remained. The sensor unit, as fitted in mid-1982, was effectively a unit that relied exclusively upon components originally intended for different applications. It required a maximum alarm speed of 22mph to ensure a reasonable chance of functioning correctly, and the typical life of such a unit varied from a few days to a few weeks.

It was in mid 1982 that the writer commenced work on the speed sensor as the major part of the agreed project.

CHAPTER THREE

EVALUATION OF THE EXISTING SENSOR UNIT, AND FORMULATION OF THE PROJECT FORMAT.

"Things never come in a flash. A solution comes as a result of months, even years of very heavy work. It is a slow grinding towards the solution: a striving towards the end.... "

Barnes Wallis
(P.R Whitfield: Creativity in engineering)

CONTENTS

SECTION

FIGURES AND TABLES

PHOTOGRAPHS

3.1 INTRODUCTION

Chapter one and two have introduced the project background, and highlighted the means by which the final project was selected. This chapter deals with the writer's initial evaluation of the existing speed sensor unit, the identification of associated problems, and bearing these findings in mind, discusses the establishment of an appropriate experimental and research schedule.

3.2 INITIAL PROBLEMS

In parallel with the technical evaluation of the unit, a literature review was commenced. The subject breadth included radar and signal processing of ground-looking systems, and applications pertaining to vehicular systems. The application of electronic systems to off-highway vehicles and non-radar velocity measurement was also included. Many false starts were made: a search of US patent files, for example, using the keywords of this project title (see summary in thesis prefix) produced a wealth of information on the measurement of blood velocity and the tracking of hurricanes! Similar problems were encountered when using library computer search programs. So, the search was performed by hand. The review was completed some eighteen months later.

In late June 1982, a joint meeting with academic and industrial supervisors decided that the project should commence with an evaluation of all problems related to off-highway velocity measurement; and examine methods by which such problems could be simulated in the laboratory. Thus, work was commenced on a rolling road simulator, in parallel with a review of the fundamentals of radar testing and signal processing. The intention was to provide an in-house capability to develop, from first principles, a ground-looking radar. To this end, a continuous belt roller was proposed; the belt covering being capable of alteration to simulate different terrain backscatter characteristics. Drawings, constructional details and costings were produced. OEL rejected the design due to the required expentiture, estimated at approximately one thousand pounds, which they considered expensive in the light of a "lack of evidence of the effectiveness of such a unit to adequately simulate moving ground". However, the literature review had already unearthed similar designs (Baba 1978, Tsuha 1982, Hyltin 1973) being used in the laboratory for the design of similar systems. Alternative suggestions of a test trailer (a car-towed trailer with suspension characteristics modified to emulate off-highway truck suspension) were accepted in principle, but no action was taken. Thus, the only means of obtaining true data was to travel to the Butterwell site, some two hundred miles distant, and incur severe resource and site access difficulties. This site is illustrated in Pic 3 and 4.

The emphasis of simulation was thus shifted from attempting to simulate terrain to examining, both in theory and practice, the effect of irradiating suitable terrain with radar. Two approaches are possible: to take samples of terrain into the laboratory, or to move the experimental apparatus out of the lab. The latter was selected on grounds of practicality. Given the partially developed speed sensor availability, the writer decided to utilise this sensor in ground return experiments. Although preliminary work had shown that car-mounted radar trials were not a good indicator of truck-mounted performance, for initial evaluatory tests such a platform was selected as this alleviated difficulties in site access.

In June 1982 the NEL report was made available: this included vibration spectra in each plane for an Aro head mounted with and without anti-vibration mounts, and confirmed NEL's earlier verbal findings that the antivibration mounts caused some reduction in vibration above 50 Hz but had no beneficial effect below this frequency. This information could not be directly acted upon, however, as the unit's outer casing was designed specifically for the mount used, and without the mounts the unit simply permanently false-alarmed. Thus the writer commenced an

PIC 3

PIC 4

PIC 3: A view of the Butterwell open-cast site (the largest in Europe). To indicate scale, a CAT 777 is arrowed. The photograph shows one-fifth of the trench length.

PIC 4: A closer view of one section of a haul road. The crane (centre, white) is loading rock from a newly-exposed coal face. The haul road at this point is too narrow to permit trucks to pass: thus truck speed must be controlled on descent.

	EQUIPMENT	MODEL	LIMITATION/FEATURE	SOURCE: WRITER	SOURCE: HIRE	SOURCE: OEL
Possessed by OEL at time of move to new Otley facilities.	Oscilloscope (*1)	Thandar	1" by1" screen. 10mV			*
	Power-supply unit	handmade	24V O/P only, ripple			*
	Oscillator	Feedback 600	0-10V O/P			*
	Digital meter	Fluke 60				*
	Soldering iron					*
	Electronic components		no development stocks	*		*
Obtained for other projects (eg Marconi)	Spectrum analyser	HP	no storage facility		*	
	Frequency meter	SD 6057			*	
	Power meter	HP 435A	X band		*	
Obtained by, or for, the writer for the speed sensor project	Analogue meter (*2)	Super 680	heavy damping	*		
	Cassette recorders	Philips	stereo	*		
		Ultra (*3)	mono	*		
	Battery charger and nicads	Tandy		*		
	UV recorder	ES Labs 3006			*	
	UV paper	Kodak/Agfa		*		*
	Vehicle trailer		modified			*
	Hygrometer, thermometer		hygro home made	*		

NOTES: *1: ceased to function in mid 1982
*2: stolen in mid 1984
*3: ceased to work

INVENTORY OF AVAILABLE LABORATORY EQUIPMENT, AND SOURCE. TABLE 3.1

assessment of the existing unit, both to ascertain its failings, and to establish possible means of temporarily improving the unit's longevity and measurement accuracy.

It is appropriate at this point to review the facilities offered by the newly-opened Otley premises: available laboratory equipment is indicated in table 3.1, and, as can be appreciated, all laboratory work had to be consciously planned so as to be feasible using only these resources.

3.3 THE PROJECT FORMAT

In late July 1982, the project brief was now fully formulated, and laboratory facilities were available. Thus it was possible to plan the structure of the subsequent work in some detail. After much consideration, three plan views were devised:

i) a general overview, indicating the interrelationship of theory and application, and indicating new and existing areas of knowledge, expertise and practical constraints. This chart (fig 3.2) also illustrates the flow of information between these factors, and provides a useful check list throughout the project. However, as will be discussed later, such naive categorisation of knowledge areas could not always be adhered-to,

ii) a diagram indicating the project in terms of problem-project-outcome grouping: this illustrates the importance of maintaining the existing unit (fig 3.3),

iii) a flowchart illustrating the stages in the development of the speed sensor as predicted at this point in time, stressing the transitions from theoretical to static to dynamic to production (fig 3.4). The stages were, in fact, approached in a more parallel manner than indicated by the chart.

It was apparent even at this stage in the project that, due to the 'interdisciplinary' nature of the project brief (physics, mechanical and electronic engineering, production and value engineering, commercial and marketing studies etc) that the written output would be

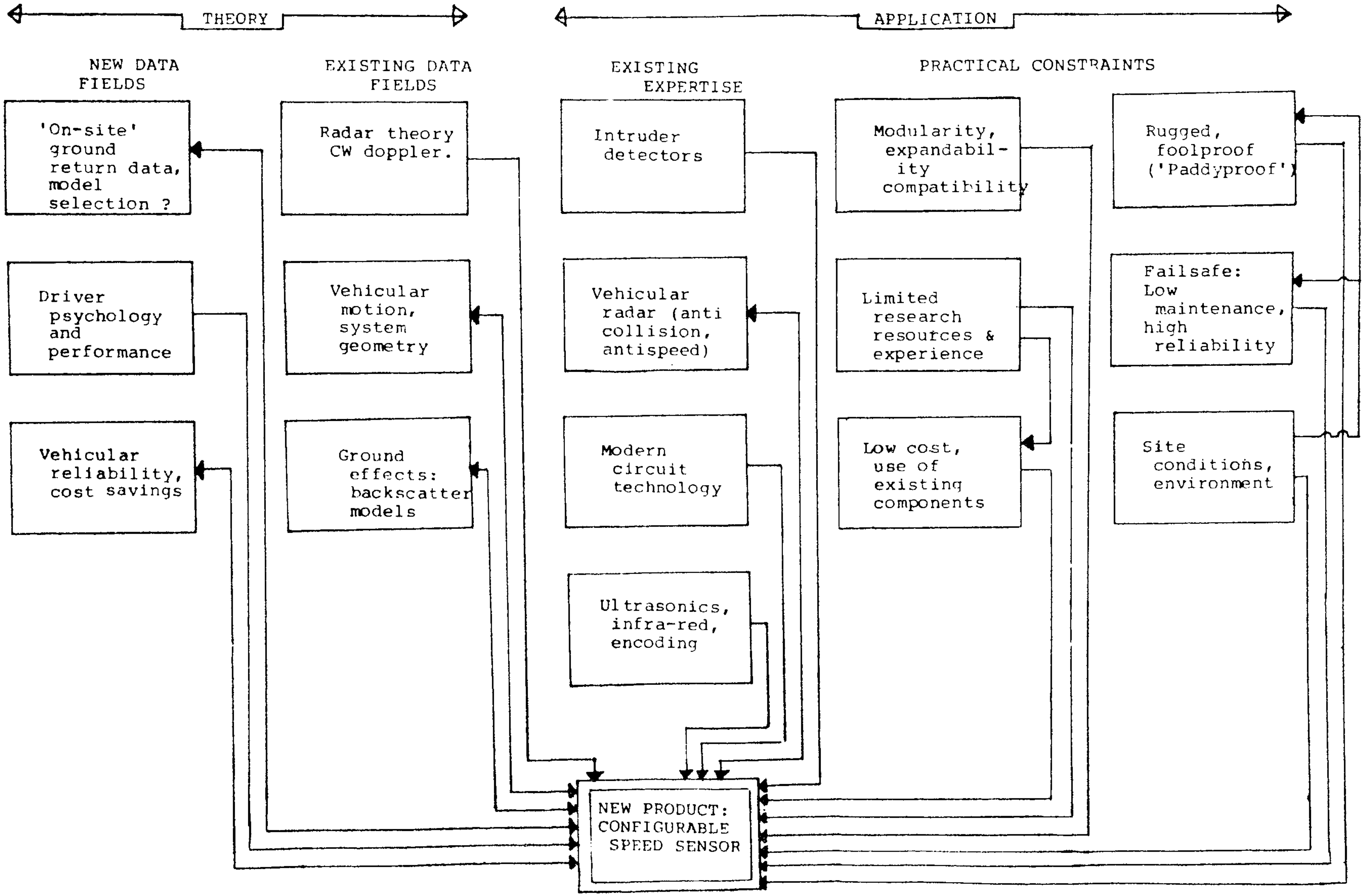


ILLUSTRATION OF THE DIVISION OF THE PROJECT INTO GROUPS OF THEORY AND APPLICATION, HIGHLIGHTING THE SUBDIVISIONS OF EACH, AND THE DIRECTION OF THE FLOW OF DATA.

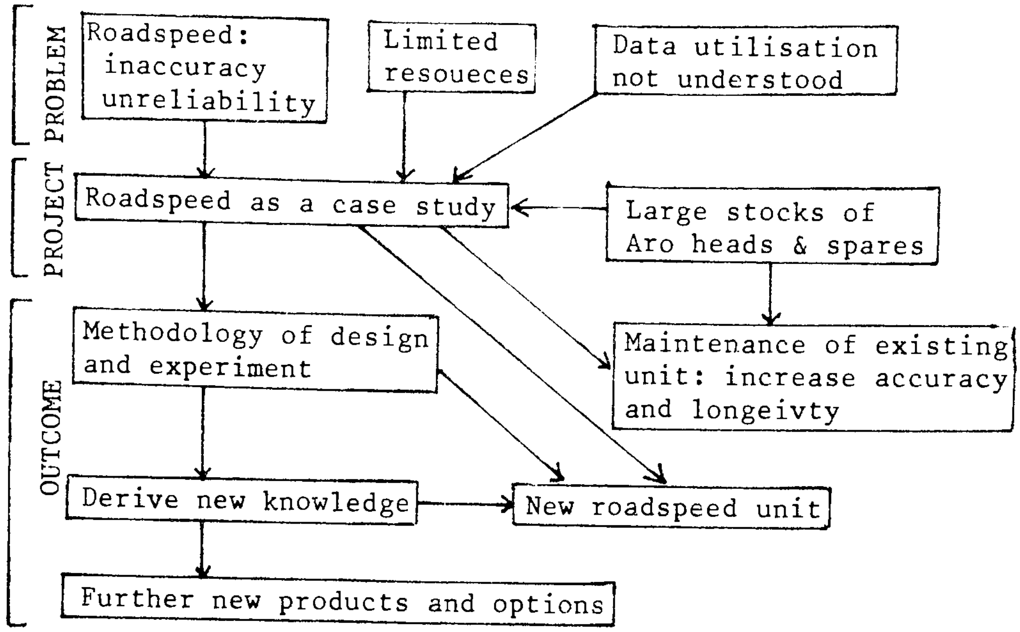
FIG 3.2

large. Thus a further objective to the main task was defined: to pass on to the company all findings obtained in the course of the product development, rather than present them with a 'fait accompli' in the form of a completed thesis. This aim was achieved by the production of a number of internal reports intended to document the results obtained, to discuss the various interpretations of the results identified and to recommend appropriate action. Such reports were considered important for a further reason. The literature review was proving time-consuming, indicating that emphasis would have to be placed on deriving data rather than passively reporting it. Also the report format would permit an efficient means of translating raw data into modular and useful papers.

With hindsight the generation of these reports was a mixed success: to the extent that thirty-six reports, totalling eight hundred pages, were produced, the intention of documenting data worked. As a collection, these reports contain almost all the pertinent information required to design a speed sensor for off-highway vehicles with no prior knowledge or experience. However, the presentation of this work to the company throughout the course of the project provoked little comment or feedback.

The process of categorising what initially seemed a complex interwoven problem into 'modular problem areas' however, was extremely useful. One outcome of this technique was the extension of the project brief to include probable future customer requirements, and to ensure design variants can be catered-for with minimal development time.

The project report linkage is summarised in fig 3.5. It can be seen that the production of reports closely followed general research philosophy: that is, to review existing approaches to the problem, identify the problem, develop an approach, and to test and modify the approach. To this extent the reports can be seen as the 'core' of this thesis.



'PROBLEM-PROJECT-OUTCOME' PROJECT PLAN. FIG 3.3

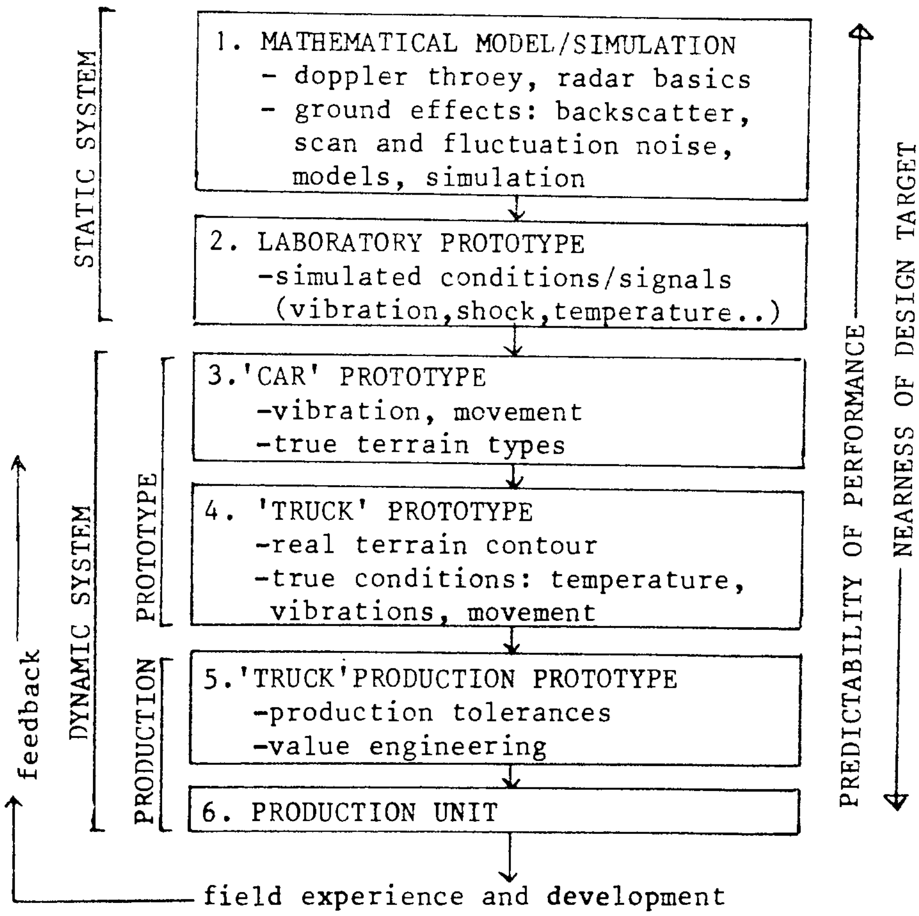
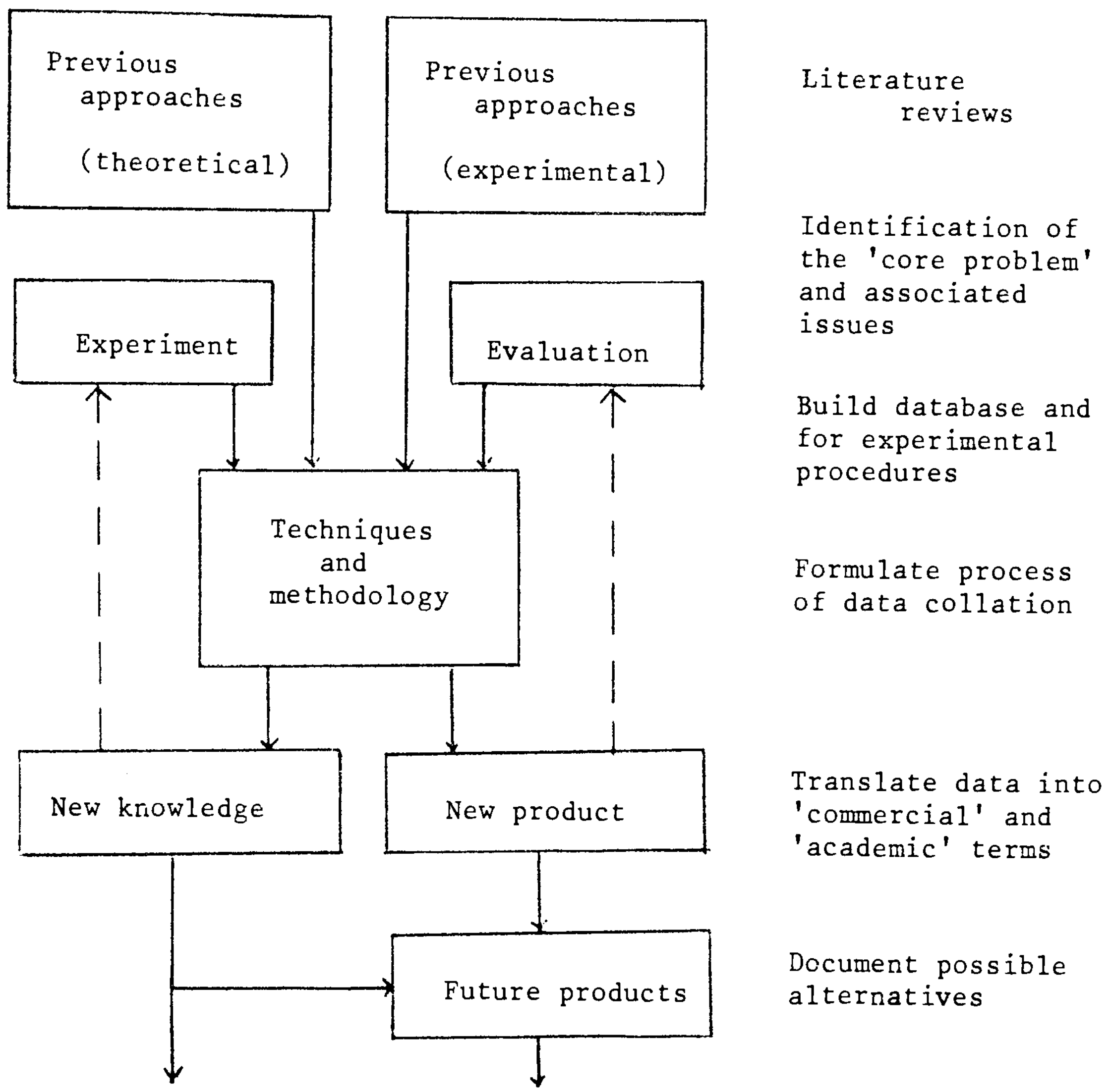


FIG 3.4

THE SIX STAGES IN THE DEVELOPMENT OF THE SPEED SENSOR UNIT.

The order of completion is not expected to be sequential.



This block-diagram gives an overview of the generalised categories of reports produced during the course of the project, and their linkage. The specific reports falling into each category are listed in fig 3.6.
The above technique was followed for each of the report 'areas', and for the overall report linkage.

REPORT CATEGORY OVERVIEW. FIG 3.5

GROUPING AND TITLE	REPORT NUMBER	CHAPTER REFS MAIN	SEC.
Literature reviews			
Theory: ground models	8	5	
ground return	8	5	
microwave radiation	27	4	9
Experiment: backscatter	8	5	
off-highway environment	24	7	
geometry effects	15	4	
vehicular radar	14	5	
non-vehicular & doppler	9	5	
Experimental:			
Shock and vibration simulation	13	3	
Interface box	11B	4	
PLL/validation logic	2,3	4	3
Window materials	20	7	
Horn design	18	4	7
Evaluation			
Alternative microwave units	18	4	
Aro unit	19	3	9
TRW unit	25	4	
Albert system and competitors	10,12	1	
Sensor unit	31		
Alternative measurement techniques	21	2	
Beam geometry	15,16		
Truck suspension	33	7	
Beacon system	32	3	
Validation logic	7	4	7
Techniques			
Data processing and results	26	4	
Active filter program	1		
Processing and data acquisition	6		
Product: present:			
Sensor environmental specification	22	7	
Sensor test specification (full)	23	7	
Sensor test specification (production)	30	7	
various: designs (seedrawings list)			app 3.2
Product: future:			
Configurable speed sensor	17	4	2,3,7,9
Minimal sensor system (MSS)	28	9	8
Beacon systems	32	3,4	9
New knowledge:			
Beam geometry	15,16	4	10
Spectra results	29	6	
UV output results	34	6	
Other:			
Circuit additions	36	9	
Simulator board	11A	4	

REPORTS TO THE COMPANY: GENERALISED REPORT CATEGORIES AND THEIR CONSTITUENT REPORTS.

The report categories are detailed in fig 3.5.
Superceded reports (eg P2,4,5) are not listed.
A detailed listing of the reports appears in section 2.1 of volume two.

FIG 3.6

3.4 ARO UNIT ASSESSMENT

3.4.1 Initial Work

A reasonable general overview of the performance of the existing unit had by now been established. Much detail, however, remained confused. In early August 1982, several apparent oddities were discussed with OEL, one of which was the ease by which the radar could be fooled by accelerating through the nominal alarm speed. The cause was found to be an incorrect frequency-to-voltage (F/V) converter integration time on the main control board, and the poor tolerance of some sensor board components. The low cut filters of ten typical boards were measured, and -3dB points between 128 and 202Hz were found: by simple substitution of higher tolerance components, this cutoff was held to 170 +- 10Hz. However, the more pressing problems were not so easily analysed: as discussed in chapter two, several difficulties in utilising the Aro units were proving time-consuming to solve. The basic difficulty seemed to be the performance of the microwave unit and its interaction with the off-highway environment. Thus two major reports were planned. One, dealing with a full evaluation of the Aro microwave unit (INT P19), and a linked report assessing the present antivibration mount system. This report (INT P13) discusses techniques of simulating vibration and shock, and of selecting and testing alternative mount systems. The information contained will not be repeated here, but it is appropriate to review the major findings in the light of the months that have passed since the reports were written.

3.4.2. Evaluation Of The Aro Microwave Unit.

It was found that the success rate of the aro unit modification from wide to narrow beamwidth was around fifty percent, and that the anti-vibration mount utilised was performing outside its design parameters, being used in shear mode loading. The Aro waveguide section was held in place by rubber strips which were suspected of allowing vibration and slippage of the unit. The power output, frequency of operation and faults of a number of returned units were examined: seven working units out of ten were found to oscillate at a frequency outside the Home Office band; and of forty-six faulty units, thirty-three had damage due to shock or vibration or other related causes. Of these units, two-thirds worked but at an incorrect alarm speed. The remaining failed to work at all. Upon scrutinisation of the fitter records, the typical life of a head was found to be around six weeks!

Unit tuning was checked against transmission frequency, mixer noise and output power: an optimum tuning was found at 3.8 clockwise turns of the tuning screw. One half a turn can reduce mixer noise by half and simultaneously double power output. However, a random check of ten working units found a seemingly random spread of tuning screw positions.

Power and frequency output were measured for a range of Gunn voltages: these were found to bear a reasonably linear relationship. Internal resistances and voltages of working and faulty units were measured in an attempt to ascertain why the heads fail: a low Gunn-mixer resistance seems to indicate a possible problem, but in general no measured parameter was found to be an adequate predictor, or even an indicator, of failure. Numerous methods of alteration of the beamwidth were evaluated: horizontal polarisation was found to provide signal levels three times greater than vertical. Seventeen types of modification were assessed, including a lens, collimation and reflection cancellation. The lens seemed to offer the best compromise of performance and practicality. Thus six lens types were evaluated further. The selected design reduced beamwidth by almost half in both planes, increased on-axis power, and reduced power asymmetry.

The influence of cable wiring on induced noise and microphony was assessed: improving intenal wiring could reduce mixer noise by a factor of three; balanced wiring showed no benefit, but glueing all cables to the case improved microphony.

The circuitry of the sensor and control board was examined with regard to component tolerance and sensor calibration. The alarm frequency of seventy units was measured: forty were found to be outside the stated acceptable range of 25+-1mph, and twelve were found to alarm at the correct frequency. This inaccuracy is a result of zener diode and resistor tolerance in the alarm speed select circuitry at the input to the control board.

3.4.3 Shock And Vibration Simulation.

Report P23 continues to consider the Aro unit from a different aspect: the mounting system. Three mount bracket sizes are currently in use, only one being adequately large. The others produce unit failure by permitting the head to strike the bracket, and of the fifty-eight units, fifty allow this to happen. Two test arrangements were devised. The first is a single strike test intended to simulate truck shock produced by the suspension 'bottoming' or the Aro unit striking the bracket. The second, a vibration test, is to assess the unit's resilience to continuous vibration as met on site. The vibrator test produced a fascinating result: units 'bed in' over a period of five hours (fitters had previously noted this verbally: see section 2.3): it is thought this is due to the rubber waveguide mount settling in. With the head covered with radar absorptive foam to prevent true Doppler signals the vibration-induced signal was examined in detail, and recorded for later playback on a UV oscillograph. Chapter six contains a detailed description of these recordings. It was found that even minimal vibration amplitude produced a strong signal output; this signal being, for certain vibration frequencies and amplitudes, indistinguishable from true Doppler signal. To ascertain the cause of the induced signal, further internal wiring modifications were tried, but no improvement occurred. Using a tuning fork target showed that even with a strong near target (0.1m from the head: terrain would be some 3m distant), the vibration-induced signal swamps the fork signal. It was concluded that the microwave unit itself was the cause of the problem; probably loose Gunn and mixer diode mountings. Tests of other heads confirmed these findings. Such a result is significant: the inherent weakness of the Aro unit to swamp true signal with vibration-induced interference must cast doubt of this unit's ability to provide the basis for either a long-term improvement to the existing unit, or to be the selected microwave transceiver in any new design.

The single strike test was crude: the unit was struck by a large solenoid. The results, however, were clear. With the existing anti-vibration mounts, twice the amplitude of signal was measured: damping the mounts with foam reduces this amplitude by around one-third. Thus the mounts used increase the amplitude of the induced signal (typically an 800Hz pulsetrain, decaying over 670 pulselengths). A further rig was constructed based on a pneumatic piston. New mounts lasted for seventeen minutes before failure; partially used but visually perfect mounts lasted only seven minutes, indicating that the rubber embrittles with use. Vertical shock allowed the mounts to last five times longer. Bearing these facts in mind, over forty tests, using numerous techniques for modifying the mounts were assessed on the same rig. Belting and thick tubing fared well on the rig, but misbehaved on site.

Thus although alternative mount systems extended mount life in the laboratory by a factor of up to twenty, these mounts did not always allow the sensor to function correctly on site. To understand the mount requirements further, the nature of shock-loading on site was reviewed, and although differences between lab and site were identified, enough similarity is apparent to give credibility to the findings of the report. Howewever, sixteen site trials were made, and the results under real operating conditions showed themselves to be unpredictable: only one unit worked accurately and consistently!

It can thus be concluded that the antivibration mounts are a necessary evil whilst the Aro unit is used as a transceiver: the mounts detrimentally affect the already poor performance of the unit when subject to vibration and shock, but removal, or substitution of other mount systems, does nothing to improve the situation.

3.4.4. Motion Simulation.

As described in section 3.2, the rolling road concept was not accepted by OEL; but the requirement for a means of simulating target motion still existed. Hence a simple rig was construced out of a motor rotating a vaned shaft. Such a test arrangement is totally incapable of giving any clues of terrain return parameters, but proved useful for providing a constant background motion upon which tuning forks could be superimposed, or circuit modifications evaluated. This simulator was combined with the shock and vibration simulator in order to assess complex terrain and platform motion, but the results, which resembled random noise, proved impossible to assess. It was thus decided to delve further into the processing circuitry in order to gain an insight into its intrinsic capability and limitations.

3.4.5 Aro Unit Circuitry Assessment.

In mid 1982 the OEL speed sensor possessed two circuit boards: board one being a modified burglar alarm PCB, incorporating power supply and preamplifier. Board two included a high pass filter and Schmitt trigger. Before summarising the work performed on the evaluation of this circuitry, it is necessary to outline the general disadvantages of this two-board arrangement. For example:

- board one comprises circuitry used in the board's original tip-edge detect application. Thus the board is unnecessarily bulky, and requires modification to disconnect the redundant section,

- the power supply transistor and potentiometer are located on the outer case, making assembly, calibration and servicing difficult,

- the cable termintations are simple solder tags: such flying leads were often found to have broken due to solder joint fatigue,

- board two uses physically large components and a poorly designed layout

- inter-board wiring is complex and hinders assembly and servicing. The outcome of the circuitry assessment formed the basis of a report to the Electrical Engineering department at Aston. The report, some 55 pages long, is not included in this thesis, but a resumé of the major findings is given in appendix 3.14A. To further assess the potential of this circuit and establish possible modifications, over forty different alternative test boards were designed and constructed over a period of months. Space precludes a detailed description and judgement of each design, but appendix 3.14B summarises the work.

To facilitate easy comparison of certain design modifications, a motherboard, containing power supply and test points, was constructed which accepted slot-in circuit modules. Modules built included preamplifiers, low and high filters, gain stages, Schmitt triggers, F/V, comparators and test LED outputs. Where possible, circuit parameters were made programmable.

To assist in the design of filters, of which over one hundred were designed, a computer program was written. This could produce Butterworth, Bessel and Chebyshev high and low pass filters from first to ninth order; and although lengthy at 540 lines, allowed filters to be scaled so as to utilise existing component stocks. The program, not reproduced here, was invaluable in reducing design time to several seconds per filter.

A technique was required to assess the possible alternative circuit designs: one means of achieving this is to simulate the returned signal phase nulls in a repeatable manner. The method used was simple: two oscillators were used, either with summed outputs or one's VCF driving the VCA of the other. By using a frequency counter at the circuit output, it was confimed that the measurement error was of a similar nature to that obtained with real signals. Further details appear in the appendix to report INT P3, app 7.

3.5 BEACON AND REMOTE SWITCHING

Much work was performed interfacing the selected beacon system to the sensor circuitry: having selected circuit performance in respect of filter frequencies and gain for the nominal 22mph alarm speed, it is important to provide suitable circuitry for each selectable speed, and to switch between this circuitry. In this way the circuit should perform optimally for all selected speeds. The disadvantage of this performance level is complexity: thirty-six CMOS gates are needed for four speed options. Clearly it is easier to simply switch between four complete configurable boards, or to revert to the intrinsically more complex integrated filter and gain stages, which would only require eight such switches.

Further complication was introduced by the immediate requirement for a go/no go remote beacon and the possible future requirement of remote alarm switching. Obviously these considerations would have a major bearing on any circuit design, so the field of remote switching was reviewed. Fortunately, much circuitry exists in similar applications (remote control toys and televisions for example) utilising continuous, pulsed and coded infrared and ultrasonic transducers. Problems were noted in the application of ultrasonics due to site ambient noise containing significant high frequencies. Such noise, of course, also negates the benefits of coded systems. Infrared transceivers proved more likely candidates, though dirt on the lens significantly reduces range. A dual frequency ultrasonic system proved iteslf in the lab and on-site, and cost under five pounds, compared to over two hundred for the retroreflective infrared sensor. Most popular configurations of transmitter and receiver were assessed, as were numerous transducer makes. Multiple transmitters, intended to widen the area of signal reception, were found to produce interference effects. A low-voltage indicator was designed to inform site personnel that the need for battery replacement is imminent.

Report INT P32 summarises the work performed on beacon systems, and concludes that the above-named systems are the most suitable for commercial applications. Report INT P17 also covers aspects of a commercial design such a self-cleaning lens, but this work is covered later.

Another aspect of configurability is the option of providing an alarm output in a form suitable for future system expansion and product compatibility. Thus outputs were designed in three forms: logic level (for an F/V and comparator within the sensor unit), fixed frequency oscillation (ditto, with an alarm frequency oscillator for feeding to the control board F/V), or a squarewave frequency output (conventional system).

3.6 RESUMÉ

By December 1982, a detailed picture of the Aro circuit failings and of possible circuit topology had been built up. Many modifications to the Aro circuit produced better performance on roads, but the improvement was not vast. Rebuilding the complete unit with high tolerance low noise components proved fruitful, but the circuit, the writer felt, was only 'doing the best of a bad job'. Large nulls in the output waveform still existed, with a commensurate measurement inaccuracy.

It was clear that further information concerning the nature of the returned signal was required before a viable alternative circuit could be designed with any confidence of a worthwhile improvement. Whilst this information was being gathered, possible designs for an alternative sensor system were considered: work described in the next chapter.

4

CHAPTER FOUR

THE ASSESSMENT OF POSSIBLE UNIT FEATURES

> "The successful firm will need not only to perceive opportunities but also to anticipate them. But the problem following from anticipation is that of acting correctly until the anticipation becomes reality. "
>
> G. Willis
> Technological Forecasting

CONTENTS

SECTION

FIGURES AND TABLES

PHOTOGRAPHS

4.1 INTRODUCTION

The result of the Aro circuitry assessment, and evaluation of alternative circuit topologies, indicated that the improvement of the existing or similar circuitry may well assist in increasing system accuracy, and, if rebuilt, extend unit longevity. But, the improvement would not be significant: the signal derived from the head unit was not fully understood, and the existing processing circuitry did nothing to assist interpretation of signal nulls, intermodulation or platform bounce and vibration effects.

Clearly the time was ripe for commencement of work to ascertain the amplitude spectrum of the returned signal for different terrain types and conditions. By December 1982 much empirical evidence had been collected regarding the performance of the Aro configuration on-site, general conclusions being:

- wet surfaces return much more signal, and skew the footprint towards the platform. This effectively raises the alarm speed,

- rocky surfaces return more signal, leaving alarm speed unaltered, although in extreme conditions, false alarms may occur,

- smooth surfaces do not return much signal: this effectively raises the alarm speed, and in extreme circumstances this prevents a valid alarm.

Factors thought to have an influence on the nature of the returned signal were:

- amplitude variation due to the changing radar cross-section (RCS) and the varying reflectivity of surfaces within the footprint,

- frequency variations due to changing RCS where a significant reflective obstacle moves through the footprint and becomes the main return area. The angle from platform to this obstacle thus defines the instantaneous tilt angle, and hence the returned frequency,

- a very wide elevation beamwidth, allowing both amplitude and frequency modulation to occur to a significant extent,

- amplitude changes due to alterations in platform velocity, which is inversely proportional to amplitude: traversing rough terrain produces rapid acceleration fluctuations.

- signal summation and cancellation due to phase nulls.

The work to be done was divided into three main sections: a literature review (chapter five), a series of experiments to ascertain the type of returned signal (chapter six), and the continuation of laboratory and site assessments.

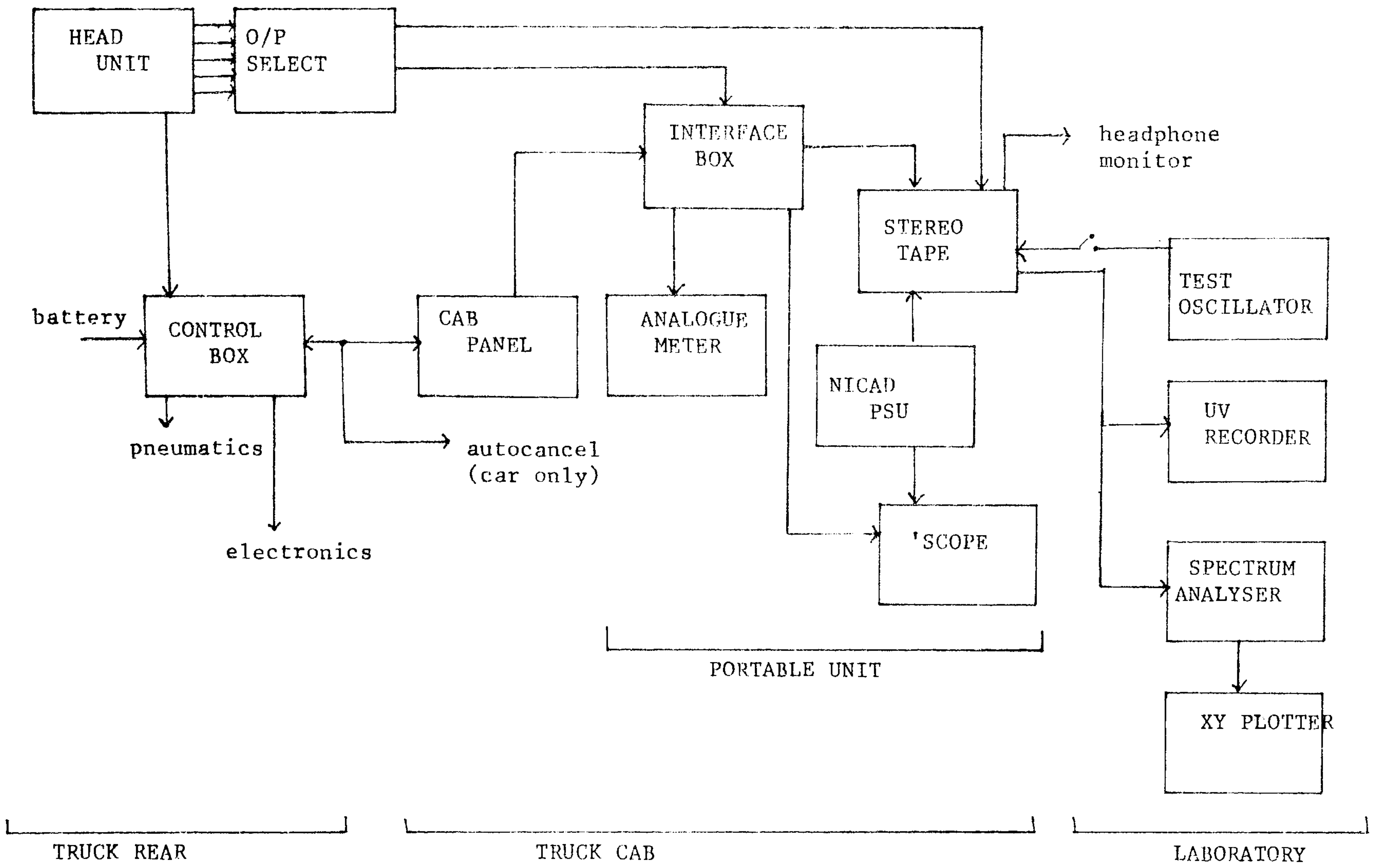
4.2 APPRAISAL OF THE TRW UNIT

The only product generally available that resembles the speed sensor is manufactured by TRW Inc (introduced in report INT P12A). OEL obtained a sample unit in order to compare its performance with their product: officially, if the unit proved itself, OEL were to purchase the unit as the basis of a new system. Unofficially, the action provided an opportunity to dismantle the unit and record its internal design. Trials were performed on earth and tarmac for dry and wet conditions for a range of tilt angles. This work is covered in report INT P25. On roads at 20mph, errors up to 10% were noted; on site, up to 80% with a typical range of 5 to 65%. Clearly the unit cannot cope with site terrain contour. The conclusion drawn, be it tentatively, was that the unit has too small a footprint in the azimuthal plane which leads to signal swamping by the return from obstacles such as ruts, rocks or puddles. Supporting evidence was forthcoming later (section 10.3.3.2).

4.3 THE INTERFACE BOX

Deriving data from a speed sensor on-site posed difficulty. Neither OEL nor Aston possessed a battery-powered data logger, and attempts to purchase such a logger, or an inverter supply, failed. Thus the solution had to be 'home grown'.

The interface box is a compact unit designed to enable ground return signals to be recorded onto tape and be displayed on an oscilloscope



BLOCK-DIAGRAM OF THE DATA COLLECTION SYSTEM FOR ROAD AND SITE TRIALS. For road trials, a combined control box and cab panel was used, incorporating autocancel.

FIG 4.1

and analogue meter. The box, oscilloscope, meter and connection cables were mounted into an attaché case. The head unit to be assessed requires modification so that signals can be derived from the pre and post-filter stages and Schmitt stage. The interface box gain is adjustable to allow calibration and/or ease of measurement. Circuit details, calibration and test points etc, are described in report INT P11B, and the general connection block-diagram appears in fig 4.1. The original tape recorder was soon found inadequate as two channels were needed to assess, for example, filter performance, where it is necessary to simultaneously record pre- and post-filter signals. Thus a portable stereo recorder was purchased by the writer.

4.4 RATIONALISING THE RETURNED SIGNAL.

4.4.1 OEL Meeting

In late December 1982, at a meeting with OEL, the Aro and TRW sensors were discussed. It was noted that the Aro unit was unsuitable for its application, but that the existing sensor units must be maintained for the immediate future. The TRW unit was thought to be rather costly in the light of its performance; it would also require extensive modification to derive the required ALBERT system-compatible outputs. The immediate possibility of locating the speed sensor at the truck centre of gravity was rejected on grounds of fitting difficulties (lack of site access, stocks of existing wiring looms etc). The company also emphasised a preference for any new system to incorporate a simple means of alarm speed switching, and, if possible, to design a retrofit for the Aro unit. Thus, further test and evaluation schedules were planned. One, utilising the interface box described in section 4.3, involved an extended road and site measurement schedule: this forms the basis of chapter six. But the search for an alternative circuit continued in parallel with this activity. So, in the temporary absence of hard fact upon which to base a detailed design, a means of distinguishing between valid alarm pulse trains and non-valid sequences was sought. Two reports were produced: the first, INT P3, seeks a means of counteracting short-term effects due to irregular continuous signal deviations due, for example, to phase cancellation nulls. Long term anomalies, missed valid alarm pulsetrains and interference-produced false alarms are reviewed in report INT P7. A brief resumé of these reports will now be given.

4.4.2 Smoothing Short-Term Anomalies

The work under this heading involved examining a typical returned signal, and identifying three major factors that influence it: phase transitions of discrete in-beam targets producing signal nulls; finite beamwidth, producing frequency fluctuations and a signal spectrum; and amplitude variations due to the complex terrain reflectivity, both surface and subsurface-related. Further secondary factors include: circuitry noise and clipping, non-linearity, supply modulation and interference, EMI and RFI, backscatter changes due to tilt angle, terrain conditions, microwave power, frequency and sensitivity, platform bounce, resonance, shocks, and vibration.

A phase-locked loop (PLL) was seen as the obvious contender for rationalisation of such signals: several were assessed and the CD4046 family was found most suitable. A circuit was designed that fulfills the module requirements, and a means of incorporating this device into the existing or any new unit is given. Being an in-line design, it is simply plugged between the sensor output and control board input, drawing power from the sensor supply line.

This circuit, costing fifty pence, dramatically improves the existing sensor accuracy: on potholed roads, measurement error decreases from 22 to 5%, and on smooth tarmac from 18 to 0%. One problem was noted: in heavy rain and on a stationary platform, the unit could alarm. Such situations, however, are rare, and a decrease in beamwidth on any new design would prevent this. The measured performance was backed by the stringent dual-oscillator test (see section 3.4.4) where measurement errors were reduced by at least half (or removed completely for an overdamped loop, but such a response time would interfere with the cancel logic of the control board).

A further advantage of this circuit is the opportunity to frequency divide and multiply by means of inserting digital dividers in the PLL feedback loop. Independent control of loop damping for both an increase and decrease in input frequency is achieved by two resistors and a diode between the phase comparator and voltage-controlled oscillator.

In conclusion, therefore, this module was seen as a valuable addition to the existing product; and a recommendation was made to OEL that it be retrofitted to all roadspeed sensors possessed by the company.

4.4.3 Distinguishing Valid Alarm Conditions.

The intention of this work was to develop a simple means of interpreting returned signals incorporating long-term measurement discrepancy, produced by, for example, truck bounce or terrain macrocontour. The solution must identify and prevent erroneous alarms; and during alarm conditions, provide alarms otherwise missed. As with the PLL module, this circuit must fulfill two roles: both of incorporation into the existing system as a modular add-on or simple modification, and as the basis of a new design.

Possible solutions are discussed in report P7, which commences by outlining the problems presented by the Aro-based circuit: notably that when using an F/V converter, signal nulls cause an underreading of output frequency. Six techniques of reducing this cause of error are examined. The method selected is a 'window timer', which compares past and present alarm states, thus distinguishing between valid nulled signals and short-term invalid alarm signals. Detailed design notes are given, including timing and circuit diagrams. A single delay test unit was constructed (see section 4.4.5) which worked successfully on all trials. Multiple window logic, offering even better valid alarm discrimination, was thus not assessed in depth.

To establish whether the delay unit would handle extremely poor quality signal returns, an Aro sensor was mounted on a foam block which permitted undamped head bounce of up to 15 degrees above and below the nominal tilt angle of 40 degrees. The normal alarm output and post-validation logic signal were monitored on five car test runs at alarm speed. On smooth road, both units worked correctly. On rough surfaces, however, the window logic alarmed four times compared to twice for the conventional circuit. On a further series of sub-alarm speed runs, the conventional output false-alarmed once on smooth road and twice on rough, whilst the modified unit produced no alarms.

4.4.4 Configurable Speed Sensor

The company's desire for an add-on module to allow alarm speed alteration within the sensor, as opposed to modification of the control board, has been noted earlier. Work had already commenced on prototype designs, but now increased in urgency as the utilisation of the PLL module resulted in an unwanted reduction in the average alarm speed of trucks. This reduction is due to the smoothing of signal phase nulls which produces a higher speed/frequency ratio (ie a correction of the F/V reading error described in section 4.4.3). This results in a reduction of truck alarm speed from 23 to 21mph; placing the alarm point between fifth and sixth gear on the Butterwell trucks. Thus, after an alarm the automatic gearbox oscillated between gears. This was unexpected, as the manufacturer's literature stated a fifth gear changeover point of 19mph. Not foreseen, however, were the oversize tyres fitted to these trucks which raised the changeover point to 21mph. Whilst the problem could be overcome temporarily by tilting the radar unit downward, a more permanent solution was required.

A means of translating the radar scaling frequency (defined as the output Hz/mph ratio for a stated tilt angle and transmission frequency) was also required for development work so that different transceiver transmission frequencies can be used with the existing electronics. A further use was also seen in the fine-tuning of sensor unit/vehicle combinations that give abnormally high or low alarm speeds.

Early designs revolved around F/V level shift modules, but the probable incorporation of the PLL into future designs allowed the preferable technique of frequency shifting by utilisation of the PLL feedback loop to be considered. The shift is performed by insertion of the ubiquitous 4018 divider: the pulsetrain frequency is multiplied, and then redivided. Such a technique is a compromise: no calibration is required and component count is minimal, but the translation can only be performed in discrete steps.

Report INT P17 records the work performed on the module. To allow a comprehensive selection of shifting ratios, only those best fitting the application were included in a switchable circuit. P17 includes both details of this circuit, a more complex variation giving more ratio steps, and a hardwired 15/16 ratio for production use. A further circuit described allows ratio selection by a prewired plug capable of replacement on-site, and a similar circuit incorporating switches and plug for remote speed switching. The latter circuit warrants further description: in section 3.5 the work performed on beacons and remote switching was introduced (report INT P32). Report INT P17 takes the development further by indicating the means by which the truck sensor, having received a valid coded signal, activates the alarm speed switching. Previous work dealt with electronic switching of the F/V in the control board: this has the disadvantage of requiring modifications external to the sensor; as considerable site access time is required to modify the control board. The configurable system, however, switches alarm speed internal to this sensor, thus ensuring accessibility. In such a system the speed select plug determines which two or more alarm speeds the circuit may select. The report also covers one means of ensuring the infrared reflector suggested for beacon use is kept clean in the rather dirty site environment.

To consolidate the work performed so far, and to provide a bench test, development and demonstration facility, a simulator was constructed. The detail of this board is provided in report INT P11a, where a list of some twenty-five requirements is given. In brief, the unit can be used in numerous modes:

- lab development
- module evaluation, including all sections of the existing circuit, and additions such as validation logic, PLL etc
- road test: production 'go/no go' and detailed performance assessment
- record and playback of data obtained on-site.

Thus the board includes a full speed sensor circuit, additional modules and control board functions. Eight LEDs and a meter give a visual indication of the workings of the circuit; the final stage being three LEDs which represent the truck retarder sequence. A typical use would be to record onto tape a returned signal processed by, say, the existing circuit alone, and by the window timer (which the writer refers to as 'validation logic'). All board time delays are programmable, so the effect of different delays on a given data recording can be noted, and by replaying site recordings the real-time operation of the board modules can be recreated, whereupon fine-tuning of component values can be performed.

4.5 DATA COLLECTION SCHEDULE

4.5.1 Supervisory Meeting

In May 1983 a meeting of all concerned took place. OEL endorsed the dual speed remote control concept as fulfilling their requirements, but restressed their more immediate concern that the maintenance of the Aro units should continue at all cost. The writer reported the work on PLL's and validation logic, and obtained a favourable response. An extended discussion on returned signal spectrums failed to reach any conclusion on whether the data gathered so far indicated that the Aro unit was intrinsically capable of gathering the required signal. All parties agreed to postpone this discussion until the results of the complete series of data collection had been processed. Due to the absence of conventional data recording and playback equipment, the results derived from the experimental series require special consideration. The techniques selected will be outlined in this chapter, but preceding this, a description of a report on beam geometry will be reviewed.

4.5.2 Effects Of Beam Geometry.

Chapter six deals with measured amplitude and spectra derived from road, track and site. It is of value to review the expected results before evaluating true data. Report INT P15 does this: derivations of scanning and fluctuation noise are given, and a graphical means of calculating the Doppler spectrum for a given beamwidth and tilt angle is explained. Examples of typical beamwidths and velocities are plotted. The standard deviation of spectrum-related errors are also dealt-with, and to assist this, a computer program was written that calculates the SD of a spectrum for a user-defined number of sample points. The theoretical value, and results obtained by both computer calculation and conventional techniques, are compared: the program gives results similar to manual calculation techniques, but both are divergent from the theoretical values. The reasons for this discrepancy will be examined in later chapters.

4.5.3 Means Of Tabulating And Processing Ground Return Signals

Previous work has dealt with inadequacies of the existing sensor unit, and proposed possible design modifications, It is crucial, however, to be able to ascertain exactly why the Aro unit is unreliable and inaccurate, and having identified relevant parameters, to optimise them. Hence new designs can utilise this data constructively. Report INT P26 deals with the methodology of data processing, and commences by listing those factors seen as determining the 'quality' of the returned signal, and of the processing. The compromise accepted by this work is indicated, and those parameters assessed by the method are listed. Calibration data for the recording is given: the system is not ideal, but with careful interpretation, capable of adequate performance.

The specific techniques of data processing is divided into three major groups: waveform, spectrum and frequency tracking. For each group, the appropriate parameters are defined in detail. Several such parameters are invented specifically to extract a certain feature from the data; for example, symmetry, corrected or normalised data, consistency etc. An example of a simplified spectrum is given, and the technique of data derivation is explained: these results are shown tabulated alongside the theoretical values.

One reason for a description of the tabulation technique preceding the extended analysis of the recorded data is to assist in the identification of those aspects of the data that may be significant. The other is that, in the event, the above technique was not used extensively: after a trial series of analyses, it was decided to process the data using an even more powerful technique: visually. The writer soon became adept at spotting factors that indicate meaningful results (with almost eight hunderd analyses this is hardly surprising !). Thus chapter six examines the recorded data on the basis of spectrum comparison and basic visual clues. Report INT P26 was not wasted, however. The analysis of exactly which characteristics possessed by data are important was not expected to be an outcome of the report, which was seen only as the tabulation of those characteristics.

4.5.4 Preliminary Data Collection Test.

Before the data collection was commenced in earnest, a 'trial run' was performed on a prototype tip-edge detect radar, which, it was thought, had previously undergone extended development by JMS. First, however, several inadequate aspects of its design had to be corrected. This unit, with its tilt angle of between 10 and 20 degrees, was extremely sensitive to terrain type and condition, and the experience of evaluating this unit was indeed beneficial. The conclusions were also helpful to OEL: it was confirmed that this device was incapable of correct functioning due to inherent limitations such as shallow tilt angle etc; limitations that cannot be overcome without complete unit redesign.

In parallel with these trials, the promising speed sensor circuit additions and modifications were reassessed. After extended tests, for example, Chebyshev filters were rejected, and an IC regulator was chosen for the PSU.

The first true system roadtest and data collection occurred in July 1983: the intention being to ascertain the extent to which tilt angle and terrain type determine returned amplitude. The experiments planned with the hygrometer, such as mapping surface and subsurface wetness (see report INT P26) had to be cancelled as personnel are not permitted to leave the truck cab whilst on site.

4.6 PLL SITE TEST

By August 1983, numerous data gathering experiments had been carried out, both on the Aro unit and on an alternative design. Thus, to adhere to the true time sequence of events, the work performed in parallel with the data recording is now described.

In order to fully evaluate the PLL addidtion on site, twelve roadspeed units were built incorporating this feature. To prevent wiring or PCB failure, these were constructed on one piece of Veroboard incorporating the new power supply. The commissioning test indicated an improvement in performance: of the twelve original fully working Aro units replaced, only eight had alarmed consistently. With the new circuit board, all twelve performed faultlessly. Fitter reports several days later indicated two unit failures, but both were found to be caused by failed antivibration mounts.

It had been clear to the writer for several months that the Aro microwave unit and mount system were inadequate. Spurred on by signs that OEL were beginning to agree, attention was turned to possible replacement designs. This work will now be summarised.

4.7 ALTERNATIVE RADAR UNIT: horn, Case and Mount

The work performed on these aspects of the new design can be found in report INT P18. In order to base the work on a sound theoretical basis, yet avoid extensive use of mathematics, the relevant literature was reviewed in some depth, and salient points extracted. The report commences with a review of the importance of microwave beamwidth and gain, listing four possible methods of optimising these parameters. The most practical solution is to decrease beamwidth and maximise gain, whilst the best solution is, arguably, an increase in transmission frequency. The argument for selection of elevation and azimuthal beamwidths is given in some depth, concluding that a wide azimuth assists in averaging return from obstacles, ruts etc; and a narrow elevation decreases the returned spectrum width. The argument is supplemented by an examination of equal power, distance and Doppler frequency contours (isodops) from a truck-mounted transceiver. The exact beamwidth selected is not crucial (fortunate, as OEL do not possess facilities capable of accurate measurement), but must follow the above guidelines. The design intention was stated as 15 by 30 degrees, with a gain of around 20dB. The azimuthal angle is chosen so the footprint will not catch other vehicles or piles of dirt at the side of the road (see Pic 5 and 6) whilst the elevation angle should be the smallest angle practicable. The latter angle is a compromise, as horn size is roughly inversely proportional to beamwidth. The benefits of vertical, horizontal and circular polarisation are reviewed: vertical being seen as the best compromise. Preliminary unit tests were planned using a proprietary horn, but a review of those available showed none to be suitable. Thus, the draft horn design, based on several design formulae extracted from the literature, was built. To save time and

PIC 5

PIC 6

PIC 5: Haul road: compressed surface of boulder clay and rock shavings. Note the load droppings: the speed sensor must not 'see' such features.

PIC 6: Haul road: compressed surface of topsoil. Such a surface presents rough passage in dry conditions and a quagmire in wet. The dirt piles are waiting for the bulldozer (top of picture) to spread over the worst of the craters money, the horn was constructed out of cardboard. Perhaps surprisingly, this performed remarkably well; it's gain and beamwidth were measured to be almost exactly the required values.

Experiments with crude lenses reduced the prototype elevation beamwidth further, and suppressed sidelobes.

Following road trials using a Plessey oscillator, the H and E plane beam widths were increased and decreased respectively, giving a beamwidth of 35 by 12 degrees. Following the success of the crude lens on the prototype, further work was performed on the lens and antenna design: zoned and dielectric layer lenses were considered impractical. Focused, non-focused, reversed lenses and dielectric aerials were also assessed, but focusing was thought inadvisable on safety grounds (see section 7.4 and report INT P27). The final design, however, described later, used a simpler technique to suppress sidelobes.

The horn design was considered a reasonable compromise between size and beamwidth, but the detailed task of converting a design into a cast unit had not yet begun. Thus, pattern makers were consulted on the design requirements of a wood pattern, and casting engineers were asked for their views on the suitability of materials. After much consultation, the finalised prototype design was committed to casting.

The company stocked several microwave transceiver types, surplus from the now defunct JMS tip-edge detector. After extensive tests, the Plessey unit was selected as the basis of the prototype design. Antivibration precautions were considered unnecessary given the rigidity of the horn and microwave assembly; nevertheless a prototype case was constructed that permitted antivibration mounts to be fitted, and tests were made with and without mounts. The results (described in section 6.3) confirmed that no mounts are required.

Although at this point only test prototypes existed, the detailed design considerations for a commercial unit were listed, and preliminary designs commenced. Factors considered included serviceability, longevity, size, environmental security, adaptability, legality and cost. These designs provided the basis of numerous discussions with OEL : the outcome, and detailed design work, is covered in chapter nine.

4.8 RESUMÉ

A technical appraisal of possible improvements and modifications to the Aro unit was needed for two reasons: first, to be able to recommend to OEL steps that will prolong longevity and increase measurement accuracy; and second, as preliminary work in the design of a new sensor unit. Such an appraisal has been carried out. By December 1983 the effects of beam geometry, means of data collection and interpretation, and draft designs for a horn unit had been carried out.

At all stages, this technical work was conducted in parallel with a review of pertinent literature. The following chapter deals with this literature.

CHAPTER FIVE

A REVIEW OF LITERATURE RELATING TO THE USE OF RADAR AND ELECTRONICS

" Knowledge is not merely an array of facts: it is a structure. It indicates the linkage of the facts, and this linkage can be more interesting than the facts themselves. "

P. Meredith
Learning, remembering and knowing.

CONTENTS

SECTION

FIGURES AND TABLES

5.1 INTRODUCTION

This review identifies work of interest from bodies of knowledge in the areas of use to this thesis. It includes a resumé of research and theories not only in the field of speed sensing, but of all topics related to the utilisation of radar looking at ground. Each section, therefore, fulfills a purpose specific to the whole task of evaluating "what is known and what is thought to be known" in this field. This chapter forms part one of the review, which summarises the findings in tabular form wherever possible. Part two, containing the extended reviews, can be found in chapter twelve.

The specific topics covered in the literature review are illustrated in fig 5.1. No one generalised subject area provides information of sufficient depth or breadth to form the basis of the review brief, which, put succinctly, was to establish, collate and prepare for practical utilisation, any available information on the application of Doppler radar-based motive plant velocity measurement. In consequence the search field is constructed from numerous research areas. These areas can be categorised into three researchers' approaches to the field (theory, theory and experiment, and experiment) and into four generalised themes (terrain and weather, the truck environment, vehicular radar, and Doppler radar).

It may well seem that the topic areas, although bearing an 'academic' relation to this project, are not of practical relevance or significance. However, the review work performed during the course of this project has been compressed into one chapter: the search brief was greatly modified during the course of the field and laboratory work. Consequently this review is as much a response to practical requirements as it is a resumé of previous theoretical work. The need for specific review topics is explained at the appropriate chronological point in the main text, but a brief summary will now be given.

It is necessary to design the radar transceiver and processing

APPROACH			TOPIC
THEORY	THEORY AND EXPERIMENT	EXPERIMENT	
Ground models 5.2.3 (5.5)		Backscatter 5.2.2 (5.3, 5.4) A	TERRAIN & WEATHER
	The off-highway environment B, F	Truck electronics 5.3.2 (5.10)	THE TRUCK ENVIRONMENT
Vehicular radar: patents (5.8, 5.9)	Radar parameters 5.2.4 (5.6)	Doppler vehicular radar (5.11)	VEHICULAR RADAR 5.3.1 (5.7)
Doppler radar: patents	Doppler radar C Non-vehicular doppler radar 5.3.2 D	Competitors products E	GENERAL DOPPLER RADAR

NOTES: Topic includes:

A: backscatter, terrain categorisation, rain and snow
B: climate, terrain, shock and vibration, electrical systems, reliability, environmental test schedule
C: fluctuation and stability, tuning fork tests etc
D: rolling road simulators, ship velocity etc
E: included in report P12A
F: included in report P24 and P33

No one subject area provides information of sufficient depth or breadth: thus the search field is constructed from several research areas. These are roughly divided into three approaches and four topic areas, although several subjects fit into more than one category. The chart above also indicates the appropriate section of the thesis, and the number in brackets indicates a table or list.

STRUCTURE OF THE LITERATURE REVIEW, INDICATING THE INCLUSION OF NUMEROUS SUBJECT AREAS.

FIG 5.1

circuitry so as to optimise the information derived from as wide a range of operating conditions as possible. Hence the effect of selecting specific radar design variations (transmission frequency, power, polarisation, beamwith E and H, tilt angle etc) and electronic circuitry (circuit gain, frequency response, processing technique and topology etc) must be analysed. This work falls under several topic headings: experimental work on backscatter (to ascertain the characteristics of the returned signal for changing terrain characteristics and radar system parameters); theoretical work on ground models (to find a means of predicting return parameters from simplified models of specific terrain types); and radar parameters (an assessment of the design and application of suitable transceivers). The above areas are complemented by a review of the off-highway environment, which provides information on the application of any relevant findings to the specific area of motive plant equipment. An appreciation of this area is augmented by a brief examination of current applications of electronics to motive plant, and a review of competitors' products. Due to the lack of information in these areas, a further search was made to ascertain the level of knowledge, both theoretical and experimental, in the areas of Doppler radar for automotive use. The conclusions of this review must be considered carefully: it is tempting to conclude that all which has gone before is of little or no use. Indeed, one outcome of this review was the conclusion that in certain fields, little work of direct and practical value exists. This is in no way a negative outcome: it provides a defined and sound platform from which to launch experimental and evaluatory work of one's own.

5.2 SECTION ONE: GROUND EFFECTS

5.2.1 Introduction.

The concept of CW Doppler radar is elegant: by irradiation of the target area with microwaves, the relative target velocity can be determined from the signal beat frequency and target reflectivity may be ascertained from the signal amplitude. Both the frequency and ampli ude of the returned signal are a function of the angle of beam incidence. So, by noting these two parameters for a range of beam angles, the relation between target reflectivity and angle of incidence may be established. Such is the basis of backscatter experiments.

In reality such a simplistic approach is inadequate. All terrain possesses different characteristics, including terrain seemingly visually identical, and this uniqueness produces complex problems of interpretation: are derived results due mainly to the radar producing expected readings, or due to the unpredictable effects of terrain parameters producing returns indistinguishable from valid signals? It is thus necessary to delve further into work published on the topic of signal intepretation.

An examination of previous research in this field should assist in providing a coherent picture of the current state of knowledge, and so help identify undeveloped areas of research. Thus, the intention of part one of the review is to examine the research performed on the effect on a radar signal of striking the ground. In the absence of an agreed terminology, the writer labelled this topic the study of 'ground effects'.

Ground effects covered are those observed and/or calculated with specific reference to radar and targets respectively of the type: X band (8 - 12GHz), low power (5 - 10mW), CW non-modulated, target range 0 to 10m (300 wavelengths), velocity range 10 to 60Km/hr, highway and off-highway terrain (or other terrain possessing similar characteristics). Inevitably few papers fit directly into such a narrow category, so all research considered relevant is included.

To assist in illustrating the flow of research, each section is in chronological order, thus providing a historical resumé and allowing an appreciation of the 'flow' of research.

The extent of review in terms of subject matter reflects the parameters affecting radar return from terrain; namely wavelength, power, beamwidth, incidence angle and polarisation, relative velocity, surface roughness, surface contour, subsurface structure and permittivity. Such a list does not break down into useful categories for review, so this section is broken into three sub-sections:

- Backscatter. A review of experimental work performed on the measurement of the returned signal amplitude for given target types (road, water, soil etc), radar parameters (transmission frequency, polarisation etc) and geometry (tilt angle etc). The effect of rain and snow in the radar path is also considered.

- Ground models. A review of the continuing search for a means of categorising ground parameters and formulating suitable models. The study is non-mathematical, and does not include complex statistical models.

- Radar parameters and practical limitations. A review of work performed into the consequences of major parameter selection (beamwidth, scanning and fluctuation noise etc) and the consequences of vibration, platform movement etc.

5.2.2 Backscatter.

5.2.2.1. Introduction. Backscatter, or the 'amplitude of radar signal reflected from a target back to the transmitter', is the major parameter affecting the behaviour of radar ground return. It is the parameter that determines the signal-to-noise ratio of the system, and hence the useability of the returned signal. Low-cost systems, which form the basis of this project, require a reasonably continuous returned signal in order to facilitate correct interpretation. Thus research in this field may assist in the definition of a system specification adequate for the project's purposes.

Backscatter from any given target is, to a first approximation, dependent upon the surface roughness (which itself may be a function of

RADAR	AIRBORNE/SEABORNE		GROUND-BASED			
TARGET	SEA	LAND	CROPS/VEG	ROAD/TRACK	RAIN/WATER	SOIL/SAND
1940's 1950's	Macdonald '56 Wiltsche '57 Grant and Yaplee '57	Grant and Yaplee '57 Wiltsche '57 Reitz '59 Edison '59 '60	Ament '59	Peake '57 Cosgriff '59	Ryde '46 Langille '51 Gunn '54 V.DeHulst '57	
1960's	Long '65	Katz and Spetner '60 Edison '60 Krason '66 Daley '68 Schwartz '68			Kerr '65	Lundien '66 Broderick & Hayre '68
1970's	Johnson & Weissman '79	Dickey '74 DeLoor '74	DeLoor '74 Ulaby '74 Bush & Ulaby '75 Stuchly '78	King '70 Hyltin '73 Nagy '74 Stuchly '78 Kiyoto '78 Johnston '79	Sackinger '73 Jones '73 '74 Chandler '75 Ulaby '77 Dyer '77 Baba '78	King '70 Cook '72 Ulaby '74 DeLoor '74 Bush '75 Clarricoats '77
1980's				Egawa '82	Takehana '81 Currie '82	Cox '82

EXPERIMENTAL WORK ON BACKSCATTER: CHRONOLOGY BY RESEARCH AREA OF THE MAJOR CONTRIBUTORS. FIG 5.3

other parameters such as moisture), beam polarisation, transmitted wavelength and tilt angle. Research, mainly at X band, into all these topics is covered, with the emphasis on experimental results.

The importance of the study of backscatter is reflected in the quantity of research performed; but since the majority of radar systems, at least until recently, have been for military or large scale civil use, the quantity of papers appropriate to the more 'down to earth' requirement of an 'explanation of real results from real terrain' is limited. The reviews fall into four main categories, listed below. Whilst it would seem that such categories are too broad to merit useful discussion, all experiments and results discussed are appropriate to this project, either directly, or by providing a coherent picture from which gaps in past research become more obvious.

Categories covered are:

- Air-based, ground pointing: mainly near-vertical beam angles; macroscopic ground types; the categorisation of general terrain groupings (eg sand, clay etc),

- Air and ground-based, sea-pointing: such experiments are of relevance to the project as some sea states provide targets of a complexity similar to off-highway terrain, but unequalled by typical terrain contours,

- Ground-based, ground pointing: unfortunately, such experiments are uncommon, and most refer to crop identification. It is under this heading that most potentially useful information should fall. Bistatic ground experiments are not fully covered as the results can require much interpretation.

5.2.2.2. Discussion and conclusions. It is clear that the topic of backscatter is one in which documented research has led to patchy and inconclusive results from the point of view of this project. Many theories reviewed are presented as 'proven', that is, backed by experimental evidence, although often this evidence contradicts other

AUTHOR	DATE	RADAR			ANTENNA					tilt	moist	ground
		freq	pwr	type	gain	height	dia	BW	pol	range	range	types
Grant & Yaplee	1957	9.4				30		3/3	V	0-80		water,vt
Wiltsche	1957	9.6,15		CW	20	8		7-28	H,V,C	0-90		sea
Cosgriff	1966	10,15,35		CWB		2			H,V	10-80	v	var
Lundien	1966	6.9,35		SP						0-60	v	soil,sand
Broderick, Hayre	1968	10				15		14/14		20	v	soil,sand
Daley et al	1968	10		P				5/5		8-60		sand
King	1970	40		CW		18	0.1	3/3	V,H			
Cook, Waite	1972	4-26		B					V,H	v	v	soil,sand
Sackinger	1973	26,35		CW	17	2		22/24	V,H,X	10-50		ice,snow
Hyltin et al	1973	55	2-5	CW		v		6/6	V,H	35		road,S
Dickey et al	1974	13.3						3/3	V	10-50		crops
Ulaby	1974		5W	FMCW		22	0.8	4/4	V,H	0-80	4-36	r,s T
DeLoor et al	1974	9.4	50	P		75		2/2	V,H	80-90		crops
Bush & Ulaby	1975	8,18	10	FMCW	32	26	0.6	3/4	V	0-70	6-26	soil,crop
Stuchly et al	1978	10.5	13	CW	21	1	0.13	14/16	V	10-60		soil,road
Dyer	1977	9.5,35	100		27		0.5	4/4	H	8-15		rainfall
Baba et al	1978	24	5	CW	18				V	90	100	sea
Johnston	1979	10.5	1.5	CW	20			10/10		30		road
Weissman et al	1981	8,11		CW		1.3		18/18	V	90	100	sea
Takehana	1981	49	30	CW	32		.3/.2	2/2	V,H		0-100	road
Egawa	1982	24,50				.8,1.6	-21	types-	V,H	20-60		ground,r/s

Key: vt = various terrain S = simulator r = rough s = smooth T = terrain
B = bistatic SP = slow pulse P = pulse v = various

Units: freq = GHZ power = mW gain = dB dim = m BW = deg (Horiz/vert)
tilt = deg moist = %

EXPERIMENTAL WORK ON BACKSCATTER: A RESUMÉ.

FIG 5.4

such theories. Bush and Ulaby (1976) summarised the extent of knowledge on this topic by highlighting:

"..the difficulty in defining ground types, of ensuring accurate data processing, and of ensuring the repeatability of measurements"

Long (1975) stated that two typical backscatter measurements:

"...over apparently the same type of terrain may differ by as much as ten decibels in amplitude."

Indeed, modern researchers have taken, in the absence of a full scientific understanding of the topic, a philosophical view: accept that no generalised theory can cover all terrain/radar combinations and make appropriate field measurements in the hope of, for any one given terrain, matching prediction to data. But researchers following this methodology can be categorised further: one group stress experimental data as the basis for fitting theory to measurement, the other stress mathematical predictions based on experimental data.

Before summarising pertinent research, let us summarise the findings of the major researchers:

Berger (1975b) stated that the tilt angle does not affect backscatter over land whereas Wiltsche (1957), Reitz (1959) and Hyltin (1972) found a strong dependence. Grant (1957), Daley (1968), Edison (1959, 1960), Ulaby (1974), Bush and Ulaby (1975), and Dickey (1974) rest in-between, showing that backscatter does not vary significantly for mid-value viewing angles. Moore (1969) found backscatter to be pronounced only for near-vertical incidence.

Cook (1972) found moisture can make a surface seem rougher to radar, Ulaby)1977), Cox (1982), Dickey (1974), DeLoor (1974) and Lundien (1966) found backscatter to be dependent upon moisture (the latter, both surface and subsurface). Cosgriff (1959) and Broderick (1973) found rougher surfaces gave returns less dependent upon tilt angle. Hyltin (1973) and Cosgriff (1959) found vertical polarisation to give less dependence upon surface type; Nagy (1974) found, for bistatic arrangements, horizontal polarisation preferable. Wiltsche (1957) found return to be frequency independent, whilst Berger (1957) and Ulaby (1974) report the opposite.

What conclusions can be drawn of a more specific nature? Although the topic of backscatter from sand, gravel, asphalt etc seems fairly well researched, several crucial aspects are lacking:

- the researchers consider only the terrain surface, and pay little heed to the capability of radar to penetrate deep into non-metallic target materials. Thus the effect of moisture in the ground is examined only in the context of a macroscopic cropped ground area. Such moisture affects return drastically: Clarricoats (1977) found that at X band, wet sandy soil produces over twenty times more attenuation than the same material when dry.

- Moisture in the ground is not covered: neither is moisture on the ground. No researcher has noted the effect of areas of water (ie puddles !). This is a serious ommission as even a small patch of surface water can modify radar return catastrophically. Such a surface would be hard to model but the relatively simple task of direct measurement has also not been performed.

- No work exists on typical off-highway terrain, namely rough compound surfaces such as potholed dirt, clay and pebbled. As with puddles, the complexity of such a surface may defy model and theory but certainly not experiment.

- Those results traced are presented as amplitude-related only: no researcher presents the effect of backscatter parameters in the frequency plane, either in the form of spectra, or reproduced signal plots such as oscillographs. By the same token, the work traced is all of a 'static' nature, assuming that the return is a spot fequency which can be measured in terms of amplitude changes. This is far fom the case. It is acknowledged, though, that this project utilises a wider than ususal beamwidth, and is thus more prone to 'dynamic' frequency fluctuations.

- For 'typical' terrain and mid-value tilt angles of 30 to 50 degrees, most researchers agreee that minimal amplitude deviations occur; and within this range the type and quantity of return is, for any given surface, reasonably predicatable. However, see below for further comment.

- Most work points to vertical polarisation being the preferable configuration for dirt/soil type terrain and monostatic radar. For bistatic types, horizontal polarisation is preferable.

Thus, undoubtedly due to the lack of knowledge concerning the surface types relevant to this project, no work would seem to exist that would assist in the prediction of the range of returns probable from a piece of terrain given its major parameters (moisture content, surface roughness and material, features etc). This point is worthy of repetition: it is not possible, by considering previous experimental work, to predict the effect of backscatter on the transmitted beam for any surface other than simple non-compound ground or compound ground considered in a macroscopic manner.

Research into backscatter from surfaces pertinent to this project (notably mud, compacted gravel and clay) are not well documented. Indeed no specific research could be traced that falls into this category of terrain composition. It is clear that much work still needs to be done before a true picture of ground return from site terrain types can emerge.

However, clues as to certain system design features have emerged: mid-value tilt angles and vertical polarisation seem to present themselves as desirable features. And, of course, the review makes clear the need for the writer to conduct his own research into backscatter for terrain specific to this project.

5.2.2.3. Backscatter From Rain And Snow: Introduction. This section deals with 'volume' clutter (unwanted radar echoes from atmospheric phenomena). Because of the distributed nature of the returned signal, the measure of backscatter from such clutter is usually stated in terms of radar cross-section density. The consequences of atmospheric clutter are significant with any radar: notably so with X band where the wavelength is of a similar order of magnitude to precipitation particles such as rain and snow. The beam attenuation is not considered, as the effect on near-field radar is negligible (Haddock, 1948, states the attenuation of heavy rain over a 10m distant range to be 0.005dB).

Much work exists on the utilisation of radar in detecting and measuring 'desirable' meteorological targets: such papers consider radr as a 'black box'. Early researchers, however, were more inter-disciplinary, and happily laid-open their methods of measurement and results. Due to the lack of research in the field applicable to near targets (a maximum of 10m distant), the following conclusion section is longer than the review!

5.2.2.4 Backscatter from rain and Snow: Discussion and Conclusion. It is ironic that the earliest paper reviewed (Ryde, 1946) presents results still used for both reference and as 'typical' data for normal rainfall rates. Later papers (Takehana,1981; Currie,1982) not only agree with Ryde, but point out difficulties in obtaining true measurements and correctly interpreting recorded measurements. For all practical purposes, Ryde's results (or Haddock's, who presents rather more comprehensible graphs) are fully adequate for estimating the backscatter amplitude from precipitation. On a matter of definition: most papers concentrate on establishing the quantity of return from precipitation, and do not assess or intepret the type of return. The exception is Sackinger (1973) who details the passage of radar through snow layers which, he states, "..produces continuous refraction and backscatter throughout the depth of the layer".

There exists a dilemma, however. Research has been performed on back-

RESEARCHER	DATE	MICROWAVES ACT ACCORDING TO / AS	FIELD / TYPE
Clapp	1946	Lambert law (modified)	optics
Berger	1957	scatter centres	statistics
Moore	1957	Lambert + Fresnel	optics & specular
Katzin	1957	facet	optics
Katz & Spetner	1960	specular + facet	scatter / partial optic
Schooley	1962	facet	geometric optics
Beckmann et al	1965	peturbation theory	Kirchoff / Huygens
Kodis	1966	specular	optics
Chadwick & Cooper	1972	distributed target	independent scatterers
Funke	1978	distributed target	interacting scatterers
Henn	1982	semi- distributed target	modified scatterers

RESUME OF MAIN MODEL AREAS AND PROPOSERS OF GROUND RETURN THEORY. FIG 5.5A

RESEARCHER	Barrick (1968) (1965) Peake (1968)	Broderick (1973)	Cumming (1959)
ROUGH DEFN	$R > 1$ ($R \approx 1$ slightly rough)	$S < 0.125\lambda_T$	(Rayleigh criterion)
FORMULA	$R = K.r.\text{Cos } w$		$\Delta h \leqslant \frac{\lambda}{m.\text{Sin } \psi}$
ASSUMPTIONS	K: $2\pi\lambda$ (free space propagation constant) r: height of surface imperfections above mean plane w: angle of incidence	S: maximum surface imperfection height λt: transmitted wavelength	Δh: rms deviation of irregularities relative to median surface m: smoothness factor ψ: grazing angle m typ 8 to 32

RESUME OF MAIN 'SMOOTHNESS' CRITERION. FIG 5.5B scatter from precipitation or from terrain. But what of that from terrain AND precipitation? For CW systems, the amplitude can be derived using Ryde (1946), but the perceived frequency may be:

- for no significant solid target, the velocity of the precipitation (multiplied by the mean value of the cosine of the approach angle): the frequency measured will thus usually be the speed of the prevailing wind,

- for a significant solid target within the nominal footprint the measured velocity will be the relative target velocity. Phase nulls due to this target may be affected in an unquantifiable manner,

- a simultaneous combination of the above may produce an output of whichever is the higher of the respectively produced frequencies,

- alternating combinations of the above produced by, for example, fading returned signal may allow the precipitation echo to fill in.

No research deals with these points: significant because as stated above, the returned Doppler frequency may be determined by windspeed! This could well prove disastrous as off-highway applications require vehicle velocity measurements BELOW typical open-ground windspeeds. Even for low average windspeed, gusting may trip the overspeed alarm. Gusting itself if not covered by any traced research: all workers have considered the easy, but unrealistic, scenario of zero windspeed.

A preliminary experiment with rain performed by the writer found that in the absence of a stronger signal, the radar alarms even off light showers. Fortunately, it is thought that a typical Doppler signal is strong enough to swamp this precipitation-derived signal. Obviously more work is needed on this topic.

Other related weather conditions are also neglected: no work seems to have been performed on return from dust clouds, for example, other than work utilising pulse radar over extended ranges (eg Chu,1979; Goldhirsch,1982), and of no direct relevance. Although dust particle size is small compared to rain, the density can exceed that of typical precipitation by several magnitudes, obscuring the true target by deflection and/or diffusion. The writer estimates that a dense dust cloud may well behave in a manner similar to that of a true random semi-rough surface. Thus it would seem that although papers exist that provide an empirical means of assessing the probable effect of precipitaition on a radar system, significant gaps exist in the understanding of the subtleties of return (the exception being long-range macroscopic radar targets, which are well researched, and not included in this review). Relevant work for this project, it may be argued, stopped in 1946. Once again, this illustrates the need for fresh experimental work.

5.2.3 Ground Models

5.2.3.1 Introduction. Models of terrain vary in complexity from physical scale models to mathematical treatises. Whatever the type, it is convenient to have access to theoretical estimates of terrain return to which experimental results can be compared. This allows categorisation of data, and possible prediction of return from terain inaccessible to measurement.

It would seem that no present theory of scattering from non-uniform surfaces can either provide a universal ground model, or assist in the understanding of those parameters which permit a specific model to be associated with a specific terrain type. To a great extent, this is not a 'mathematical' failing, or a lack of intuition of the researchers. It is a problem of adequately describing terrain in terms of its radar-dependent parameters: there is no easy means of mathematically describing any given surface. Thus the generalised conclusion of this section is that even after several decades of study, no fully adequate description capapable of providing the basis of a general terrain return theory exists. In an attempt to bridge the gaps in this field, numerous basic models have been proposed over the last forty years. Most cater only for one very specific surface type by assuming a model far too simple for any real terrain. But, and this point may be important, by considering such models it may be possible to associate a model type with a given terrain type; or, by examining a terrain sample, to select potential model types. The first two decades of ground model research fell into two catgories, depending upon which difficulties the researchers chose to ignore:

- scatter and facet model theories. By representing the surface by collections of objects with known scattering properties, the return can be predicted, and empirical formulae generated to explain the angular dependence of terrain return. Such models are difficult to apply to real surfaces, whose directly observable properties seem unrelated to the usual interpretation of results obtained,

- theory of scattering. By concentrating on detailed solutions of specific, carefully chosen scatter cases, theories were proposed assuming impractical, oversimplified surface types.

More recently, 'complete' models have been suggested and developed, which aim to answer both the above criticisms: the ultimate intention being to characterise terrain by parameters capable of direct measurement, so that all returned signal characteristics may be derived from surface (or at least, accessible) properties only. Such models, however, inevitably become impractical from the mathematical viewpoint. Fig 5.5A summarises the major model types.

Also included in this section of the review is a brief assessment of terrain categorisation techniques; as to quote Ballard (1975):

"Frequently surfaces will deform after the passage of just one machine; require constant maintenance and rarely receive it. Ground materials vary from the softest silt to hardest rock, which may degenerate into a dust bowl or quagmire..".

Indeed, the range of surfaces over which large off-highway trucks operate is wide, and even small sites do in reality possess the

RESEARCHER	DATE	EFFECTS DUE TO BEAMWIDTH & TILT ANGLE		OTHER EFFECTS
		PAPER COVERS	SOLUTION?	PAPER COVERS
Berger	1957		dual beam	
Fried	1957	spectrum errors		
Bushnell	1958			long term TX freq stab
Brady	1959			short term TX freq stab.
Kelly	1961			S/N effects
Craig	1962			vel error, TX freq stab.
Bushnell	1965	Fluct noise		
Ishii	1965			TX freq stability
Ehrman	1965	Scan noise		terrain backscatter
Gill	1969	Scan noise: negligible	none req	
Broderick	1969	Scan noise		
Fried	1969	Scan noise		
Cowley	1971			AM noise
Jones	1973	Scan, fluct noise: strong		phase nulls, zero cross
Hyltin	1973	Scan noise (=0.1of Fluct)		scatt. coeff, TX freq
Bryant	1973			noise (elect, mechan)
Walsh	1972			general perf. limits
Grimes	1974	Scan noise: negligible if:	dual beam	vibration
Augustine	1975	error		vibration
Acker	1975			AM, FM noise
Saw	1976			ripple, noise of PSU, VIB.
Kiyoto	1976	Scan noise: negligible	none req	

FIG 5.6
(PTO)

Stuchly	1977	Scan and fluct noise: big	CoR	phase nulls, zero cross
Angwin	1977	error		noise, nulls
Millard	1977			noise
Krage	1977			noise
Hosking	1977			noise, zero crossing
Neininger	1977			PSU, noise
Whetton	1977			nulls, AM
Baba	1978	error negligible	none req	
Johnston	1979	Spectrum		mud, water on lens, TX freq
Fisher	1980			AM, noise
Fritzlen	1980	Spectrum		
Greneker	1980			poor filters, AGC, CB
Aker	1980			m.path backscatter
Holford	1980			PSU, noise
Gautschi	1981	Spectrum (skewed)	ST,MP	nulls
Richardson	1982	Spectrum	dual B, CoR	zero cross
Egawa	Spectrum		ST	noise
Tsuha	1982	Scan, fluct noise	ST, MP	vibration

ABBREVIATIONS: ST: statistical algorithm; MP: microprocessor; CoR: centre of rotation;

THE EFFECTS OF BEAMWIDTH AND TILT ANGLE GEOMETRY ON THE ACCURACY OF VELOCITY MEASUREMENT, WITH PROPOSED SOLUTIONS, AND EFFECTS OTHER THAN GEOMETRICAL: IN CHRONOLOGICAL ORDER OF PUBLICATION.

FIG 5.6 (Continued)

variations in terrain indicated by Ballard. It is important that this probable range of terrain types is identified: thus the review considers work intended to provide an accurate and easy means of categorising real ground.

Thus this section attempts to establish which means are available to describe a surface in simple terms, and to appreciate the limitations, even if qualitative, of the selected model type. It is shown that such models exist conceptually, and are indeed applicable. As of knowing the limitations: ineveitably the model proposers found few. Later workers were quick to highlight many. In this field, as in many others, no one theory has been adopted as no one theory has been proven correct.

5.2.3.2. Ground models: Discussion and Conclusion. All the models considered can be categorised in such a manner that their weaknesses become apparent:

- All models are 'static' in formulation, and neglect the consequences of continually changing parameters. The amplitude, for example, of the received signal when mounted on a moving platform fluctuates widely due to phase-shift variations and intermodulation. Such fluctuations can mask the true return.

- Many models take into account static, discrete scattering centres. However, for targets in the 'near field' region (defined here as targets nearer than 300 wavelengths: for X band, around 10m)such discrete points are better described as 'regions of return', as it is easily possible for one region to dominate the return from others by interaction and interference. Thus, Funke's work (1978) provides the most realistic basis for a working model, as he considers 'interacting' scattering centres.

- Continuing from above, the tilt angle is, for any stated nominal angle, constantly fluctuating about the mean angle. As the radar moves past a given surface contour, the mean angle of incidence at that instant produces a return from a discrete target point, having a specific phase and amplitude envelope. If the found envelope is low in amplitude, the radar effectively 'looks' either nearer or further away so that the return from a different target point will dominate.

- Many models consider the scattering centres to be randomly located. If so, the returned envelope is a random variable with an amplitude described by the Rayleigh distribution. For a superimposed large surface, the resultant phase-gradient produces a sinewave type spectrum on the returned noise (random amplitude return). As the large surface area increases, the envelope approaches a normal distribution about the mean frequency (determined by the major radar to target centre distance and angle). The problem of signal interpretation is now that of extracting a signal from noise. Many papers, eg Ehrman (1965), Kobayashi (1974), Schultheiss (1954), Strakhov (1968) and books, eg Wainstein (1970) and Mityashev (1965) all describe statistical methods of signal extraction. but this topic has now entered the realms of pure mathematics, and is of little use to this project. Indeed the proposers of the random scattering model themselves stop short of involving the necessary maths. Clearly such an assumption as random scattering is not an ideal basis for a practical model.

- The majority of the proposed models assume a rough boundary surface between air and an infinite homogeneous half-space: few atttempts have been made at extending the model to include a partial homogenous boundary. Both models are still cumbersome and of limited use: being by necessity idealised as very few ground surfaces are even remotely homogenous. Certainly, if the definition of surface includes the 'thickness of terrain penetrated by radar' (see the conclusions from the backscatter review), this is certainly not the case. Scattering boundaries are certain to exist both on and under the surface.

The assumption of isotropic statistics is also of limited use: ploughed fields, regularily rutted roads and even cobbled roads and taramac all defy any basic model.

- Typical off-highway terrain may have, for example, a construction that takes the above point further. Consider a muddy surface and a rock subsurface. Internal reflection and scatter modifies the reflection to such an extent that no one model can suffice, and neither can the combination of mud and rock models. Moisture may also be present in a non-uniform location and quantity.

The extent of validity of any ground return theory is only as correct as the mathematical model used to describe the gound type. It is this description that has proved difficult, for even a simple surface defies modelling. The terrain described in the above paragraph is a typical site construction: thus it would seem that no model is of use in a mathematical sense, although certain work does provide a useful 'feel' for the topic, notably the facet and scatter models. So yet again, the importance of obtaining data from the terain over which the radar is to be used is exemplified. Lundien (1966) took the terrain into the laboratory; but for this project's purposes, the more conventional technique of in-situ measurements must be made.

5.2.4 Radar Parameters.

5.2.4.1 Introduction. This section examines research performed and theories proposed on the consequences of real radar system limitations and of the environment on the returned signal. Clearly any radar system, even the most basic Doppler unit, is prone to numerous sources of 'interference', from subtle modifications of the received signal to total lack of the required signal. An examination of work performed in the field of identification of these sources of interference is mandatory, to ensure that both no findings are 'reinvented', and in such a complex field as this, to provide a realistic starting point for this project's experimental work.

Backscatter has been covered in some depth earlier, where it was stated that it is perhaps the most important aspect of radar return. But given that a suitable signal amplitude exists (ie an adequately decipherable and processable signal), what factors are next in the chain of importance? The answer can be broken for our purposes into several distinct considerations:

- The transmitted beamwidth, presence of sidelobes, and assymmetry. These parameters give rise to scanning and fluctuation noise, and beam 'hunting',

- Radar platform movement and vibration. Four main categories: mean tilt angle (covered in section 5.2.2.2) due to the interdependence on the instantaneous tilt angle; instantaneous tilt angle, dependent upon the dynamic movement of the radar platform producing rapid deviations from the mean tilt angle, giving rise to both amplitude and frequency fluctuations. The third source is amplitude and frequency modulation due to the above point, and also ground contour both below the vehicle (producing tilt angle variations due to pitch and roll) and behind it (causing beam hunting and modulation). Finally, vibration: numerous modes exist in the platform's dynamic system, including engine, transmission, body, radar unit etc.

- Signal processing methods. Signal integrity is a function of signal-to-noise ratio, dynamic range, frequency response, reaction time, integration time etc (ie the processing methodology). The integration time deserves special mention: signal amplitude averaged over an extended time period may produce a valid average, but averaged frequency may misinterpret instantaneous alarm conditions (see section 4.4.3).

- Instantaneous return amplitude. Backscatter was earlier considered to have a relatively constant amplitude for any given surface type and contour. For rapidly varying contour or wide beamwidth the backscatter will possibly include three features. First, total nulls, ie periods of no signal; secondly, phase changes, which produce an effective reduction in perceived frequency. And finally, peaks and/or nulls due to inteference produced by complex surfaces.

- EMI, RFI and interference. This heading includes power supply smoothness, impedance and regulation etc. The usual Faraday cage precautions are inadequate as interference has direct access to the mixer diode.

At this juncture it is worth noting the appropriate definitions of 'noise'. The first point above uses the term in a sense of 'unwanted disturbances superimposed upon a useful signal' (IEEE handbook), whereas later points use the sense of 'an intrinsic internally generated signal, having random amplitude and frequency content'.

The importance of the above points can be illustrated by catalogueing the requirements for a Doppler-based measuring system:

- A signal must be received. Thus all radar parameters must be fully understood and optimised (transmission frequency and power, polarisation, antenna gain, beamwidth, target RCS, backscatter properties, propagation effects etc),

- The spectrum of the returned signal must fulfill bandwidth and signal-to-noise requirements (minimal phase nulls, tracking, filter and processing techniques etc),

- The relationship between measured frequency shifts and vehicular velocity must be known for all terrain types; platform movement, vibration tilt angle etc.

Not all aspects of radar parameters have been discussed: several have a value or performance determined by present equipment or practical limitations.

5.2.4.2. Discussion and conclusions. This section of the review indicates that much work has been performed explaining mathematically the causes of error in velocity measurement by the utilisation of Doppler radar, and several proposals to increase the accuracy of measurement and interpretation have been proposed (Notably Richardson, 1982; Egawa,1982; Augustine,1975; Tsuha,1982). Several methods utilise complex algorithms implemented by microprocessors to perform statistical analyses of data, but the analyses will still misinterpret groundspeed when either there is a valid signal for an insufficient proportion of the time (due to platform bounce or extreme ground conditions), or when there exist certain terrain features that invalidate the statistical methodology (such as large boulders to the beam edge, regular spacing of ruts in the footprint, or platform bounce being a harmonic of platform speed). Such circumstances are a common feature of off-highway terrain.

As discussed in the review proper (chapter 12), such a microprocessor based system manufactured by TRW Inc was assessed by the writer in an off-highway environemnt (see report INT P25): the unit underread by up to a factor of five. Unfortunately at the time of writing, this product represents state-of-the-art, being expensive and designed specifically for off-highway applications.

Let us summarise point by point the relevant conclusions from this section of the review:

- The importance of beam geometry is confirmed by the review. Scanning and fluctuation noise, and their dependence upon tilt angle and beamwidth, are reasonably documented. No work, though, presents a useful graphical illustration of these effects (such graphs are included in report INT P15).

- Multiple beam systems are shown to be preferable in performance terms (see also appendix 3.7b). The dual Janus configuration is well researched, and reduces errors due to platform tilt.

- Many sources of probable error appear in the research; notably platform vibration, transmitter frequency and amplitude modulation, frequency stability (long and short term). All such sources must be minimised, and indeed several papers do examine techniques of achieving this. Fig 5.6 summarises this work.

- Continuing from above, it is clear that the whole radar environment must be quantified, and considered in system design. This heading includes temperature, humidity, dust, oil etc. In the apparent absence of a significant quantity of research in the literature, this has been performed by the writer, and appears as report INT P24.

- Numerous processing techniques are suggested: all are to some extent a compromise, so each must be fully assessed (specifically zero-crossing counters, automatic gain, power supply, filters etc).

- The optimum transmission frequency must be selected. Again, this is a compromise: for the same terrain, 10, 35 and 60GHz have been suggested as optimum by different researchers. Factors to be considered include the appropriate legislation, unit size, backscatter etc.

- The problem of ascertaining the centre frequency of a broad and changing spectrum is noted, although disregrarding complex laboratory techniques, few solutions are proposed for dealing with the problem. Several patents have been traced, but deal only with conceptual solutions.

- No work seems to give a full account of sources of measurement inaccuracy due to phase nulls, intermodulation, or inadequate amplifier bandwidth curtailment. Errors thus produced are likely to be of greater significance than several sources commonly noted and researched by workers.

- One aspect of error not covered (Kiyoto,1976 notes the effect in passing) is that of the interchangeability of noise effects for certain target types: for an extreme terrain, for example, a non-reflective surface apart from regular protrusions perpenducular to the beam, theory predicts a lessening of fluctuation noise for a decrease in beamwidth. The lessening is not that expected: the beam 'sees' protrusions outside its nominal beamwidth. If the beam is made too narrow the slight scanning noise predicted will be considerable and the beam will 'hunt' between protrusions.

In conclusion it must be said that the literature of the topic of radar parameters is more comprehensive than the other topics covered. This is not surprising, perhaps, as the effects dealt-with are more tangible.

Thus there exists a valid core of knowledge on which to base further work towards achieving the aims of this project.

5.3 SECTION TWO: AUTOMOTIVE RADAR AND ELECTRONICS

5.3.1. Vehicular Radar.

5.3.1.1 Introduction. Before commencing design work on the speed sensor, a comprehensive literature review must be carried out to ascertain exactly what work of a similar nature is documented, and the extent to which the traced literature is pertinent to this project.

Part one of this review dealt with the influence of the terrain on radar systems, including surface contour, type, models, platform geometry and movement, interference etc. This section continues by examining the types of radar employed in vehicular (in the widest sense, including agricultural, off-highway and automotive) radar systems.

Initially only vehicular radar, specifically Doppler, were reviewed, but much relevant literature was found in non-vehicular applications. Thus the review brief was expanded to include truck electronics and non-vehicular Doppler systems. In consequence the review is very selective: there exists a wealth of useful information. Although this search provides information on specific design approaches, the 'theoretical' and 'review' treatments are nevertheless of value. For example, much information was found in patents and journals not apparently connected with the subject-matter of the original search brief. But the review should provide data upon which to establish a list of 'common factor' problems encountered in previous research; and hence provide a suitable base upon which to commence design work. The review is divided into three categories:

RESEARCHER		RADAR CONFIGURATION			ANTENNA		APPLICATION	NOTES
		TYPE	FREQ(Ghz)	PWR(mW)	TYPE	BW(E/H)		
Boyer	1963	diplex, fmcw	10, Q		dish, dipole		vel, range	
Milner	1968	cw	10		dish	14/14		
Harokopus	1971	cw diplex	16	50	array		vel	micro
Hopkins	1972	cw bistatic	10			25/25	vel, detect	
Ives	1972	fmcw	35		horn	5/5	range	
Augustine	1972	cw janus	21	25			vel	
Ives	1973	fmcw diplex	10, Q				range	
Hyltin	1973	cw	60	10	circ horn	6/6	vel	
Wood	1973	cw diplex	10		dish		vel, range	
Holmstrom	1973	cw bistatic	10	30		26/26	range	
Johnston	1973	cw	10					
Stevens	1974	cw diplex	10		hyp lens	10/10	vel, range	
Augustine	1974	cw janus	21	25	horn, lens		range	CRAR
Ross	1974	pulse						
Shefer	1974	cw/fmcw	10	100	p.cct	5/5	range, vel	micro
Hamid	1975		10	10	horn		vel(flow)	micro
Krage	1975	cw binaural	10				range, vel	
Stuchly	1976	cw	10		ell lens	14/15	vel	
Mullard	1976	cw	10				vel, detect	
Thansandote	1976	cw	10	13.5	horn, lens	15/15	vel	
Kiyoto	1976		24		horn		vel	micro
Belhoubek	1977	fmcw	10	27	p.cct	10/10	range, detect	
Heiden	1977	fmcw	16,35	10	horn	3/6	vel(flow)	micro

RESEARCHER		RADAR CONFIGURATION TYPE	FREQ(Ghz)	PWR(mw)	ANTENNA TYPE	BW(E/H)	APPLICATION	NOTES
Dull	1978	pulse	24	10w		3/3	range	
Ross	1978	pulse	10,K				range	
Baba	1978	cw	24				vel	micro
Flannery	1979	pulse	24	10w		10/10	range	micro
Johnston	1979	cw	10	1.5	p.cct	10/10	vel	
Gautschi	1981	cw	37				vel	micro
Takehana	1981	fmcw	50	30		2/2		
Richardson	1982	cw	24				vel	micro
Mayhan	1982	cw diplex	10				range	
Egawa	1982	cw	24		lens,horn	16/21	vel	diversity
Tsuha	1982	cw	24	10	circ	5/5	vel	micro
Kopp	1983	cw	24	10	circ	5/5	vel	micro
Neininger		fmcw				3/6		micro
Hylderbad			10	25				
Manufacturers:								
RCA		cw bistatic	9	100			vel, range	
RCS		cw diplex	10	20			range	
Bendix		cw diplex	16	20		4/4	range	micro
		cw diplex	36	20			range, vel	micro
Texas		cw janus	60		horn		vel	
Bentley		cw	10	10			range	

RESUMÉ OF RESEARCH ON AUTOMOTIVE AND RELATED WORK.
FIG 5.7

- Vehicular radar. All applications (range, object detect, and velocity measurement) although emphasis is placed on techniques appropriate to velocity measurement.

- Non-vehicular Doppler radar. Papers which are of use, although the application is superficially dissimilar to this project.

- Truck electronics. An examination of the types of electronic systems fitted to trucks, and of the problems encountered.

In common with the general format of the review, researchers and pertinent features of their work are wherever possible summarised in a tabular manner.

5.3.1.2 Discussion and conclusions. The outcome of the review has three main uses: to catalogue and briefly assess documented relevant work such that quick and easy reference can be made to all appropriate literature; to provide the groundwork for this project's experimental regime; and to summarise trends and points worthy of note. The first intention has been met: figs 5.7 to 5.9 tabulate appropriate work, and several anomalies within the literature have been identified, namely:

- Many, often otherwise complex range/velocity systems use a conventional speedometer for velocity information: even those using advanced microprocessor data processing,

- Almost without exception, the researchers do not document practical problems met. For example, no references are made to: weather, tilt, vibration, shock, unit reliability, interference, and notably the effect of the general environment.

- Nearly all the systems described are laboratory prototypes, and are unrepresentative of production units (this comment also refers to systems referred-to by manufacturer name), being unwieldy, impractical and expensive laboratory-only solutions. This point is of importance: no system reviewed is truly 'commercial'.

But nevertheless, much information of interest and practical use is contained within these papers. The problem of 'ground clutter', ie realising that terrain presents a complex radar target) has been acknowledged for over two decades, and surprisingly techniques for coping with the phenomenon have not differed. The major improvement has been the introduction of the solid-state oscillator (appendix 2b), and the availability of integrated circuits. Thus, whilst for example, Gardner describes phaselock techniques, now ine IC performs the whole task. Such modularisation simplifies processing, but does not necessarily improve it. Few papers traced differ from the 'accepted' topology of amplifier, filter, squarer and counter. Even the more daring deviations (eg Pacozzi, 1979) are additions rather than replacements.

The more successful research programmes seem to have several common factors: notably the use of PLL's, and comprehensive signal filtering. Such filtering takes many forms: passive, localised active, tracking (feedback), multi-band and phase-locking. Thus, specific circuit details are available for examination, comparison and utilisation.

The lack of data available on the automotive environment is disappointing. It is clear that further work must be performed to identify and quantify this environment from the view of the doppler radar and associated electronics.

5.3.2 TRUCK ELECTRONICS

This section reviews the application of electronic systems of off-highway trucks and agricultural equipment. Clearly the problems of applying electronic systems (including radar) are common to this group of vehicles. Numerous semi-electronic systems are available as commercial products: these are not covered as they are effectively an electronic analogue of a simple electromechanical module. for example, an electronic (in terms of either pre-processing or display)---

(continued on Page 96)

RESEARCHER	DATE	SYSTEM TYPE	SYSTEM BAND	APPLICATION FOR:	NOTES
Fathauer	1969	cw	x	vel	
Gupta	1972	cw	x	vel,range	Gunn diode
Berry	1972	cw	x	vel	
Lewis	1972	cw	x	vel	
Flannery	1973	cw		range	
Augustine	1974	cw	x	vel	Janus
Watanabe	1974	cw		vel	diplex
Augustine	1975	cw	x	vel	Janus
Fathauer	1975	cw	x	vel	
Nissan	1975	cw		vel,range	diplex
Angwin	1977	cw		vel	
Krage	1977	cw	x	vel	
Millard	1977	cw	x	vel	freq track
Whetton	1977			vel	
Endo	1978	cw	x	vel	dual mixer
Pacozzi	1979	cw	x	vel	freq track
Fukumori	1979			vel	noise detect
Fishbein	1980			detect	diplex
Aker	1980	cw	x,k	vel	micro
Fritzlen	1980			vel	
Stauers	1981	cw	x	vel	
Hiroto	1982	cw	x	vel	mpx
Mawhinney	1982	cw	x	vel	sweep filter
Brown	1982	cw		vel	
Berry	1982			vel	

PATENTS PERTAINING TO DOPPLER VEHICULAR RADAR. Researchers in chronological order. Full title listed in bibliography.

FIG 5.8

RESEARCHER	DATE	PATENT No.
Barker	1953	2 679 865
Rashid	1957	2 804 160
Meyer	1961	3 102 263
Chu	1961	2 996 137
Dworetzky	1963	3 095 562
Meyer	1963	3 102 263
Taylor	1963	3 094 693
Marlo	1964	3 152 326
Handschin	1964	3 137 538
Durstewitz	1964	3 118 139
John	1965	3 213 375
Marlo	1965	3 176 294
Zadig	1966	3 241 138
Hagemann	1966	3 277 430
Stavis	1968	3 371 341
Gray	1969	3 480 954
Lalone	1969	3 448 822
Pryor	1970	3 517 998
Bruckett	1971	3 624 410
Lewis	1972	3 701 568
Berry	1972	3 689 921
Desipio	1973	3 727 142
Iten	1975	3 893 113
Goyard	1978	4 101 890
Patterson	1980	4 214 243

PAPERS PERTAINING TO DOPPLER VEHICULAR RADAR: SECONDARY LIST. These patents do not appear in the review or bibliography but are of interest.

FIG 5.9

RESEARCHER		SYSTEM	APPLICATION	TASK
Taylor	1963	ultrasonic	earthmover	velocity measurement
Stuchly	1976	radar	agricultural	velocity measurement (slip prevention)
Stuchly	1978	radar	agricultural	velocity measurement (slip prevention)
Gruben	1980	microprocessor	earthmover	transmission functions + diagnostics
Kays	1980	microprocessor	earthmover	transmission functions
Dickson	1980	radio link	trucks	remote control
Steel	1981a	magnetic tcr + digital	trucks	overrev prevention (retarder control)
Steel	1981b	radio / infrared	trucks	remote alarm speed setting (retarder control)
Masai	1981	microprocessor	trucks	cruise speed (retarder control)
VanSchoiack	1982	micro / radio	trucks	truck remote control
Jones	1982		agricultural	groundspeed and other
Ullrich	1982		agricultural	general review
Weber	1982	microprocessor	trucks	hydraulics
Johanningmeir	1982	microprocessor	trucks	transmission, on-board diagnostics
Kruse	1982	microprocessor	agricultural	speed sensor
Weiss	1982	electronic	commercial	speed sensor and limiter

RESUMÉ OF MAIN RESEARCHERS ON TRUCK ELECTRONICS.

Competitive products are covered in report INT P12A

FIG 5.10

speedometer (ie using a conventional cable and display but with an electronic interface) does not lend itself to analysis as nothing applicable to this project can be learned. Commercial products that in some way overlap functions performed by the ALBERT system are reviewed in report P12A.

The electronic systems covered can be categorised into two main headings: speed sensors (radar and magnetic transducers) and transmission/engine controllers. Of the latter, little documentation exists other than the manufacturers data which is of minimal use. The former category does not, unfortunately, contain any clues as to possible problem areas of the truck-electronics interface. The search for suitable papers, therefore, continued throughout the project.

5.3.3 Non-Automotive Doppler Velocity Measurement

5.3.3.1 Introduction. This section delves briefly into the wealth of literature pertaining to the application of Dopper radar principles, excluding vehicular systems. Such applications are of interest, as often the processing circuitry for a system has great similarity with another system performing a totally different function. For instance a gun shell velocity meter circuit may differ little from an intruder detector circuit. Indeed, Stuchly (1976) points out that the problems of applying such radar to the task of measuring flow of wheat are identical to those met when trying to measure the velocity of an aircraft.

Road simulators are also covered in this section: unfortunately only four such systems were traced. Due to the quantity of literature available, only the work considered specific to the project is included.

5.3.3.2 Discussion and conclusion. Much work reviewed has direct parallels with vehicular velocity measurement: many papers review the use of Doppler systems in airborne applications. The researchers in the latter systems document similar problems to those of the former type; namely fluctuation and scanning noise, platform tilt etc. Similar solutions are suggested, although many fall outside the category of practicality for low-cost ground-based systems. Many intruder detector circuits and applications are available: over four hundred patents in Britain alone. Several utilise similar anti-false-alarm circuit topologies as vehicular radar: the more useful work is given in the review proper.

RESEARCHER	DATE	ACCURACY	NOTES
Augustine	1972	+- 1%	Janus configuration
Hyltin	1973	7.5%	60GHZ system
Johnson	1973	+- 1%	obtained in dry, smooth conditions
shefer	1974	1% (*1)	obtained in dry conditions
Thansandote	1976	+- 1.5%	obtained at speeds below 10mph
Baba	1978	10%	average result. TX of 24GHz
		50%	in heavy rainfall
Johnston	1979	+- 3.5%	obtained at 10mph
Fisher	1980	+- 1mph	FCC calibration standard
Richardson	1982	3 to 9%	obtained below 10mph
Tsuha	1982	5%	average. TX of 24GHz

*1: This represents the best of a series of measurements. A more representative average accuracy is not stated.

VEHICULAR RADAR SPEEDOMETERS: CLAIMED ACCURACY. FIG 5.11

Notes: It is important to note the conditions under which these reported accuracies were obtained. Excluding higher frequency transmitters, Janus configurations, 10mph maximum runs, and quoting 'best of' results, leaves only Johnson's work!

CHAPTER SIX

DATA RECORDINGS: ANALYSIS

"It is terifying to think how much research is needed to determine the truth of even the most unimportant fact. "

Stendahl

CONTENTS

SECTION

6.1. INTRODUCTION

Previous chapters have referred to the data collection experiments performed during the course of the project. In order to simplify the description of data gathering work performed over a period of two years, the interpretation of this data is discussed in this one chapter. Included are discussions on the findings of the work and a description of how the findings were utilised in the final production design. The recordings are divided into five major sections: calibration (figs D1 to D4), amplitude (5 to 14), spectra (18 to 59), waveforms (60 to 68), and frequency tracking (69 to 71).

To facilitate referral to the appropriate graphs, these are located in volume two supplementary material, section one (prefix D). The majority of spectra are hand-traced: this allows interference from mains to be omitted, and two or more spectra can be superimposed by dotting lines.

The graphical data presented in volume two reflects the outcome of field and laboratory examinations of factors thought or known to bear relevance to the speed sensor design process. Around six hundred such graphs were produced (a list of data recordings made appears in appendix 3.1): this chapter deals only with those recordings that contribute either to the body of knowledge and/or to the project brief.

The requirement for such data extended over the whole project period, and changed emphasis according to the practical needs of the project. Thus, for example, in response to the need to ascertain the contribution of radar beamwidth to the returned signal quality, numerous data recordings were made using a variety of transceivers, vehicle platform types, terrain conditions etc. So, over a period of time, a picture of the relative contribution of each aspect to unit design could be built up. It is important to stress, though, that the majority of such recordings provide qualitative information and like-with-like comparisons only: care must be exercised in the comparison, interpretation and utilisation of this data.

Many data recordings derived using the Aro unit on a range of surfaces do not have an equivalent horn unit recording. This is because the selected test site, an unused section of road, railway line and station car park, was demolished some months into the recording process. No similar terrain could be found within practical travelling distance.

6.1.1 Calibration.

The hardware for the data gathering schedule has been described in section 4.3, and the experimental philosophy covered in section 4.5.3. Report P26 deals with the processing methodology.

To ascertain the accuracy of this rather crude equipment, several calibration tests were performed. Figs 1 and 2 (section one, volume two) illustrate that the recording system frequency response is far from ideal, but adequate for near-alarm frequencies: data derived at vehicle speeds above 10mph will be reasonably accurate. In practice, the stated radar frequency response is further bandwidth limited by the schmitt trigger and phase locked loop stages. Input amplitude linearity is acceptable, being within the reading accuracy of the analogue meter utilised.

The repeatability of the record/playback process is demonstrated by fig 3, which illustrates five recordings derived from the same section of road. Given the practical difficulty of repeating a data acquisition run under exactly identical conditions (refer to section 10.3.3.5), this test confirms the record/playback consistency.

The replay of recorded data was checked for calibration accuracy by recording three sinewave frequencies of pre-alarm, alarm and post-alarm. The tape was then replayed through the spectrum analyser. The results appear as fig 4: whilst the plot diverges from an ideal 'pencil line', spectrum spread is well controlled, with minimal intermodulation.

6.1.2 Amplitude.

The first road tests performed involved measuring signal amplitude measured at the post-filter stage for a range of tilt angles. Fig 5a illustrates amplitude measurements taken with an Aro unit on several surfaces in wet and dry conditions for two tilt angles. The results are difficult to interpret: at a shallow tilt the wet tarmac gives a lower returned amplitude below 20mph. As it is unclear why this should be, further tests were devised. Figs 5b and 6 show similar measurements for a smooth tarmac road in wet and dry conditions respectively. The points of signal amplitude peaks in the range 15 to 25mph were 45deg although the amplitude is most linear for 50deg wet and 45deg dry.

An alternative presentation is given in fig 12: these curves represent readings at 20mph. It is interesting to compare the general trend indicated by these results with typical literature findings (eg fig 13). The data from a dry road illustrates an increasing average return for steepening tilt angle, with a linear region from 35 to 50 deg. Fig 12 indeed confirms this trend. The wet road results would seem to indicate a peak corresponding to the dry condition linear region.

It was noted early in these tests that visually identical sections of terrain or road can give divergent readings. Fig 7 shows the signal amplitude measured from five sections of a tarmac road with readings taken at five second intervals within each section. The differences between sections is greater than that between section intervals; Elland Road, for example, gave consistently higher readings than Kirkstall Road. A section recently resurfaced gave a distinct dip in returned amplitude (YEB section of Kirkstall Road) although the tarmac roughness was visually identical. Fig 7b summarises the range of returned amplitudes measured using an Aro unit on numerous terrain types. The results of fig 7a are indicated, and compared to further road and site measurements. Perhaps not surprisingly, an unladen truck produces the greatest range of signal amplitude, but a laden truck can be seen as a relatively stable platform, giving a smaller range than any road surface. Reasons for this are proposed and discussed in section 6.2.1. Fig 7c replots the previous findings, indicating the returned amplitude as a function of road surface. Clearly the category of surface is no indication of signal strength: smooth tarmac appears at the top and next to lowest on the amplitude scale. Fig 8 shows the returned amplitude from three surfaces at each of three tilt angles. The rough tarmac surface and cobbled road have similar average readings, but the cobbled road has a greater maximum reading. The pitted track gave a low average but a high peak. Fig 10 plots the amplitude obtained from a section of site haul road for a laden and unladen truck: the laden readings are more compressed but have the same average level as the unladen readings. To further establish the range of signal amplitudes, measurements were taken at each of four speeds for flat and bumpy sections. Results for a laden truck are illustrated in fig 11a, and for unladen in fig 11b. These plots indicate the problems in setting the circuit sensitivity: even with a long integration-time meter, the range of readings at 25mph approaches 10 to 1. Instantaneous readings indicate deviations in the order of 40 to 1. It seems that the speed breakpoint is 15mph for an unladen and 20mph for a laden truck: above these speeds the range of returned amplitude increases dramatically. This finding corresponds well with section 2.4.1, which reported that the Aro unit malfunctioned between 20 and 25mph.

Early investigations into the effect of different tilt angles examined the changes in signal amplitude. Fig 14 illustrates the relation between tilt angle and alarm speed. Fig 14a compares theory (for a nominal 22mph alarm speed: an incorrect assumption, but one made by OEL), a standard Aro unit, and Aro with the PLL module (see section 4.4.2). However, if a 40deg tilt is assumed and the results are replotted, the value of the PLL module can be appreciated. Now the alarm speed is only 1mph above the theoretical relationship. Fig 14c shows theory and measurement for an Aro and prototype horn unit on wet and dry roads. The horn unit is significantly more accurate: for wet tarmac the output holds within 1mph above theory from 35 to 45deg tilt. Thus the horn unit is far more accurate and consistent in weather extremes: a variation in alarm speed of 0.5mph (the limit of the modified speedometer reading accuracy) is typical, compared with 0.5 to 2 mph at 35 eg for the Aro unit. As any stated tilt angle is nominal (discussed in section 5.2.3.2), and the instantaneous angle will vary about this value, these results are important. They indicate that the prototype horn unit should give a more consistent performance regardless of tilt angle or ground condition.

6.1.3 Spectra.

Before commencement of data runs for spectrum information, the noise output, measured post-filter, for an Aro head was plotted (fig 18a and b). The spectrum clearly reflects the circuit filtering: the peak occuring at 'alarm speed'. Fig 18c compares a typical recorded signal with the intrinsic noise. Care must be taken here: the automatic recording level of the tape recorder amplifies the noise. In reality the noise is a factor of forty down on a typical signal. Fig 18d compares Schmitt and PLL outputs for a tuning fork target seen by an Aro unit mounted in a vibrator rig (see section 3.4.3). Whilst the Schmitt output seems unrelated to the tuning fork frequency, the PLL clearly indicates a centre frequency of around 440Hz. One final test was made: comparison of two recordings of the same stretch of road using the prototype horn mounted on the test trailer. The recorded spectra are almost identical, as displayed in fig 19.

Three spectra are given based on TRW experiments (see section 4.2): fig 20 illustrates the spectrum width from wet and very wet unmade road. Fig 21 shows the return from wet tarmac: in conjunction with unmade road there is a significant lack of lower frequencies. The spectrum produced by laden and unladen trucks are given in fig 22: the smoothness of the spectra are due to the 15mph speed, which is below the signal breakup speed, although the low-frequency interference is visible in the case of the unladen truck.

Several amplitude versus tilt angle plots have already been described. Figs 24 to 27 show the spectra for wet tarmac, and fig 28 for dry tarmac. Unike the averaged amplitude responses, the spectra clearly show, for decreasing tilt angles, increasing amplitude; with a decreasing and widening centre frequency. The rough, dry terrain, at 35 to 345 degrees shows a significant increase in low frequency inteference over the smooth wet tarmac at the same angle. High frequency interference is similar.

Fig 29 compares spectra from two sections of damp road: these are almost identical, although visual terrain examimation indicated different surface material and roughness. A similar experiment in dry weather again showed almost identical spectra from visually similar terrain: the concrete spectrum peak is at a higher frequency than the tarmac-derived signal, and contains significantly more high frequency interference.

A further insight into the relative effects of surface and subsurface type on the returned spectrum is given by fig 32: the local council timely stripped and resurfaced a tarmac section of road, enabling measurements before and after resurfacing. Although the new surface was concrete, the spectrum remained almost identical. The implications of this are discussed later.

Fig 33 illustrates the spectrum obtained from a rough pitted track at 15mph. The width at half-amplitude is 150Hz; half the spectrum centre frequency. Dry pitted track and loose cobbles are featured in fig 34: both have an inward skew, the track more so. A comparison of wet cobbles and tarmac (fig 35) shows the spectrum width of return from cobbles to be some 300Hz half-amplitude, compared to 175Hz for tarmac. The influence of ground wetness on the return from a rough track is exemplified by fig 36: it can be seen that for such very rough terrain its wetness is a secondary factor; low frequency amplitude is significant in both cases.

Spectrum variations with tilt angle are summarised in fig 37: plot 37a illustrates how the centre frequency and 'Q' (spectrum width) vary with tilt angle for return from wet tarmac; and 37b indicates bandwidth and relative amplitude. These figures indicate clearly how the Q and centre frequency decrease with increasing tilt angle, whilst bandwidth and relative amplitude increase.

So far, all spectra have had linear amplitude axes. Figs 38a and b illustrate previous spectra replotted using a logarithmic axis. Such plots place the amplitude differences between wet and dry, rough and smooth, etc in perspective: the spectrum peak for dry terrain is visible: that of wet terrain is indistinguishable from background return and noise. It is also difficult to distinguish terrain material and roughness: fig 38b shows a small decrease in low frequencies for smooth terrain, but a spectrum indistinguishable from rough terrain at around alarm speed. Indeed it is not possible to visually ascertain the spectrum peak (and hence, hopefully, the platform velocity) in either of these spectra. A direct comparison with figs 53 and 54 show the improvement possible: these spectra will be examined at a later point.

Fig 39 deals with return from haul roads, both laden and unladen trucks, and for rough and smooth terrain. For both categories of terrain the spectra are more defined for a laden truck, although the peaks do not correspond to the correct frequency, being some 70Hz below the correct centre frequency of 470Hz. Not surprisingly, perhaps, smooth haul road spectra are narrower than rough. Terrain roughness is taken a stage further in fig 40, which illustrates the complete breakdown of returned spectrum on such terrain, wet or dry. Indeed, lower frequency return dominates the true spectrum peak. These curves indicate the effectiveness of the low frequency filtering: below 175Hz the returned signal dies away. Interestingly, the wet spectrum is shifted downward by 100Hz.

6.1.4. Prototype Horn.

The majority of spectra presented up to this point have been derived using a standard Aro unit. Figs 41 to 52 illustrate returns obtained from the prototype horn unit (a cast horn and microwave assembly mounted on a case capable of operating with or without antivibration mounts). Fig 41a compares spectra from an Aro unit and the horn mounted on a laden truck, driven over a muddy, rough surface. The improvement in spectrum definition is marked: specifically, lower frequencies are all but eliminated. The results for a laden truck appear in fig 41b: again the horn spectrum is narrower than the Aro-derived measurement, but comparison with fig 41a is difficult, as the run for fig 41b had to be performed at 15mph due to the extremely muddy conditions.

An improvement in spectrum shape is also apparent on car tests: fig 42 shows this well. Indeed this improvement, due to the lack of terrain roughness-induced low frequency interference, is achieved simply by a reduction in transmitted beamwidth. A test on puddled track at 10mph showed the horn's ability to view puddles out of its defined beamwidth (fig 43): measures to combat this undesirable occurrence are detailed later.

As a further gauge of the beamwidth of the prototype horn, the spectrum from a section of haul road was compared to the TRW signal. The results , fig 44, illustrate the lack of high and low frequency signal and the narrow spectrum peak of the horn. Similarily, a test on extremes of terrain, such as newly-laid tarmac and a potholed track, showed that the horn could cope well with both, although the very rough terrain produced high and low frequency components. Compared to fig 40 for the Aro unit, fig 45 is a significant improvement: the spectrum width for dry terrain is 400Hz and 125Hz respectively. The result from smooth road was further investigated by fig 46 which indicates the results of wet and dry surfaces: in dry conditions the spectrum is perfectly defined, being 90Hz wide at half-amplitude. For a wet surface, the spectrum widens, but retains a defined spectrum peak. Fig 47 shows the return from a haul road for a laden and unladen truck. On this surface the usual problem of an unladen truck producing low frequency components does not appear: indeed the lower end of the spectrum is almost a negligible level. For the unladen truck, however, there is a shift upwards in centre frequency.

The influence of antivibration mounts is examined in figs 48 to 52. Their effect on a very smooth road is to produce spurious high and low frequencies (fig 48) of a very low amplitude. However, a rougher stretch of tarmac reversed this trend (fig 49). On rough terrain (fig 50) little difference in spectrum shape is apparent, apart from HF interference at 1KHz for the mounts fitted. To confuse matters, on the roughest surface available, the removal of the mounts showed a small advantage. On a truck (fig 52), again little difference was obtained although with mounts, the returned spectrum was minutely narrower.

To ascertain the optimum value of PLL damping, a section of pitted track was selected to give the poorest return, and the trailer tyres were overinflated to simulate a hard vehicle suspension. Fig 53 exemplifies how a 'slow' PLL response assists the spectrum. This spectrum has a logarithmic scale; fig 54 directly compares the Aro unit and the production prototype, and the improvement is clearly visible; with the peak being more defined for slow loop damping.

Results so far have been measured post-filter and post-Schmitt or PLL. Fig 55 gives an interesting insight by reproducing the preamplifier output for a rough road. Again, the horn unit provides better frequency definition. The fine-tuning produced by the PLL is indicated by fig 56: this result was produced on a smooth, dry road. Fig 57 shows the improvement on the prototype horn produced by the production unit: the horn no longer sees targets outside its nominal beamwidth, and has a very narrow spectrum peak.

To illustrate the improvement in performance of the production prototype, spectra derived from it and the test horn are given in fig 58. The production unit suppresses low and high frequency interference efficiently. The best illustration, however, is fig 59, which compares the measured spectrum with an Aro-derived result. The spectrum widths are 30Hz and 220Hz respectively. The total lack of LF or HF interference is clearly appreciated: indeed the spectrum is very similar to the calibration curves of fig 4. This improvement, interestingly, is also appreciated when monitoring the audible output signal from the tape recording system. The Aro unit produces, effectively, tuned white noise, whilst the production prototype 'whistles' at the specific velocity-proportional frequency.

6.1.5 Waveforms.

The first waveforms reproduced are laboratory derived. Fig 60 illustrates the output from an Aro unit mounted in the vibration test rig. Fig 60a represents the poor preamplifier signal and the Schmitt output, which is a 160Hz broken pulsetrain. A modified belting mount was tried (fig 60b): the preamplifier produces a cleaner signal, but a PLL module is fooled into producing a strong 370Hz pulsetrain. The test prototype (with no antivibration mounts) and the production prototype horn produced no significant output, and thus their waveforms are not reproduced. The above test had no real target: figs 61a and b show how the Aro unit responded to a tuning fork target. In fig 61a the unit was struck heavily with a rubber hammer: the preamplifier output is seen as a decaying oscillation which swamps the 440Hz target vibration and prevents the Schmitt trigger from operating. Fig 61b shows the combination of the fork and the vibrator rig. The Schmitt output is modulated by the vibrations, but the PLL rationalises this signal to the correct frequency. Fig 62a illustrates a strike/tuning fork test, showing the

PLL seeing the strike, but changing frequency only minimally. An interesting result was obtained by a strike test on an Aro unit and mount: the preamplifier output stops long before the Schmitt output, implying perhaps some post-preamplifier derived interference caused by the strike-induced vibration.

6.1.6. Tilt Angle.

Fig 63 illustrates the waveform types for a range of tilt angles using the Aro unt. The 40deg tilt waveform contains less nulling, although the 50deg result is surprisingly good. Low angles such as 25deg produce a poor waveform containing frequency bunching and nulls. The return from four terrain types is exemplified by fig 54: a smooth road produces a reasonably consistent squarewave pulsetrain; concrete is a little more broken; pitted track produces significant frequency fluctuations. Perhaps surprisingly, a potholed track produces a reasonable frequency consistency, due partially to the small dynamic range of the preamplifier signal.

Signal amplitude is further examined in fig 65, where the output for seven tilt angles is compared on a compressed timescale. When viewed in this manner, the decrease in amplitude with diminishing angle is clear. But further, the range of amplitude increases with diminishing angle. Fig 66 shows the preamplifier output for four tilt angles: the 40deg waveform is less broken (the 30 and 35 degree waveforms are on a compressed timescale).

6.1.7 Horn Unit.

The prototype horn unit is compared to a standard Aro unit in fig 67a and b: the preamplifier signal form the horn is almost perfect, being consistent in frequency and containing only one null in the sampled time period. This test, however, was on a tarmac road. Fig 67c and d deal with site recordings: the contrast between Aro and horn performance is more marked. Now, the Aro Schmitt output is wildly erroneous, whilst the horn output is almost perfect even when the recording is made before the PLL!

To ascertain the effect of various antivibration mounts, a series of recordings were made using the horn prototype. These appear as fig 68. It can be seen that little difference is perceptible between a horn unit with no mount, or one with hard or soft mounts. This figure also compares preamplifier output on one stretch of tarmac: the horn unit has good frequency constancy and is lacking in signal nulls.

6.1.8. Frequency Tracking.

The spectra and waveform analyses are all relatively instantaneous 'snapshots'. The time recordings (figs 69 to 71), however, are long-term tracks of the main signal frequency peak. Each vertical dividing line corresponds to half a second, making each sample twenty seconds long. Fig 69 compares Schmitt and PLL output for an Aro unit on road and site: the frequency breakup for an unladen truck is highlighted, as is the improvement brought about by the PLL. It is clear that a long loop time constant (6 sec/8ve for trace e) improves the frequency tracking constancy dramatically: the output frequency corresponds, in terms of measured speed, to 20+-0.5mph for 90% of the sample time (this accuracy tallies with the findings discussed in section 6.1.2). Such an extended time constant, unfortunately, interferes with the main control board alarm cancel sequence, so the 3meg loop of fig 69d represents the optimum output quality.

The TRW unit was assessed in a similar manner: its internal PLL does not improve the signal significantly; indeed on site it degrades the Schmitt output. It is thought the PLL is acting, and fooled, on the short signal dropouts, thus centering on its lowest frequency (which for the circuit configuration is DC). Fig 71 examines the prototype horn unit: here the unit would seem to perform better with no antivibration mounts. Trace c represents the optimum PLL damping, and it can be appreciated that this result is an almost constant frequency.

6.2. DISCUSSION AND CONCLUSIONS

This section will illustrate how the gathered data assisted the production design, and also form conclusions on particular findings: some expected, some surprising.

6.2.1 Terrain Surface And Subsurface.

The amplitude data derived using an averaging meter is, with hindsight, of limited use. As later spectra illustrate, the Aro unit beamwidth permits much signal out of the defined band, and a long-term averaging process gives misleading results for wide ranges of tilt angle. However, for a given angle the data would seem to provide a useful yardstick for average signal amplitudes. Indeed, it was possible to examine numerous roads and draw conclusions as to the subsurface structure. This finding is very important, and will now be examined in greater depth.

Comparison of several stretches of one road, all with visually identical tarmac surfaces (even upon close examination of such factors such as the proportion of tar to stone chippings, chip size, quantity of loose matter etc) gave repeatedly different average readings (fig 7a). The spectra from two different sections of the same road, visually dissimilar, produced almost identical spectra (fig 30). And the signal from two roads of approximately similar roughness, one tarmac and one concrete, gave almost identical spectra; with concrete producing high frequency peaks (fig 31). Examination of the return from a road, one section of which had been resurfaced, showed no change in overall spectrum other than a few HF spikes (fig 32). These results would indicate that the terrain surface plays a minor part in defining the spectrum shape or average amplitude: the subsurface being the determining factor. For roads, the surface wetness will determine any bias shift, as tarmac or concrete are not particularily porous. Off-road, however, the ramifications are greater: the returned amplitude and overall spectrum may well be determined by the volume of water absorbed by subsurface layers.

Hence, to return to the average amplitude results, tilting the radar unit to extreme angles will emphasise the 'layering' of subsurface material, and provide unpredictable results. But for a stated angle, the return from one type of road surface may indeed be expected to vary (fig 7a and 7b illustrate this: the range of returned signal varies to a greater extent than the return from a site haul road, and the average return can vary by a factor of almost four for visually identical road). Indeed, slow speed tests with the tip-edge detect radar (see section 4.5.4) in the OEL yard showed anomalies in one area of ground. Upon checking the architect records it was found that a petrol tank was located two feet underground. Although the yard surface was six inch thick concrete, the metal tank was located due to the oddly fluctuating returned signal amplitude over the tank.

6.2.2 Terrain And Platform Type.

The above findings confuse the interpretation of any data. It is, for instance, impossible to ascertain, for any two isolated recordings, whether the differences in spectrum and amplitude are due to the terrain surface, including wetness, or due to the subsurface. Thus, many data gathering runs must be performed, and the researcher must use discretion in selecting 'typical' results. The writer found, for example, that runs specifically located on a given stretch of road produced divergent results. After much contemplation and reruns, it was found that not only do trial runs have to be measured over a given stretch of road, but the distance to the side of the road must also be kept constant. Driving even several inches to one side of the path of a previous run produces divergent results!

Thus, although the influence of terrain surface type on the returned signal will now be examined as a separate topic, the results must be interpreted carefully. Perhaps not surprisingly, the rougher terrain surfaces produce wider amplitude ranges; surfaces with perpendicular 'facets' (for example, cobbles) return both a high average and high peak signal (fig 8). A haul road, as measured from a laden truck, gives almost constant amplitude return on smooth sections and a range similar to tarmac on rougher sections (figs 10 and 11a). Wet terrain shifts typical spectra peaks downward in a manner similar to smooth terrain bias shift, and extends the spectrum tail to higher frequencies. Very wet surfaces provide an extended width spectrum of large amplitude. Signals from dry, dusty terrain are of low average amplitude, often with accentuated lower frequency interference: this tallies with site experience, where it has been found empirically that a rough dry surface provided the greatest number of missed alarms.

It is also clear from the data that unladen trucks are by far the most difficult to deal with. Figs 10, 11a and 11b illustrate the wide range of signals returned from an unladen truck, even on a smooth haul road. This point is true for all radar: Aro, horn and TRW. Figs 22, 47 and 41A respectively illustrate this point.

Figs 39a and b show that the spectrum differences between laden and unladen trucks are minimised in muddy conditions; the mud effectively provides a 'suspension' for the truck. The mud, however, does induce high frequency interference for a laden truck.

6.3. PRODUCTION UNIT DEVELOPMENT

The data presented in this chapter illustrates an extended period of speed sensor development, from initial data gathering through to the design of the production horn and microwave assembly.

Early data derived using the Aro unit showed a reasonable correspondence between measured spectra and site/road experience, and proved conclusively that even on smooth terrain, the spectrum width was too great for accurate processing. The frequency distribution manifests itself as a significant quantity of unwanted frequencies, and, as exemplified by the waveform recordings, a large number of signal nulls. The addition of a PLL module significantly improved the squarewave output but obviously the unit can only mask the symptoms: fig 60b illustrates how the PLL can easily be fooled by a poor returned signal. Further, to obtain a suitably narrow spectrum, the PLL damping has to be so extreme that it interferes with the operation of the alarm cancel sequence logic. The solution is deceptively simple: to narrow the transmitted beamwidth. The prototype horn data illustrates the success of this solution: the preamplifier phase nulls are reduced and the returned spectrum now possesses a well-defined, correctly located peak whatever the terrain type, wetness, or platform type.

However, anomalies remained. Some low and high frequency interference was still present, and the spectrum peak was not always located at the correct frequency in extreme terrain conditions (notably very wet or smooth, and very rough). As covered in section 4.4.4, the PLL also lowered the sensor alarm speed to nearer that predicted by theory (figs 14a to c).

The effect of antivibration mounts was examined and found to be of little benefit; indeed in some circumstances, detrimental. Hence lenses were tried. It was found that a perfectly symmetrical lens was difficult to construct: a typical result (the appropriate data is not included) of such an experiment was to throw the footprint centre in or out. Hence emphasis was placed on sidelobe reduction and further elevation beamwidth reduction. To assist in reducing the consequences of 'in-beam hunting', the azimuthal beamwidth was further widened. The result of these measures can be appreciated in the results derived using the production prototype unit: signal strength is dramatically increased (fig 54 indicates a gain at spectrum peak of some 30dB over the Aro unit) and the spectrum is better defined, with minimal out of band interference. Fig 56 illustrates how even the preamplifier output before filtering, Schmitt or PLL stages, is a remarkably better spectrum that from the Aro unit.

A further analysis of the design resulted in a foam wedge being fitted inside the horn; this modification is cheap, simple and effective, reducing sidelobes by a factor of four.

Figs 57 to 59 illustrate typical spectra from the production design: the amplitude at spectrum peak is typically over ten times the interference level, with a half-amplitude width of 45Hz for tarmac surfaces. It is informative to compare these final results with those obtained using the proprietary TRW unit. The TRW gave, typically, a half amplitude width of 150Hz with considerable high and low frequency interference.

6.4. CONCLUSIONS.

This chapter has described in some depth selected data recordings performed during the course of the project. Space precludes a detailed description of the specific reasons for the inclusion of certain experiments or an extended assessment of the findings.

The work described, however, is important for three main reasons. First, the available literature could be assessed to establish any agreement in findings and to identify gaps in this knowledge; second, these gaps could be filled (in a manner adequate to complete the project brief: the emphasis is on practical as opposed to theoretical results); and finally, the prototype and pre-production designs could be evaluated against a valid frame of reference.

Generalised findings and a brief comparison of these results with the general body of knowledge are located in section 10.3.3.

CHAPTER SEVEN

ENVIRONMENTAL ASSESSMENT AND SPECIFICATIONS

"It is not enough simply to show that a chasm can be spanned by a bridge: te bridge must continue to span the chasm for a long time to come whilst carrying useful loads. "

US DoD handbook HBK MIL 217C (1979)
The Reliability Problem

CONTENTS

SECTION

7.1. INTRODUCTION

Chapters five and six summarised the results from the literature review and from this project's data gathering and processing work. One theme common throughout chapter five was that of a lack of information concerning several aspects of a typical off-highway environment. Although chapter six concluded that the prototype horn performed well, it was not possible to test it in all conditions of weather, terrain etc. Thus, to assist in the design and development of a production unit, an extended study of the off-highway environment was performed. This chapter outlines the work done, and describes the design procedure adopted for the horn and case. Work performed in parallel with this is also reported, in chronological order.

7.2. THE OFF-HIGHWAY ENVIRONMENT

The prototype design for the speed sensor did not, at this time, take full account of the likely range of conditions expected on site. This is no lack of forethought, such information was simply not available. Thus, over several months, a review of all appropriate literature was undertaken. Unlike the literature review proper, which used 'learned journals' for references, this review examined rather less impressive sources: an atlas, manufacturer's literature, trade journals etc. The result is a rather lengthy report, appearing in this thesis as report INT P24. Four main aspects of the off-highway environment are covered: mechanical, electrical, climate and terrain.

Climate robustness may seem an easily dealt-with aspect of unit design: but even examination of a UK site indicates potential problems. Temperatures of -20C (including chill factor) to 160C (near the vehicle exhaust) are met. However, the commercial design brief is also intended to cover sale of the unit abroad, so note is made of likely world locations and the special problems that each area presents. Report P24 thus analyses world climatic groupings with respect to off-highway truck distribution. Solar radiation and wind chill factor are also examined.

This data is then used to assess the likely effect of temperature and humidity extremes on each component of the prototype sensor design. Several techniques are utilised: classification of semiconductors into commercial, industrial and military ranges; the effect of temperature on passive components, PCB and the microwave unit. Information on the latter was derived experimentally as no manufacturer provided adequate data on the changes in transmission frequency and power with temperature. AGREE tests 1 to 4 were then theoretically applied to the unit: the results give a MTBF of 13, 0.8, 0.4 and 89 years respectively. Based on these results, recommendations for unit modifications corresponding to each environmental category are made. These modifications involve component substitution, addition of a heater/cooler circuit, and cutout circuit. One crucial finding was that all microwave units tested exhibit a non-linear relationship between power and frequency with temperature: a temperature increase of 20C pushes the frequency out of the Home Office band, and changes power output by up to 30%. One unit, the MA, failed at 60C! It was hoped to continue these tests to below-zero temperatures, but no facilities were available.

Terrain categorisation techniques proved elusive, and a further review was performed to isolate pertinent literature. The results are useful in defining terrain types; notably for comparison of typical site terrain with literature assessments. It also allows site maps to be drawn and filed so, for example, in the event of repeated unit failure in one area of the site, possible causes can be examined.

Shock and vibration are covered in superficial detail: it is clear from a cursory examination of causes and effects that many unquantifiable factors contribute. However, equipment reliability can also be assessed from standardised test procedures. Thus the US DoD specifications on system reliability (MIL 217, 756 etc) were used to estimate unit MTBF for seven categories of environmental severity. The MTBF was calculated as between 19 and 321 hours, with an average of 133. It is difficult to intepret such results: unlike the AGREE tests which emulate likely temperature variations, the DoD tests require the appropriate environmental severity categoty to be selected. This, in the absence of firm data, can at best be a guess. The intrinsic weakenss of the design is the microwave transceiver: hence there is no remedy for the seemingly poor MTBF prediction. Fortunately site experience indicates that typical use parallels the gentlest of the DoD categorisations. The problems of providing antishock and vibration measures are also covered in the report, although no specific conclusions are drawn as this section was written before the analysis of the production prototype data recordings was performed.

The electrical environment of the truck provided severe problems: significant RF energy is radiated, and the power supply is 'dirty'; fluctuating in long-term level with severe superimposed spiking. Again relevant literature was sifted in an attempt to establish all likely causes of problems, and possible solutions. General theory is not always adequate, however. The sensor case is thick aluminium, which was considered a Farday cage. But it was found that to prevent interference, all internal low-signal cables had to be screened.

The influence of truck and terrain on speed measurement accuracy is analysed in terms of suspension bounce, laden and unladen, platform height accuracy, terrain contour and terrain obstacles. Probable maximum reading error is calculated for each source of inaccuracy. A concave terrain dip of 1:7, for example, could introduce a fluctuating measurement error of 14%; whilst platform height inaccuracy can alter alarm speeds by 7%, although this error, being constant, is of less concern.

By consideration of all environmental factors, the unit design process is assisted: to aid future design work, a five-point recommendation (based on MIL 217) is summarised, and the major researchers' criteria for environmental tests are tabulated.

The results of this environmental assessment take the form of an extended environmental test schedule suitable for the speed sensor unit, or any similar equipment. Seven major sections are included: temperature, humidity, water, dust and gravel, pressure, shock and vibration, power supply, and combinations of tests. The tests assume a climatic grouping emulating the UK, although alternative test values are indicated where appropriate. Such a test schedule, however, would require the assistance of a standards laboratory: the equipment needed is beyond that possessed by OEL at the present time.

7.3. MICROWAVE UNIT WINDOW

The previous section examined conditions in the 'outside world'. The microwave horn mouth is the crucial interface between the microwave unit and this 'world'. Due to the severity of the off-highway environment, the task of designing this horn termination, or 'window' was lengthy. The window must, for example, be impervious to wind, weather, oil, grease, steam cleaning, withstand minor impact etc, but yet not absorb or reflect significant proportions of energy. The work performed on the selection of a suitable window is detailed in report INT P20, which highlights the techniques used to select the material and thickness of the window. A resumé of this work will now be given.

The first test devised involved measuring the reflection amplitude of a given material thickness placed on, or a stated distance from, the horn mouth. Ratios of maxima and minima are then calculated. This technique, which the writer terms the MMR (Maximum to Minimum Ratio), gives a result similar to the VSWR. Other measurements made include bias voltage and transmitted power. Both X band CW and K band FMCW radar were used for these tests; the latter type undergoing appropriate thickness scaling. Theory predicts the optimum interface to be a half-wavelength thickness window, and this was confirmed by experiment, where for a minimum MMR the window thickness must be controlled to two percent of a half-wavelength. Several problems present themselves, however. For example, such accuracy is expensive, and often the tolerance of the dielectric constant is not held within these limits. Also, as a low dielectric constant material is used (to obtain a low MMR), the significant thickness of the window required to present a half-wavelength was found to radiate energy at right-angles to the required beam-axis.

Alternative designs were considered, using for example, the Brewster angle in a pyramidal or compressed pyramidal (concertina) shape; (see appendix 3.12). Each was found to be a compromise, but on balance, none could improve on the half-wavelength slab. Having established a suitable design, over fifty materials and combinations were assessed. Where possible, ASTM test specifications were also charted.

To place the derived results in perspective, proprietary window materials, both standard thickness and specially machined, were obtained and tested. The standard thickness materials were found to possess too great a spread of thickness and dielectric constant for any useful comparison to be made. The machined slabs showed promise, but the cost is prohibitive for any commercial application. Thus the design brief concentrated on alternative low-cost materials.

Numerous sandwich windows were tried. Several gave promising results, although the method of joining the layers proved to influence the MMR to the same extent as the material type iteslf. Hence sandwich types were excluded from further consideration.

The final short-list of materials, therefore, consisted of easily obtainable plastics of standard thickness. After elimination of several materials on grounds of susceptibility to sunlight and oil etc, five materials remained. In the final set of experimental results, grey polypropylene was found to be the most suitable, possessing a low MMR, low power reflection, and minimal effect on the mixer bias. Further, the material is cheap and readily available.

7.4. MICROWAVE RADIATION: LEGISLATION

Any new design of radar unit must, of course, fulfill all legal requirements. Transmission frequency and power are easily defined on paper, but lens and focused beam configurations confuse matters. In order to establish whether any type of horn or lens combination exceeds the safety legislation, the means by which such danger is assessed must be examined. Report INT P27 does this, and considers the legislation in the USA, UK and USSR.

The findings are interesting: a focused lens of 10mW power exceeds all recommended power density levels; indeed such a system exceeds the USSR standard by a factor of 1000. Thus several recommendations are made for the handling of microwave equipment within the company; for example, that the testing of transceivers utilising horns and lenses should be performed with due regard to the time of exposure, nearness, power level and the number of units.

The findings also provide the basis for the microwave section of a unit specification (see reports P24 and P30).

7.5. FURTHER PROTOTYPE TEST AND DEVELOPMENT

Site access, due to the nature of the open-cast industry, is difficult to arrange. In the light of continued problems of access to trucks requiring new sensor units, and to simplify stocks of spares, the decision was taken by OEL in September 1983 to make the speed sensor primarily a direct replacement of the existing Aro unit, and thus to leave the control boards already fitted to the trucks unaltered. The facility to transfer the speed sendor logic located within the control board to the sensor case, therefore, was to be considered a 'future upgrade'. Such an upgrade would indeed be necessary at some juncture, as several faults have been located on the control board that require time-consuming modification and repair.

For the past two months several circuits incorporating PLL's had been evaluated on-site, and no problems had been encountered. Indeed the modified units showed welcome improvements in measurement accuracy. On the assumption that OEL would require their stocks of Aro units to be upgraded, over a dozen companies were requested to return quotations for the PCB design and manufacture. The quotes ranged from £2 to £30 per board, but OEL indicated a reluctance to 'go firm' at this time, so twelve complete circuit boards were constructed using Veroboard. These boards possessed all the main features of the intended PCB design, including component type and location, cable termination, board size etc. The opportunity was taken to utilise this exercise as a true 'dry run' was taken, so listings of components and suppliers were prepared (see appendix 3.0), and a trial full order was placed. On the basis of the efficiency of response of the suppliers, alternative sources were substituted. At this time, component cost was placed secondary to ease of supply. This trial order took no less than nine weeks to complete: the delay stemming mainly from difficulty in locating suppliers that would deal with OEL on account.

The twelve mock-up boards were then assessed using data recordings, temperature sensitive labels etc. Note was made of their uniformity of performance: no problems were encountered.

Whilst peforming these tests on-site, the writer took the opportunity to question the truck drivers and site foremen on the practices used to disable the sensor. Most drivers indicated a preference for a 25mph alarm speed, and described how they disabled the sensor at any available opportunity. They use two methods: disconnecting the supply line to the cab panel, which is an intrinsic design oversight; and placing thick clods of wet mud on the microwave window. The latter can be prevented in any future desisgn by careful shaping of the case and window.

Following the apparent success of the main PCB testing, a meeting was held with OEL in October 1983 to discuss the company requirements for the new sensor unit. It ensued that their requirements had indeed changed emphasis from previous discussions: size was now seen as a critical factor, and the option to configure the alarm speed on-site was no longer required, although the ability to program the alarm speed at the production stage was still thought useful. OEL stated their desire for a specific PCB manufacturer and for component legends to be incorporated: this feature incurred a cost premium; placing the cost of each board at almost £30, compared to the writer's recommended manufacturer's quote of £4.

At this time, the PCB designed had the facility to incorporate further modules by means of an on-board socket and links. The writer, after assessing the success of the site trial results and the data recordings, decided not to incorporate the validation logic module (report P7), but to utilise the socket for the frequency translation module (report P17). Hence the draft PCB design for this second board was commenced. In parallel with this work, the mock-up Veroboard circuits were exposed to a range of temperature tests by using several densities of foam within a small sealed box. Maximum board temperature measured less than 50C above ambient for compressed foam: this temperature increase is well within the ratings of every PCB component.

In December 1983, the company stocks of Aro circuits became depleted, and the decision to order the new PCB's became crucial. Indeed the writer was relieved that OEL's hand had been forced as a delay of three months had passed since OEL had indicated it's intention to purchase replacement PCB's. The order for ten sample boards arrived in January 1983.

7.6 TEST SCHEDULES

The opportunity was taken, whilst the PCB order was being processed, to prepare the board and unit test facilities. A test trailer, first suggested over a year ago, was finally constructed. This possessed a mounting tower for three units placed at the height of a truck rear light bracket (see pic 2). Tests with the trailer (discussed in chapter six) showed that with overinflated tyre pressure, the trailer platform simulated certain truck and site combinations well. To ascertain the exact performance of the trailer, six typical used and six rebuilt and fully working heads were assessed using the trailer. Further tests included assessing the performance of several lens types and ascertaining the effect of antivibration mounts. The findings confirmed the design previously considered was an optimum compromise. Several minor circuit component changes, such as cheaper IC's, smaller heatsink etc, were tested in the field using both the Vero mock-up and the new PCB. Such tests gave a reasonable indication that no severe malfunctions plagued the design, but no data on sample consistency or on absolute performance was made at this time.

To assist in this process of detailed assessment, two test specifications were written: one for production use and one for detailed circuit analysis suitable for debugging. An overview of these schedules will now be given.

The full test schedule for the speed sensor system is intended for 'spot-check' production testing, fault location, and to form the basis of monitoring the result of circuit or unit modifications. It appears as report INT P23, and covers, separately, power supply, preamplifier, filter, gain stage, output, PLL, microwave unit bench test, microwave unit beamwidth, sensor unit commissioning, car test and site test. Each section indicates the test points and conditions, and quotes a passband (minimum, typical and maximum values) for each measurement. It should be noted that these tests cover the electrical parameters only: environmental tests are covered in report INT P24. The production test schedule, reproduced as report INT P30, is designed to be utilised as a continuous production monitor. It consists of only twelve test measurements, as compared to over one hundred and sixty for the full schedule, and is intended to provide an OK/fail decision only. Consequently the tests can be performed in under five minutes.

However, as discussed in section 7.6, the consistency of performance of the boards is such that this test can, for all but the most severe assessments, be substituted for the full test schedule.

7.7. SENSOR SPECIFICATION

As draft designs for the complete speed sensor unit were drawing nearer a practical solution, the time was ripe to produce a specification for the complete unit. Such a specification performs several roles: as a discussion document before the design is finalised, and as a check that all practical problems (such as financial, legal, size, environmental etc) have been acknowledged and to some extent dealt-with. The specification can form the basis of technical data provided to potential customers; and, further, can form a technical requirement specification for alternative designers and manufacturers.

The specification, which appears as report INT P22, comprises two main sections: a general specification, and an 'external' specification. The latter section was rewritten to exclude factual information that might give an advantage to potential competitors. It is thus capable of being readily supplied to anyone requesting such a specification (for example, subcontractors).

7.8. UNIT DEVELOPMENT: THE CRUCIAL PHASE.

Previous case designs assumed the need for antivibration measures (see report INT P18). On the basis of the data analysis in chapter six, however, the antivibration mounts were seen to be superfluous. Hence alternative methods of mounting the horn assembly were drafted. In many respects, therefore the case design became a straightforward matter of placing a box around a horn. However, many contradictory factors such as, for example, serviceability and longevity, had to be balanced. Also, as a result of the data analysis, the prototype horn casting dimensions were increased and decreased in the H and E plane respectively.

Following the depletion of the Aro circuit boards in December 1983, OEL also used all their stocks of Aro microwave units by the end of January. Consequently replacement transceivers had to be constructed out of salvaged used parts: a lengthy and unrewarding excercise. The writer thus made a concerted effort to use these events as the basis of an argument to coherece OEL into the next stage of the new unit design: producing a cast horn prototype. Hence all suitable local casting companies were visited, and one was selected as being both well priced and pedigreed (conforming to Def Stan 05-24). Three horn patterns and casting were ordered in February 1984: wood patterns were selected as this design was not a pre-production prototype, and only three horns of this design would ever be made.

Supplies of Aro antivibration mounts also became exhausted around this time: the writer recommended a stronger type be purchased (of the type assessed in the horn suspension trials), and OEL purchased one hundred.

Based on a decision by OEL to offer one alarm speed only during initial manufacture, the FTM module (PCB two) was committed to PCB. Due to OEL's cost consciousness, the writer arranged for these boards to be produced at Aston University. Around the time of receiving these PCB's the horn castings arrived, and complete prototype units were built up. The system performed well (see vol 2, section 1, fig 14c), and draft case designs had already been produced: a procedure assisted by full-size cardboard models.

7.9. RESUMÉ

Hence in March 1984, the proposal to produce a complete new speed sensor unit was put to OEL. The the design would consist of a cast horn based on the prototype design, and PCB one and two (see fig 9.2 and 9.3). Aro-based units were still failing on-site, although due to the replacement of many PCB's with the new Vero prototype, the causes of failure were mainly due to the microwave unit. No stocks of Aro microwave units, circuits or cases remained. Test schedules for environmental robustness, board debugging and production pass/fail tests had been prepared, as had a unit specification. But, OEL made it clear that the decision to put the new unit into production was by no means definite, although no specific reasons were stated. It thus seems appropriate at this juncture to review the company's structure, product, management attitude, strengths and weaknesses; in an attempt to unravel the influence of these factors on the progress (and possibly the success or failure) of this project. The next chapter covers these aspects.

CHAPTER EIGHT

THE EFFECT OF COMMERCIAL FACTORS AND THE INFLUENCE OF COMPANY STRUCTURE AND ATTITUDE

"There will be moments when employers will appear obstinate, narrow-minded and unappreciative. However, you have to play for higher stakes now: capitalise on whatever creative skills you possess, and find your true vocation."

Aquarius horoscope.
Daily Mail, 8.1.84

CONTENTS

SECTION

FIGURES AND TABLES

8.1. INTRODUCTION.

To this point, the thesis has charted the progress of the sensor unit in the context of a technical development excercise performed with due regard to the constraints imposed by the company structure, resources, product range etc. Although in many ways the project brief is purely technical: the aim being to develop a low-cost groundspeed measuring device, the emphasis throughout the project has been to produce a commercial solution, and the thesis title reflects this aspect. This chapter is divided into two sections:

Section one will attempt to illustrate the required 'interdisciplinary' approach to the work by assessing the commercial aspects of the project.

Section two analyses the state of the company in terms of resources, management, the product and the technological base; with the intention of identifying problems contributing to the difficulties experienced by both the company and the writer throughout this project.

8.2. COMMERCIAL FACTORS.

8.2.1 Introduction.

The thesis title indicates that the work done in developing the speed sensor, whilst utilising research methodology, is intended to produce a commercial product. But what exactly is a 'commercial' solution? This section will attempt to set the scene and outline the approach used.

From the company's point of view the product must fulfill several criteria: the unit must be developed and manufactured within existing, or easily available, financial, manpower, expertise and facility constraints. The unit must conform to the technical requirements as seen by the management; and it must be capable of being easily incorporated into the company's existing product line.

The writer's view certainly incorporates these factors, but continues further: compatibility with all existing products must be ensured as should a smooth product 'changeover'; the unit should have an inbuilt facility to ensure compatibility with all probable future developments; it must utilise readily available components and require simple and infrequent calibration and maintenance. The unit must also be developed in a framework of past, present and possible future market trends, and appropriate contingency plans must accompany the final design.

We have so far summarised some generalised requirements, but have not delved deep enough to provide the basis of a 'commercial design stratagem'. The writer also sees the consideration of such a stratagem as an intrinsic part of the project brief. Hence the assumptions, and the reasons behind the assumptions, made by the company concerning the desirability and necessity of factors viewed as commercially viable and desirable, are examined. To an extent such an examination will by necessity be technical in overview, and will deal with the matching of company technical capacity with design requirements, but it must necessarily entail an assessment of the criterion adopted by the company for quantifying product problem areas and for establishing a new design brief.

Excluding the ill-fated TRW unit, off-highway speed sensors have not been marketed by any company at the time of writing, and although several accounts of automotive sensors are available (see section 5.3), all commence from a technical standpoint. In other words the end result is a working prototype, and not necessarily commercially viable. Thus it is impossible to examine the characteristics of a product that has already satisfied the 'commercial viability' criterion, although intelligent guesses can be made. The lack of alternative commercial products is intrigueing: is there no suitable market, and hence no manufacturer has produced a saleable unit; or is it that because no manufacturer has managed to develop a suitable product, then no new market has been created and existing markets are not fulfilled?

The problem of developing a technological product is one of compromise between market suitability, technical simplicity and company ability (in terms of experience, material resources, and perhaps ingenuity?) Gerlach (1970) defines a product as being feasible in three main areas: technical competence; manufacturing ability and capacity; and commercial, financial and market acceptance. Hence it is clear that to approach a development programme from the technical standpoint in isolation is incompatible with this definition. Therefore, although there is a lack of literature pertaining to the commercial aspects of a product in the off-highway speed sensor field, it is necessary to establish the commercial base upon which this project evolved. This will be performed from two standpoints: a general overview and a consideration of specific technical factors.

8.2.2. Commercial Base: General View.

It is widely accepted that most companies need to innovate to remain competitive. A company that relies on existing products, markets, production techniques etc will eventually be eclipsed by a more progressive competitor whose products more closely fit market requirements. Such stimulus gives rise to the concept of the product life-cycle, and, more importantly, technology life-cycle (Charlton,1981). The Advisory Council for Applied Research and Development (HMSO,1978) define industrial innovation as:

" ..improvement of existing products or processes; introduction of novel production methods based on new technology; or introduction of novel products or processes.."

The former factor is the more common in the commercial context as the latter two must usually also incorporate technical 'breakthrough'. Given these as appropriate definitions of innovation, how does this differ from invention? Twiss (1974) distinguishes invention as the conception of an idea, whereas innovation is the process of commercialisation by which an invention is translated into financial gain. Thus this project can be defined in general terms as the devlopment of an innovative product; the label of 'innovative' being applicable due to the significant development of an existing product and the introduction of a novel (in terms of design detail, rather than concept) product. Such a development is a difficult task for a company as it incorporates such uncertainties as demand, competition, reliability, functionality, financial and resource impositions. Kotler (1973) for example, estimates that fourteen percent of development projects become a successful addition to company product lines. Cooper (1978) concludes that too many organisations embark on new product ventures lacking an understanding of the marketplace, the customer and the competition. Twiss (1974) lists seven factors most commonly linked with successful innovation. These are: market orientation; reference to company corporate objectives; effective project selection and evaluation, management and control; a source of creative and practial ideas; an organisation receptive to innovation; and commitment by one or more individuals.

It must not be assumed that innovation is related purely to aspects of market and management: clearly any technical product requires technical development; indeed, technical competence is required in all aspects of the project. The mutual dependence of R & D, production and marketing for a successful innovatory outcome is well documented. Blois and Cowell (1971) for example, describe how R & D is the usual source of ideas, and that the technical and marketing sides of a company must liaise to develop the idea.

Rothwell (1977) estimates that of all successful innovations, around seventy five percent arise in response to a market need; the remainder follow a new technological potential. He suggests that most successful innovators combine both aspects to some extent; the latter group would determine, typically, that a need exists before proceeding with the project and establish precisely the user needs. Wilson (1980) also discusses the merger of marketing and technological skills, and states that the two must complement each other. Kotler (1973) defines successful marketing as depending upon market research which is:

".. systematic problem analysis, model building and fact finding for the purposes of improved decision-making and control in the marketing of goods and services. "

It would seem then that marketing is a necessary aspect of any innovatory process. At worst, the writer considers it as a useful tool and guideline. Of the available literature on marketing research, the vast majority relates to consumer rather than industrial marketing. Although similarities exist between the two, the differencs are significant enough to prevent a direct transfer of methodology. Thus, this subject will not be pursued in any greater depth. Before considering the specific technical factors contributing to the 'commercial' viability of the intended product, it is interesting to note that innovation is not necessarily a science. Unlike pure or applied scientific research (which itself plays a part in the innovation process) where problems are stated, and solutions proposed in numerical terms; innovation calls for subjective assessment. Such assessment is often based on incomplete data about a changing scenario, constrained by any number of complementary or contradictory factors.

8.2.3 Speed Sensor: Market Overview.

It is of interest in the light of the generalised discussion presented above to attempt to define the market priority of this project, that is: is the project the development of a technical product requiring a market, or the fulfillment of a market need by the development of a technically-based product? The writer believes that the project does not necessarily fit, or have to fit, into one or the other category. As stated at the beginning of this chapter, just as a company view of the phrase 'commercial' can possess several connotations, the company sees this project as the fulfillment of a specific and immediate market need. The writer, however, considers the design process as including the capability to access potential new markets. However, due to external factors (discussed further in section 8.3.3), the project must chart a course of gradual technical improvement towards an unchanging market. That is to say the market requirement from the project's view remained unchanged during the course of the project, but due to advances in product performance, reliability, applicability and cost, the final product is expected to affect the market in terms of requirement, application areas, purchase quantities and profit etc. Put succinctly, the final product should be more saleable. And, as mentioned above, the writer sees the project's course as one that includes the consideration of new areas of potential sales (see reports P28 and P17 for example).

The generalised market requirements for the speed sensor are summarised below. The list is not in order of importance, and asterisks indicate those points considered by the company. The unit should:

- cost as little as possible, commensurate with acceptable performance, with a rigid upper limit of £100 (*),
- be a repeatably accurate device (*),
- be as small as possible, specifically widthways, and be capable of fitting onto the existing mounting bracket and holes (*),
- interface directly with the existing system (*),
- be impervious to minor impact, either by mishandling or by external projectiles,
- look 'rugged' and capable of site use,
- have an alarm speed setting capable of alteration in-situ, either manual or with the option of upgrading to a zonal system,
- require minimal calibration, maintenance etc,
- be easily fitted, retrofitted and removed, without other

sections of the system requiring disassembly,

- not contravene Home Office or Health and Safety regulations,
- be incapable of disconnection or partial disablement by unauthorised personnel.

It might be argued that this list comprises several requirements better categorised as technical. However, when presented as an unquantified and unqualified summary, as above, these points must form part of the total market brief. The customer is in reality likely to judge the product on such factors.

If this list is taken further, inclusion of the more superficial aspects of marketing is possible. For example, the design brief may include the decision to refer to the unit being 'British-made' (as does the sales literature: see appendix 3.6). Such considerations, given the psychology of the typical customer, are of passing interest only.

8.3. COMMERCIAL DESIGN CONSIDERATIONS.

8.3.1 Discussion.

The generalised process of design can be said to be the 'satisfaction of objectives subject to certain constraints or criteria'. This is no less true of the technical design task. Criteria for such a task fall into a number of categories: technical, ergonomic, economic, aesthetic etc (Clarke,1978). Of these categories, the technical aspect should usually be the foremost in the designer's mind during the initial design phase, although the cost, ease of maintenance etc are of equal importance. In many cases, however, technical constraints override the designer's brief. This point is illustrated by several case studies reported by Beakley (1974). The fundamental resources necessary for carrying out any task are time and money: the success of a commercial venture will often depend on the time taken to develop the product, and money is necessary for the acquisition of resources (manpower, machinery, space and materials). The availability of these resources has a great bearing on a company's design capability, and must be balanced carefully with the designer's requirements and objectives in order to reach an optimised design process.

The resources which a designer might call upon are experience, technical knowhow, experimental technique and appreciation of technology. The experience may not necessarily by gained on previous design briefs but may be obtained specifically for a project. Knowledge of experimental technique can yield useful information upon which to base decisions, or to accredit previously held theories. It can also yield data where the corresponding theory is intractable or necessitates simplification or approximation. Gregory (1966) criticises the modern trend of rejecting data-derived information and relying upon mathematical models. Technology concerns the availability of information of an applicable nature: this wealth of factual data is ever increasing, but must be kept pace with for a design to be considered technologically competent.

It is possible to classify design procedures by the relative contribution of new ideas, experience etc. Furman (1970) distinguishes between evolutionary, repetitive and innovative design; Asimov (1962) covers only innovative and evolutionary. Design by evolution is effectively the process of modifying or improving an existing design concept; and design by innovation usually requires an aspect of novelty. Most engineering design, whether innovative or evolutionary, consists of three distinct yet very much related phases: a feasibility study, preliminary design phase and a detailed design phase (Asimov, 1962). In reality much feedback will exist around these phases. At the start of the feasibility study, the design task will be specified and the designer must identify those factors limiting his actions, and operate within these constraints. Cain (1969) suggests suitable requirement categories for the brief, but stresses that at this stage an open-ended set of guidelines is of value.

In the preliminary phase, the relative merits of alternative designs (

either interim or radically different approaches, or of subtle component alterations) are assessed: the detailed phase will concentrate, usually, on the most promising design.

8.3.2 Speed Sensor: Design Considerations.

It became clear from the point at which this project's aims were finally defined that the design methodology adopted would have to serve two masters: immediate need and future requirements. At first an examination these factors may seem to correspond to the evolutionary and innovative design phases respectively, but this is not so. The two are inextricably linked: short term development work cannot be undertaken without considering the incorporation of the resultant design into long-term design requirements.

In consequence, two types of design work were undertaken simultaneously: basic redesign procedures, and innovatory design work. The resources discussed previously very much shape the constrictions placed upon the designer: OEL possesses, for example very limited resources in the form of equipment (see fig 3.1), finance or expertise; yet its product category leaves the designer almost free in the areas of ergonomic and aesthetic constraints. These technical constraints are by far the most important, and the next section deals with these.

8.3.3. Technical Constraints.

The needs of the commercial and design aspects of this project, and product, have been reviewed in a general manner in the previous section. The specific constraints of a technical manner will now be reviewed. The speed sensor, as discussed in chapter one, was developed in very much a 'prod it and see' manner in the early stages of the company history. Whilst it was clear that this design required reviewing and appropriate modifications incorporated, it was considered likely that eventually a new design would be needed. The technical constraints thus fall into two broad categories: the redesign must be compatible with the old design, and the new design must follow on from the redesign as far as is possible in component and system compatibility. Thus the product should 'evolve' in accord with all pertinent constraints and considerations.

The specific technical constraints imposed by the old design on any new or modified design are, for example, such factors as:

- truck mounting bracket and holes of a fixed dimension and location,

- connection to the rest of the system by an unscreened, thin 10-way ribbon cable of limited current carrying capacity,

- the second half of the signal processing circuitry is located on the control board, located remotely from the sensor unit,

- an alarm speed of nominal 22mph, and cancel at 20mph is required (although this is unofficial: no defined company policy exists on this matter),

- large stocks of components held specifically for the design,

- a lack of appropriate test equipment,

and the extra constraints imposed by the old unit to be borne in mind when considering possible modifications are, for example:

- the microwave unit, lens and case are of a bought-in type,

- the sensor casing, mounts and bracketry are unmodifiable.

Thus any modification to one or more components of this design must allow full compatibility with the other components. This is difficult to achieve: often it can be performed only by improving a component, thus obtaining a different result, and then adding a 'retrograde' step to obtain the original result. An example of this is the use of the PLL to remove the effect of phase-nulls (section **4.4.2**): the vehicle speed as 'seen' by the electronics drops by over ten percent (section **4.4.4**). The intention is, at the end of the day, that all retrograde steps should be removed, leaving a fully upgraded system. To return to the PLL example, the divider circuit can be dispensed-with when the microwave unit is tilted to the final design angle, or when the control board alarm frequency is raised. The former cannot take place until the unit and mounting bracket are completely redesigned, and the latter requires a modification to the control unit. Many other such examples manifiested themselves during the course of this unit's development, resulting in the unavoidable outcome of a significant slowing of the design process, requiring innovatory design to assist evolutionary design. Progress by such 'retrograde' steps does, however, ensure commercal viability and continuity at all stages: a very important factor.

Technical facilities available were limited: the available resources for research, design, development, servicing and repair within the company are tabulated in fig 3.1. This list is not extensive: a factor which presents a considerable restriction on the design activity, and limits research and development to a degree that forces 'alternative' approaches to the conventional approach to these disciplines. Greater emphasis, for example, must be placed on repetitive design (change an aspect by a minor degree, evaluate, change, evaluate.. etc) and empirical approaches. Preselection must be performed to ensure that any design might stand a chance of being developed within available resources. However, as Gregory (1966b) points out, subjective decision-making plays a large part in this process, and the full consequences of such decisions may not become apparent until far into the design stage.

Such a 'delay in accountability' is an inevitable outcome of the 'trial and error' approach. And, unlike several ubiquitous texts on project management would have the reader believe, cannot be circumvented by judicious use of project management and control techniques. It falls into the domain of the entrepreneurial skills of insight and informed guesswork. Examples of 'alternative' techniques adopted in the project are described in the main text; but include, for example, the use of a cardboard and tin foil horn to prove the applicability of textbook theory; the quantity of site and road data recordings made to enable an optimum setting of circuit gain and frequency response etc; the writing of a test specification that utilises only those resources possessed in the laboratory; testing several common plastics in order to identify a suitable window material etc.

8.4. THE COMPANY.

8.4.1 Introduction.

Previous chapters of the thesis have charted the formation and early history of OEL in a chronological and, as far as is possible, an objective manner. As discussed in chapter one, this sequence of events has had a direct bearing upon the state of the company, both at the commencement of the project, and subsequently.

This background has affected both the running an outcome of the project, both directly and indirectly. Directly, as when the writer joined OEL the staff count was in the process of dropping from almost forty to five, with a commensurate decrease in the availability of resources (manpower, expertise and finance); and indirectly, as the company seemed to lose direction, with procrastination and overcautiousness prevailing. Both outcomes resulted from two main facts: the ALBERT system was seen to have intrinsic design faults, and the inability of Marconi to develop a replacement sensor in an acceptable time.

As a consequence of these problems, and their effect on the running and outcome of this project, the writer considers it part of his brief to analyse, be it superficially, probable causes of these problems. It is certainly not the intention of the writer to judge the actions of the OEL staff with the benefit of hindsight, but rather to identify key factors that may assist in the prevention of future problems.

Due to the contentious and subjective nature of this section, the company was given the right of reply. No response was forthcoming.

The specific circumstances that surrounded the formation of OEL are certainly unique, and yet many factors common to well-documented company analyses exist. It is prudent to commence by identifying the exceptional aspects of the company and its product:

- the company has no direct competition: no product exists that claims to perform the same, or a similar function to ALBERT,

- there is no knowledge base, whether within the company or easily available externally, on which to build technical, developmental, production or sales strategies,

- there has been, is, and will be a great demand for the product, almost irrespective of its final form or price,

- the company possesses no resources to assist product development: neither equipment nor technical expertise,

- the company is not staffed by management personnel with experience is the field of electronics or electronic engineering.

A detailed discussion of the issues contained in this list of factors would require a lengthy analysis to do the subject justice. Thus, this chapter will deal with, admittedly, rather naive observations, and make rather crude and generalised conclusions.

8.4.2 The Product.

OEL was formed specifically to manufacture and market one product: a product dissimilar in every respect to the parent company's previous experience. This is, if not unique, certainly uncommon. Penrose (1970) states that most firms embarking on the development of a new product tend to diversify into areas that have technological or marketing factors in common with the company's previous products or service areas ('marketing factors' here refers to a more tangible link than simply relying on having contacts in potential sales areas), and that:

" when a firm's strength is not related to its technological strength, it is more difficult to move into entirely new areas of specialisation. "

Radical product diversification certainly does happen, often successfully; usually due to the company's strength in the market in general (company name, image, contacts, distribution outlets etc). But these general strengths are of use only when the technological base of the company is established, or where the product rights are acquired after the technical development of the product is complete. For whilst a company with experience in radar systems might successfully develop and market any electronics product, as the technological base is very similar, a company with no electronics experience should expect great difficulty in developing and marketing radar systems.

Cooper (1966) identifies five major areas of feasibility that must be considered when designing, developing and marketing a new product: technical, manufacture, commercial, financial and marketing. This list, which does not refer solely to technically-based products, gives technical feasibility priority. Reiss (1967) states that:

" a new technological product requires a synthesis of the contributions of experts whose knowledge matches the understood problems, and experience matches the required solutions. "

It can be appreciated that an underlying theme is appearing: that of an adequate technological base, and of adequately identifying present and potential problems. Both are discussed in depth later.

A company that relies upon one source of profit for which there would seem no immediate, or indeed foreseeable, threat from competitors is certainly in a peculiar situation. The belief that the product is a revolutionary innovation and able to shrug off competition with patent protection (OEL hold 3 patent applications in each of 10 world patent areas: ref OEL p) or other restrictive devices can be dangerous. It is inevitable that the success of such a product will generate interest, and in time it will face stiff competition or be overtaken. Indeed the opposition may well be 'biding their time' in order to let the leading company sort out the basic product design problems and market identification etc. For this reason one product may be considered a precarious position on which to base a company. Especially, as in the case of OEL, when a significant financial investment has been made before the company had ensured, to the best of its ability, that the backed product is fully developed. But given that all the company's 'eggs are in one basket', then it should have been recognised that the product would evolve (this may also be considered a euphamism for 'requires further development') further over time, and likely changes should be identified and catered for well in advance of the immediate need to act upon such changes.

It is interesting conjecture that if OEL had developed a more modular system topology, those aspects of the system that performed adequately could have been sold as a basic system with the option to upgrade; thus assisting cash flow, and company credibility. But further, marketing the system in such a manner would ease the problems of developing and marketing a product that has no direct competition, namely the inability to gauge progress by comparison with external factors and developments. Such an inability leads to comparisons only with internal plans, hopes and expectations. Hence the company has no means of establishing realistic research, development and marketing timetables, costings, resource allocation etc. On a more practical note, it is harder to conceive a true 'market price' for the product, and to assess the tolerance of potential customers to delay, unreliability etc.

The above insinuates that a single product can be considered too high a risk on which to base a company, but several researchers review the advantages of the 'single product company'. Pavitt and Warboys (1977) state that the small firm and/or lone innovator can make a significant impact in a technical field, and quote several advantages and disadvantages of this arrangement. The advantages are: rapid decision making, ease of merging research, development, production and marketing. Disadvantages include high risk, lack of specialised skill, research facilities and management. Gerlach (1970) also considers these factors, stressing that it is crucial for development and production to be interrelated if a new product is to be launched successfully.

The ALBERT system has further peculiarities in market type: the product application is one in which, within reason, safety precedes financial outlay. Potential customers of this system would not necessarily be dissuaded by price increases, as to an extent the system cost is negligible. If the ALBERT system were priced, for example, at £3000, this represents around half of one precent of the cost of the vehicle it is protecting. Hence the captive market is truly 'captivating': with such potential financial rewards it is not surprising that OEL commenced production before much of the system was fully developed. Nor is it surprising that the company pushed the marketing process rather too early. And further, this untapped market, lucrative by any standards, may be said to have weaned the company into 'less than objective' decision-making (see also Kraushar, sect 8.4.3). The product's lack of competition, and the great demand might also account for the relatively fixed nature of the product; for, without real opposition there exists little need to continually identify and assess changing market needs and means of fulfilling them. Hence OEL did not, and do not, know the potential value of, for example, the speed sensor unit. Unofficial policy is to consider it an option that is offered as a 'throw-in'; but could it attract new customers? Could it be sold as an independent unit? What would be a realistic price to charge? The company's only information on such issues is based partially on the original marketing push some three years earlier, and partially guesswork. On the one hand the writer is told that the speed sensor is a minor add-on to the main system and not marketable as a feature or as a stand-alone facility (the latest sales literature does not even indicate the existence of such a unit, even in the context of it being an option). On the other hand, the site operators seem well pleased with the unit, and claim impressive savings in engine and tyre wear. At £60000 per set of tyres, such operator's views would seem to indicate a market for the sensor limited in number only by the total truck market, and limited in selling price only by ethics!

In mid 1981 the marketing push extended to the USA which had established itself as an important potential market. Two factors concerning this activity remain a source of confusion to the writer.

First, to what extent were OEL aware of the international legislation of microwaves and EMI concerning such products? The system was designed, it would seem, without regard for such legislation. In the UK the product could simply have been sold until tested by the Home Office, and the company may then have been able to plead ignorance; but neither the US import legislation nor the FCC authorities would let this happen.

Reports P24 and P27 deal with the appropriate legislation and system conformance: in its present form the system would not be granted a US import license.

The second source of confusion is that the product was marketed, effectively, as a system based on technology a level above that utilised in reality (the documented interchanges with Euclid, sales literature and journal articles illustrate this: see section 1.2.1). It must be asked to what extent the 'microprocessor myth' was a marketing ploy conceived by OEL, an exaggeration of JMS originally, or mere confusion of technical jargon. Ironically, over three years later, the University of Bradford was commissioned to utilise microprocessors in a new scanner design. If the system had, in fact, been truly digital, the 'intelligent scanner' concept might have been considered, and incorporated, earlier.

8.4.3. R & D: The Technological Base.

The factual basis upon which the formation of OEL and the merger with JMS were undertaken is unavailable to the writer. It is reasonable to assume that by merging with JMS, OGC considered that the expertise required to convert ideas into products would be part and parcel of the deal, as no plans were laid to provide development facilities other than to rely on those already possessed by JMS.

The problems and advantages of joint management after such a merger are discussed elsewhere, but the following will examine points in greater detail. Certainly, the usual expected advantages of acquiring a company (Kraushar,1977) do apply here, namely the acquisition of R & D experience and technical facilities etc, but other factors were not so easily gained. Such factors include experience in the market in which the business has been identified (knowledge was already held in this area by OGC due to their involvement with plant equipment), and, importantly, the techniques by which concept is turned into saleable products. Hindsight would suggest that the company misjudged the phase of technical development of the ALBERT system: this is easy to do when no expertise in the appropriate technologies are available in-house. Thus two questions must be posed: why did the company not appreciate the failings in its technical understanding of the potential product area, and if indeed it did appreciate this, why did it not take appropriate action?

The first question would seem to be easily answered: a lack of communication. The exact state of product development at the time of the merger is witheld information, but it is known that not all aspects of the system performed as intended. So, surely it is a safe assumption that the system was not fully developed. In fact the situation was rather more complex: the OGC staff were given demonstrations by JMS that with hindsight can be seen as 'laboratory' or 'controlled environment' simulations only. The outcome of these demonstrations seemed to indicate a rather more advanced state of product development than was the case in reality. In fact the demonstrations also seemed to indicate technical competence and understanding. It is not known whether JMS knew that the conditions surrounding these demonstrations to be unrepresentative of the final operating environment of the product. It would seem, however, that the 'extended field trials' as advocated by both common sense and most researchers did not occur. Blakstad, (1979), for example recommends a combination of technical qualifications, lateral thinking and in-depth discussions concerning the planning, executions and intepretation of suitable field trials.

According to the 'official' company history, the Dalton facilities were intended to develop the system fully, whereupon the Bowburn plant would manufacture. But to what extent was the Dalton development seen as 'ironing out a few preproduction bugs', or 'converting an idea into prototype'? If JMS sold ALBERT as a researched and lab-prototyped system, why did OGC not set up a development laboratory facility. Or, if JMS sold the system as a developed concept, why did OGC not assess the design independently or at least examine its existing performance and future potential rather more carefully. In other words, it is unclear who was to have performed development work.

A review of pertinent literature proves fruitful in attempting to comprehend OGC and JMS's confusion. Burns (1977) distinguishes three categories of research: pure (knowledge gained with no direct application), basic (directed towards useful results) and industrial (basic research directed towards a commercial application). It would seem that the handover of the ALBERT system from JMS to OGC occurred some way between Burns' second and third definitions, and that some confusion arose in determining responsibility for the completion of the industrial research phase.

The root cause can be seen as one of technological competence. OGC did not have an appropriately detailed knowledge of the technicalities of the projected product (to assess the amount of development needed) or of the technological base required (to assess the type of development needed). Such a technological base is crucial: Penrose (1980) says:

"A strong market position without technological competence is as precarious as a strong technological competence but a weak marketing ability."

Indeed, the available literature is full of criticisms concerning the technological base of British companies, both large and small, new and old. Lothinan (1984) surveyed twenty-six companies and Myers (1968) examined over five hundred: both found a lack of understanding of the ramifications of incomplete R & D, either derived from low financial commitment or technical incompetence. Norris (1971) also found that a sound R & D basis is lacking in most companies. And, considering the lack of existing knowledge (no competing products, no documented research, either technical or commercial etc), the development phase can only build on the research phase, even though this may well be disadvantageous for a small company (Hassid,19..). It is appreciated that this is certainly a difficult problem: how to identify the lacking knowledge and resource areas in a field in which no experience has been gained. To an extent standard texts can provide a basic checklist upon which to base such identification. Rothwell (1980) points out that successful technical innovation requires the balance and integration of activities often considered separate: namely research, development, production, marketing and planning. Hindsight would sugest that acqir-iring expertise in research and partially in development is inadequate to assure a successful outcome.

So, once again, one must conclude that the project should have been overseen by one or more personnel with no vested interest, and capable of appreciating and linking all functional areas, including the all-important technical area. Fig 8.1 illustrates such a hierarchy which, it is acknowledged, is atypical. Perhaps more realistically, OGC could have expanded their expertise by either employing a technical specialist or by commissioning a consultant. Kraushar (1977) recommends this course of action in order to provide objective advice. Buggie (1981) describes a technique of evaluating a design by forming an 'assessment team' of several experts, each experienced and technically knowledgeable in areas similar to the intended product. He stresses the need for this team to be independent of the company in order to assure objectivity.

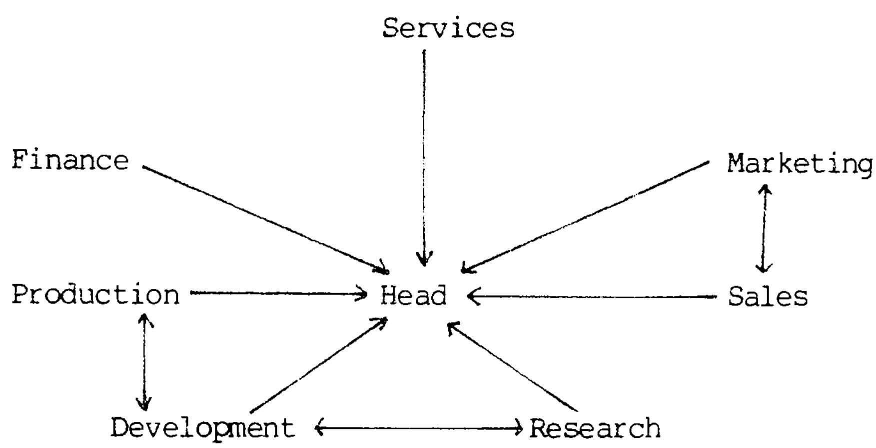
Certainly, when a technical advance is foreseen or achieved by a small company, decisions are, by convention, made by the company management or often specifically the chief executive. In larger companies, or those with technological management experience, adequate planning and evaluation is achieved by consulting specialist opinion either from within, or external to, the organisation. And yet it is the smaller company who truly needs specialist advice: the stakes are higher. So perhaps it is not surprising that if a project turns out to look unprofitable, it is difficult to reverse the enthusiasm and optimism generated by earlier thoughts of success. Kraushar (1977) states that in such circumstances:

" ... every conceivable extenuating circumstance and argument is sought to explain why the project is better than it looks, and so why it should proceed to the next stage. "

Care must be taken in the enlistment of external advice: Douglas (1978) warns against using specialist consultants as severe problems can occur if they are wrongly briefed or misunderstood (both very possible if the briefing and debriefing is peformed by a non-technical manager). Hence as a compromise, it is suggested that an internal group chaired by an external consultant would provide a useful basis upon which to make optimal decisions. The 'wrong briefing' referred-to above can have many guises, from factual inaccuracy of a specific nature to a bad and misleading presentation of correct data, through to no data at all! JMS did not document their research (or, more accurately, scant documentation was handed over to OGC), and at present OEL document only when specifically necessary. Thus any external consultant's task would have been compounded by the lack of written information. In the event this lack became apparent to the OEL employees at a late date; the passage of time further blurring the issue. Of the information available from the early design stage of the system, none documents the day-to-day progress of the system; so when a problem is found, the assumption must be made that this problem is a new one, and the method of solution must commence from first principles. The unfortunate aspect of this situation is that, given the product and its intended application, it is likely that many such problems have occurred previously, and although remaining undocumented, have been successfully overcome.

This section ends with Galbraith (1968) who observes:

"Technology requires specialised manpower so organised knowledge can be brought to bear by those who possess it. Technology makes a claim on manpower and planning, and requires a high level of specialised knowledge."



An Example of an Interdisciplinary Management Structure

FIG 8.1

8.4.4 Management Aspects.

In addition to the list of exceptional aspects discussed in section 8.2.3, further, and more subtle, aspects play their part in the company's fortunes. Such an aspect is that of management style. It is apparent to the semi-objective obsever that difficulties were, and still are, caused by the contrast in company management style and technique. OGC was run, effectively, by the owners on a daily basis.

The birth of OEL required new skills: an understanding of the methodology and appropriate timescales that pertain to the electronics industry. Clearly such an appreciation takes time to develop, and as no expertise was 'bought in', the initial phase of OEL management was mechanistic (vertical structure, hierarchic communication etc) as opposed to the more appropriate 'organic' form. Hence the advantages of the latter form, namely recognition of the contributive nature of specialised knowledge, skills and communications based upon exchange of information (Klein,1956; Burns,1954) were lacking. This is unfortunate, as the latter approach might have given rise to a better technique of dealing with the company's numerous technical and technological problems than that resulting from the more conventional structure.

Indeed the company's difficulties in the early days were compounded by the management structure: the caretaking directors that oversaw the birth of OEL comprised one owner, two directors of OGC and the director and owner of JMS. This may well have created problems in several areas: presumably the JMS director has a strong interest in his own company, and being new to the Ogden Group, the well documented (eg Douglas,1978) problems of joint management after a merger or takeover diverted attention from more pressing and crucial issues to the more 'day-to-day' problems. Pettigrew (1973) provides an in-depth review of the problems associated with personal interactions within a merger with a developing technology company; and further work on the manager-technical specialist relationship can be found in Peltz (1966) and Burns and Stalker (1966).

The geographical spread of the OGC management team further complicatd matters, introducing both strain in the physical sense due to the significant distance separating the various factions of the OEL division, and strain psychologically, as the passing on of information and decisions are delayed and sometimes distorted. But, more importantly, the caretaking directors had a lack of previous experience in the field of technical management, and those employees comprising the Bowburn workforce similarily lacked significant expertise or experience. This lack of fully-trained staff was not short-term: some eighteen months passed from the inception OEL to the appointment of a technical manager (see fig 1.2). Excluding test engineers employed at Bowburn, this manager constituted the only technically trained employee.

The apparent reluctance to employ experienced staff could be explained in part by the changes in company location and the geographical area: the north has only three percent of the national count of electronics industry jobs (Tank,1983) with a commensurate dearth of suitably qualified personnel either in the area or willing to relocate. However, no earlier attempt to recruit was made; any yet the span of time when no technical expertise or management was available was a most crucial period: the period when the ALBERT system was first seen as inadequately developed. Indeed from this period stemmed the confusion about the technical base of the product, the erroneous judgements upon the readiness of the product for manufacture and marketing, and the management type which pervades the future progress of the company. From this period also stems dire confusion about several aspects of the system. The managing director stated in a production meeting, for example, that sufficient components were held in stock to produce one hundred and fifty roadspeed units (OEL,4/82). In reality no such stocks did, or ever had, existed. In a technical meeting the autocancel facility was proposed as desirable (OEL 5/82) whilst general feeling within the company and from customers was that this was not the case. Many such examples exist.

The belief in the 'all-rounder' manager is not uncommon (Allen, 1976): perhaps the caretaking directors felt that as their past experience has successfully encompassed various fields (see section 1.1.2) then the need for specialists or experts was not of especial concern. Surely this was, and still is, a fundamental problem: it is understandably difficult for experienced and successful management to identify such a need. This difficulty is widely acknowledged, both in general terms, and specifically to the modern British electronics industry. Mumford and Pettigrew (1975) identify the typical decision-making behaviour of the industrial manager as being based upon values rather than factual data; and Pavitt (1980) illustrates the amateur standard of the British technological project manager with a series of case studies. And the effects of this aspect of management are also not understood. Malik (1964) for example, says that:

"..one of the fascinations of electronics is that so much is dependent upon the quality of management."

The results of non-technical management are often subtle: problems at OEL occurred frequently when dealing with component suppliers, for example. Whilst the OGC policy for witholding payment for ordered goods may be financially sound and an acceptable practice in the plant equipment and general industrial field, this is not so in the electronics industry. Hence OEL soon became 'cash customers' only. The cheque-raising policy was also bureaucratic and slow, often with a significant delay even for urgent requirements. It is obviously rather difficult to perform research and development when a company is both unable to open accounts, and has difficulty raising cheques. The halting of work due to the unavailability of ten pence worth of components seems amusing on the first occasion, but frustrating thereafter. In an attempt to speed the ordering process, the writer used his Access card to order via mail-order companies to ensure next day delivery, and then channel the receipts through the 'personal expenses' procedure. In one year this procedure had to be resorted-to over seventy times. Hazel (1977) indeed, identifies a lack of component suppliers as specifically detrimental to developmental progress within the electronics industry.

In any research and/or developmental phase it is crucial to ascertain likely resources and to plan accordingly. Such a course of action would prevent the harmful state of affairs outlined above. This argument should, indeed, be continued to encompass the whole management function: it is therefore in keeping to establish what should have occurred. Thus this section concludes with a checklist of factors identified as contributing to the present state of the company, and of having an influence upon the course of the writer's project. This list was compared to the findings of several notable researchers in the field of industrial and technological policy (Certer,1957; Hayvaert, 1973; Langrish,1972; Myers,1969; Rothwell,1976; Schock,1974; Szakasits ,1974; Utterback,1975). An asterisk denotes that a point is common with their findings. The list appears thus:

- R & D, production and marketing should have been balanced both quantitatively and qualitatively (*)

- all technical defects should have been eliminated before commercial launch and mass-production (*)

- alternative sources of technical information and means of assessment should have been identified and utilised before and during product development (*)

- management style should have been 'technology oriented', and staff should have been technically trained (*)

- Sources of finance and R & D financial needs should have been tied closer together, both in general terms and on a day-to-day basis

- the market should have been identified fully rather than relying on one customer's needs

- an in-house research facility should have been developed and maintained in the early stages of product devlopment

- detailed and up-to-date documentation, technical and managerial, should have been kept.

CHAPTER NINE.

PRODUCTION PROTOTYPES: CONSTRUCTION AND TEST.

"If a problem is to classify as
soluble, there must be rules that
limit both the nature of acceptable
solutions and the steps by which
they are to be obtained. "

T S Kuhn,
The structure of scientific revolutions.

CONTENTS

SECTION

FIGURES AND TABLES

PHOTOGRAPHS

9.1. INTRODUCTION

Chapter seven left the sensor development history at a crucial phase: OEL agreed that the Aro performance, both in terms of accuracy and longevity, was inadequate. They agreed that the sensor would be difficult to modify sufficiently to provide acceptable performance, and that the unit could not provide the basis of any new design. But would they agree to the construction of a full production prototype sensor? The discussions were extended, and involved several commercial factors (some of which are discussed in chapter eight). Ironically, as the performance of the Aro-based unit was much improved by the addition of the PLL module and new PCB, as no stocks of Aro microwave heads remained, OEL were seriously considering the purchase of a new batch.

This chapter continues the story, commencing in late March 1984; only six months before the SERC award terminated, and into the time period IHD allocate for project documentation!

9.2. ORDERING. AND RE-ORDERING.

Discussions with OEL revealed that if the go-ahead to produce the proposed new unit were given, the projected selling price would be £200. In the writer's opinion this is underpriced, as site foremen have estimated the savings on engine and tyre wear at tens of thousands of pounds per year per truck. They also reported a significant lessening of speeding-related accidents such as overturning trucks, out of control skidding etc. However, the writer accepted this price ceiling, which implied a maximum manufacture cost of around £100.

The process of value engineering the whole design was thus commenced. Cabling, case design, brackets, components and microwave assembly were all downgraded. To save further cost, a case design wherein the horn assembly was an integral part of the outer-case casting was devised: this design necessitated extensive consultation with the selected pattern-makers.

The process of engineering an acceptable compromise between reliability, accuracy and cost required several further laboratory experiments. Such attention to detail as the collation of alternative sources and types of components was undertaken. For example, selecting an alternative power resistor saved 40p: in isolation a trifling amount, but the total saving achieved was over £5 per unit.

OEL gave the go-ahead in early April 1984 to commence ordering components for five production prototypes. Hence the sides, brackets, windows and castings were ordered. In response to an appreciation of the gravity of the situation regarding the maintenance of the existing units, OEL placed a further order for thirty new PCB's and a further ten PCB2's (FTM board). Twenty full sets of board components were also sent-for. The ordering took several days as over two dozen suppliers were involved.

A sudden increase in the awareness of side issues also struck the company: OEL commissioned a report from independent consultants regarding the legal ramifications of manufacturing and selling microwave emitting devices. The report, however, confirmed the writer's findings (report INT P27) that care must be taken to ensure the stringent requirements are adhered-to; and confirmed that most of the present units, as discussed in report INT P19, operated at an illegal frequency.

Delivery of the ordered components complicated the seemingly simple process of unit assembly: indeed the list of problems took over a month to resolve. For example:

- Brackets. The first set were incorrectly made. After discussions with the manufacturer, a second set were delivered, poorly made; the welded join made fitting impossible. Upon reorder the replacement brackets were no better. An alternative supplier was then used.

- Sidepieces. The holes were inaccurately drilled. These too were reordered, but the original sides were returned with oversize holes. To save time, these were retained.

- Castings. These arrived unsandblasted on the horn inner surface, too wide, with an incorrect front face window recess, the wrong aluminium alloy, and with holes drilled on one side of the casting only. They also arrived six weeks late.

As a metal pattern had been commissioned for this design, and modifiication and re-casting would be both expensive and time-consuming, the castings were accepted. Consequently further brackets and windows had to be designed and ordered so as to be compatible with the casting dimensions. The final list of suppliers was also consolidated at this time, after discussions with potential suppliers on the types of problems they face with such orders. Hence the writer is confident that subsequent orders will be (relatively) straightforward both to place and to have process.

9.3. DE-BUGGING.

Bench tests on the now completed prototypes indicated a promising performance. The radar footprint, when mounted at operational height and angle, measured two by seven feet (E and H plane respectively, at half-power), and possessed minimal sidelobes. Preliminary car and trailer trials showed perfect consistency both in unit performance, with a repeatable alarm speed of 23mph, and between units.

Site tests, however, were not so promising. One unit entered permanent alarm on a haul road; effectively stopping the whole site working. The fault was identified as an earthing error which did not manifest itself on car trials due to the independent battery power supply used. Other problems noted include several trucks with non-standard mounting brackets, and intermittent false alarms when the truck was stationary near a bucket-crane. Hence the casting mounting was further modified, and unit earthing and screening was completely redesigned.

Spectra derived from the horn unit illustrated the minimal frequency spread of the returned signal (see fig 9.1 in this chapter: these spectra illustrate the improvement in spectrum shape over a standard unit: the half-amplitude spectrum of the horn-derived signal is one-seventh that produced by the Aro unit. Volume two, section one discusses such graphical data in greater detail), and site trials confirmed that the unit did indeed provide accurate and consistent velocity measurement. To ascertain an appreciation of the long-term stability and reliability of the sensor, four units were delivered to site and their progress monitored.

9.4. OPTIONS AND MODIFICATIONS.

The production prototype units were built to correspond to the sensor general specification (report P22). Hence the options suggested both to improve, and to reduce the cost of, the system had also to be assessed. Two reports were produced: INT P28, which describes a lower cost sensor and sanction system, and INT P36, which details circuit improvements (incorporated at a cost penalty). A resumé of the contents of these reports now follows.

Several options are available that improve the 'failsafe' operation of the sensor: those detailed include a box connection and unit failure test, and a self-check oscillator. Further modifications can be made to reduce total system costs. INT P36, for example, details a far simplified control board circuit which reduces the component count by sixty over the conventional board. This unit replaces the existing control board with a simple circuit which produces a painfully loud sound, varying in pitch with the duration of the overspeed 'offence'. Sample designs are given and a typical costing calculated: including the speed sensor, the system would cost under £150. Several visible indicator options for inclusion in the truck cab are illustrated (including indication of the operating zonal speed, if used with the beacon option: see report P17 and P32). The benefits of a non-retarder sanction enforcement are detailed in the report, but one

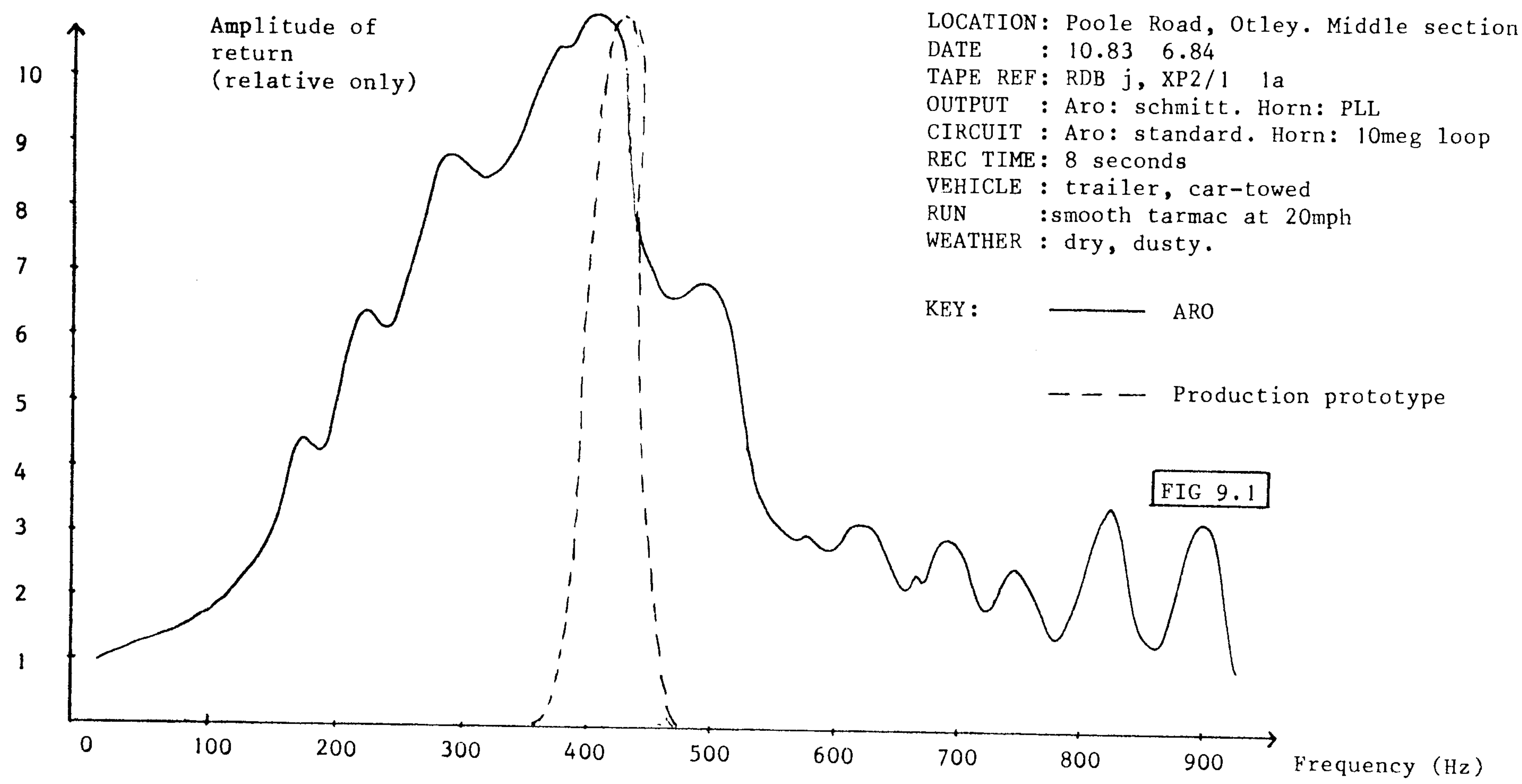


FIG 9.1

A COMPARISON OF RETURNED SIGNAL SPECTRUM FOR THE STANDARD ARO UNIT AND THE PRODUCTION PROTOTYPE HORN UNIT. PERFORMED ON A SMOOTH TARMAC ROAD IN DRY WEATHER. BOTH UNITS ARE TRAILER-MOUNTED.

pertinent aspect is that of failsafe operation: in section 9.3 it was stated that site operation was halted due to a fault in the speed sensor. Such occurrences, of course, could not happen if the sanction was 'psychological' as opposed to 'physical'.

Further, more subtle, unit modifications assessed in the latter stages of development included changing the low-cut filter cutoff frequency. The cut point was selected after extended field trials over a year ago on the basis of a configurable alarm speed. In the light of OEL's decision to incorporate, perhaps, only three speeds (15, 20 and 25 mph are the most likely selection) in future, the filter performance was reassessed. One unit was thus modified to allow speed equivalents of 12mph downwards to be filtered out, as opposed to 7mph. Although laboratory performance would seem to be improved, site results did not indicate any measurable improvement. This filter was thus left unaltered.

A further ten PCB'S were ordered in June 1984, allowing all speed sensors to be upgraded to the new circuit, although due to a lack of spare units, it was necessary to wait for sensors to be returned for repair before the upgrade could be effected. Under the heading of 'modifications' also comes the topic of reselection of suppliers: after the experience of incorrect unit components being delivered, it was decided that future orders would, if at all possible, be placed at one casting/metalwork manufacturer, allowing the progress of orders to be monitored more easily, and assisting the early correction of errors.

9.5. EXTENDED FIELD TRIALS.

Four full production prototypes were 'put to work' on the Buttewell site in July 1984. Their progress was carefully monitored, although the truck operators were not informed that the sensors differed from Aro-based units. Some intermittent problems concerning interference near bucket cranes was still experienced, so the screening of low-level signal cables was improved and the system gain reduced. No such problems were noted after modification. In November 1984, one unit was returned having sustained severe rockfall damage: the 5mm thick aluminium side plate (located firmly by twelve screws) and one 6mm thick steel mounting bracket, were badly bent. The unit, however, was found to be functioning perfectly!

The robustness of the new PCB has been demonstrated by its incorporation into all old Aro units: of twenty-five units so modified, none has been returned with a circuit-related fault over a period of seven months. Comparing faults on recently returned Aro units with typical returns two years earlier (see section 3.4.2) showed all present faults to be microwave transceiver or antivibration mount based. The average lifetime is now some three months.

A further ALBERT system problem of a more generalised nature was found when discussing driver reaction to the speed sensor. Unless an OEL fitter is present on-site, drivers feign unit problems and have the unit switched off. Not only does this result in many trucks operating with no speed sanction (and no externally visible indication of this fact is fitted), but also checking each truck produces a significant amount of work for the OEL fitter. The requirement for an external indication of system disablement is thus strong. In this light, the minimal sensor system, as proposed in report P28, gains credibility.

In February 1985 the test trailer facility was lost following the sale of the car fitted with a towbar.

9.6. THE FINALISED DESIGN.

In September 1984, after almost three months of field trials, the pre-production sensor unit was considered robust and accurate enough for the design to be frozen. This final design is illustrated in Pic 7 and 8: fig 9.3 provides a component identification key. A block-diagram of the circuitry is given in fig 9.2: the basic unit consists of PCB one and two, the latter being necessary until OEL redesign the control board interface. PCB three is an option available for future applications where terrain roughness or a different vehicle (eg a truck with a soft suspension) necessitates validation of a detected alarm. The alarm speed switch option, either manual or automatic, is available for present or future applications. These diagrams, then, provide an overview of the constructional and electronic aspects of the culmination of the speed sensor development work: the finalised pre-production prototype. The detailed story of the evolution of this design is covered in depth in chapters 3,4,7 and 9. Technical detail, in keeping with the general format of this thesis, is located in the company reports in volume 2, section 2 (notably reports P3,7,15,17,18 and 20).

In March 1985 the site operators reported a significant reduction in truck queuing time, and an improvement in truck downtime and site safety due to the incorporation of the speed sensor and sanction system. Some problems were encountered, however, with horn unit accuracy in very wet conditions (such conditions had not occurred in the previous several months, and the circuit parameters responsible for maintaining performance in such climatic extremes had to be estimated). However, this problem only requires the modification of one resistor value. In such extremes of weather, truck speed usually reduces to below alarm speed, so this failing is not major.

The accuracy of the new unit, and of the upgraded Aro-based sensors, is much improved over the conventional Aro-based sensor. For the upgraded Aro unit, alarm speed is now held to 22-23 mph systematic, compared to the previous 21-25mph; and terrain or climate variability error is reduced from +-1.5mph to +-0.5mph. Site trial-derived reliability figures show a MTBF improved from six weeks to three months including antivibration mount fatigue, or greater than nine months exclusive. The production prototype sensor has a systematic alarm speed range of 22.5-23.0mph, with no terrain variability error (

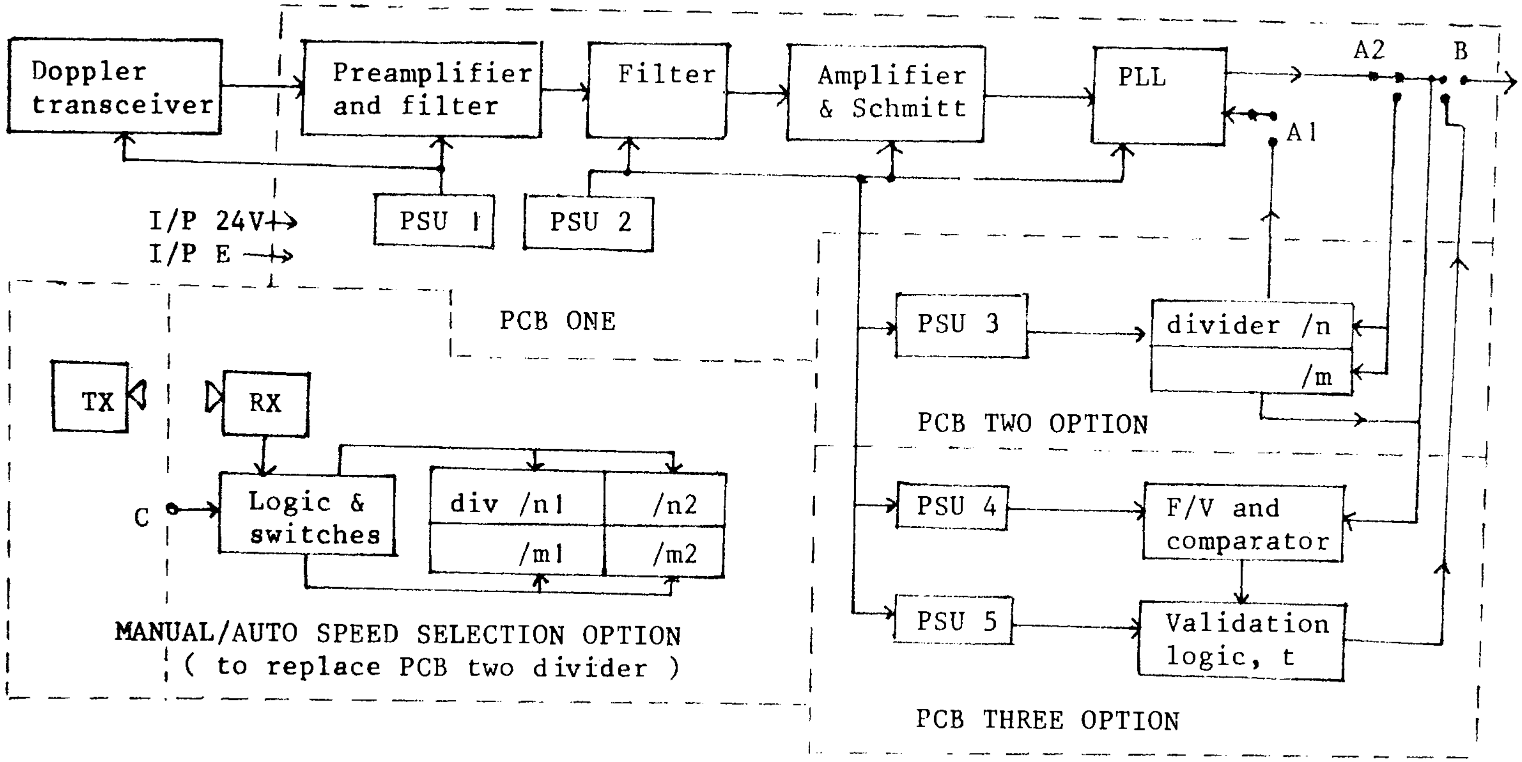
excluding torrential downpour conditions as noted above) and robust, with a longevity at the time of writing of at least ten months.

9.7 RESUMÉ

The modified Aro-based sensor is now more accurate and reliable, and the production prototype sensor has proved to provide an extremely accurate indication of truck overspeed irrespective of weather conditions, or terrain profile or construction.

After a review of the practicality of manufacturing the new sensor unit, OEL have stated that mass-production should commence simultaneously with a new man-detect radar sensor unit, currently being evaluated (July 1985).

This chapter has dealt with the final steps in the sensor development and assessment. Chapter ten continues by discussing the project outcome in greater and broader detail.



BLOCK-DIAGRAM OF THE BASIC SPEED SENSOR CIRCUITRY FOR THE PROTOTYPE UNIT.

The prototype horn unit (which formed the basis of the site trials) **comprised PCB one and two**. For commercial reasons, the circuit diagram is **not included**, although numerous reports (P3, 7, 11, 17, 18, 32) describe the circuitry in further depth.
For the Aro unit, PCB 1 only is used, with modifications to circuit gain, filter frequencies, PLL damping.

NOTES:

1. If PCB 2 fitted, output is a squarewave fed to the control box F/V. PLL damping on PCB 1 should be increased. For Aro-compatible O/P, n=15 and m=16

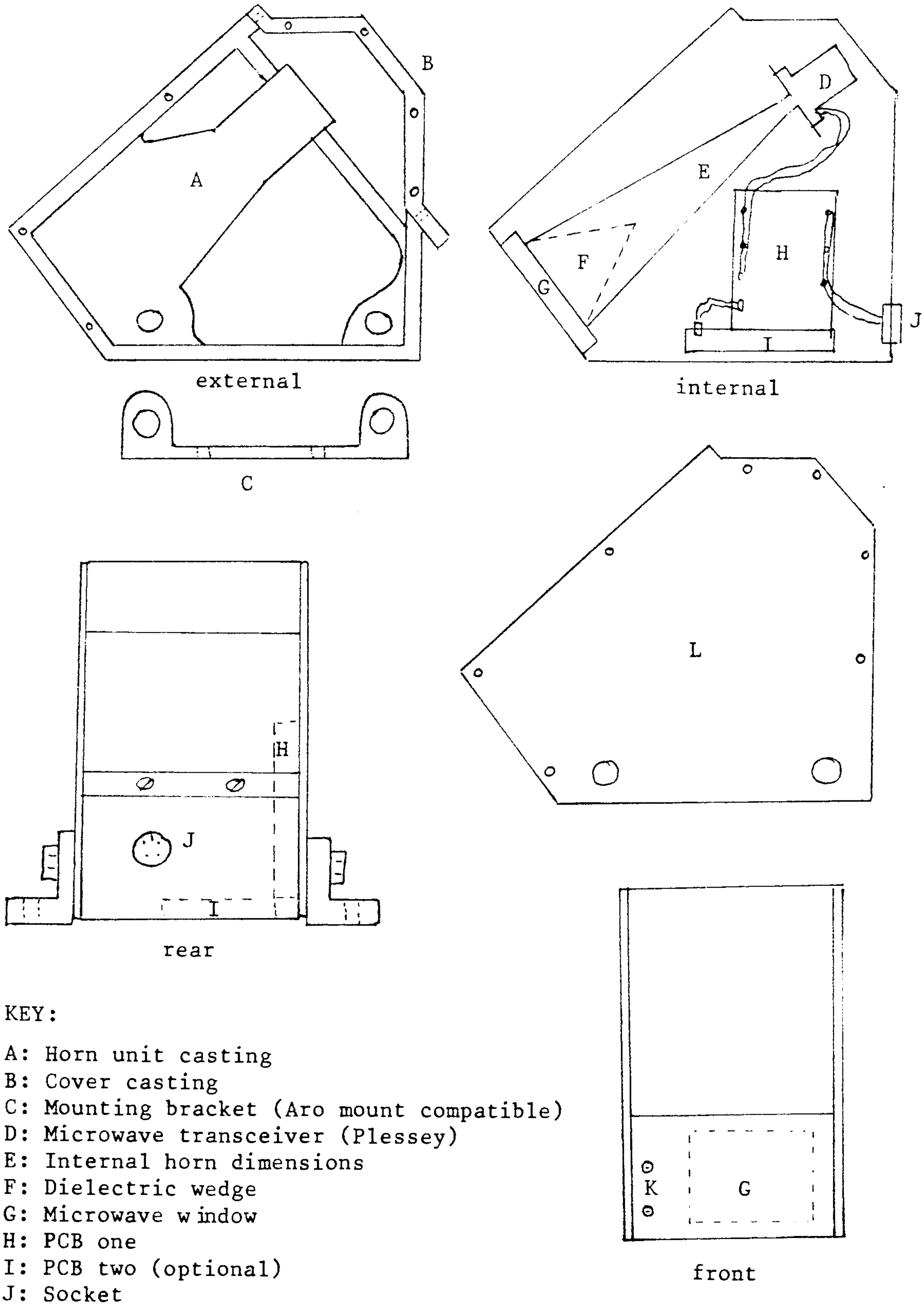
2. If PCB 3 fitted, output is a DC voltage fed to the control box comparator. PLL damping on PCB 1 should be decreased. For site use, t=1 second.

3. If PCB 4 fitted, divider ratios are set according to the required alarm speeds (see report Int P17). TX and RX can be ultrasonic, infrared or radio.

4. Switch A selects PCB 2, Switch B selects PCB 3.

5. I/P C is manual over-ride

FIG 9.2



KEY:

A: Horn unit casting
B: Cover casting
C: Mounting bracket (Aro mount compatible)
D: Microwave transceiver (Plessey)
E: Internal horn dimensions
F: Dielectric wedge
G: Microwave window
H: PCB one
I: PCB two (optional)
J: Socket
K: Indicator LEDs
L: Side piece

FIG 9.3

PRODUCTION PROTOTYPE SPEED SENSOR: Simplified construction details.

These drawings are not to scale. Full production drawing reference numbers are located in appendix 3.2. See PIC 7 and 8 for photographs. Five such units were constructed.

HORN UNIT DOCUMENTATION PACKAGE.

1. General specification (including 'external' specification)

2. Component and assembly listing of component type, value, tolerance, quantity, supplier, price (1 and 100 off), alternative components and suppliers

3. Production test schedule ('Go/no go')

4. Full test/repair schedule (diagnostic)

5. Full environmental test schedule and climatic category modifications

6. Full circuit diagrams of basic unit and all options combinations

7. Full drawings of basic unit and all option combinations

8. Series of reports outlining the design philosophy, lab and site assessments of: PLL, validation logic, simulator board, alarm speed selection (manual and remote), circuit modifications, calibration accuracy

9. Series of backup reports on microwave legislation and safety, the off-highway environment, beam geometry, competitive products, microwave units and windows etc.

10. Set of data recordings and graphical representations of relevant laboratory, road and site data.

DOCUMENTATION PACKAGE FOR MODIFIED ARO UNIT

As above, but

2. Electronic component listings only

5. Not available

8. Includes anti-shock and vibration measures

DOCUMENTATION PACKAGES FOR THE ARO AND PRE-PRODUCTION PROTOTYPE HORN UNIT; AS SUPPLIED TO OEL.

FIG 9.4

PIC 7

PIC 8

PIC 7: Production prototype speed sensor unit: view with side removed. This unit is fitted with the optional PCB 2 (frequency divider) visible to the bottom of the unit. The foam padding has been removed from the case.

PIC 8: Outside view of the unit. The 'signal present' and 'power applied' indicators can be seen on the front face of the unit. The brackets fitted are for a CAT 777.

10

CHAPTER TEN

DISCUSSION AND EVALUATION OF THE PROJECT.

"Science may proceed from fact to interpretation, or a tentative interpretation may be tested by facts. Any scientific system must be composed of empirical data and its interpretation. "

B B Wolman
Contemporary theories and systems in Psychology.

CONTENTS

SECTION

FIGURES AND TABLES

10.1 INTRODUCTION

This chapter evaluates the work performed during the course of this project by presenting a review of the achievement of objectives, discussing the outcome, and highlighting the contribution to the existing body of knowledge. Let us commence with an overview of what can reasonably be expected from the project.

Research results are, in general, quantitative. It is difficult to measure the effectiveness or 'productivity' of research, since its output is usually knowledge rather than the more tangible benefits of other business functions. It is reasonable, for this chapter, to divide knowledge into two related categories: knowledge directly serving the objectives of the research, and knowledge gained incidentally in performing the research. Perhaps the only outcome of interest to the pure researcher is information which was previously unknown (irrespective of the impracticality of putting that knowledge to use), or is radical in outlook. However, research within an industrial organisation is rarely aimed at creating new knowledge: it will usually seek to apply existing external knowledge to the activities of the organisation in an original way. This project, as with most IHD TT projects, places the emphasis firmly on applied research. Thus this chapter will deal with both the contribution to the 'body of knowledge' pertinent to the subject-matter; and the benefits to the company (such benefits as: a greater knowledge-base, experience of the 'hands-on know-how' type, etc).

As reviewed in some depth in chapter five, the concept of speed measurement by radar is not new. Indeed, several decades have passed since the first experiments. However, work performed by researchers in the field can be summarised in the following sequence: collate selected previous findings, build a laboratory prototype, test, and report results. This approach is, in the writer's view inadequate. It does not attend to the fundamental problems of speed measurement by radar;

namely a lack of knowledge concerning backscatter, platform and beam geometry, and unit construction. It does not attack the specific problems of the vehicular environment, or the difficulties in coping with varied and severe terrain types. But most seriously, it does not adopt a commercial approach to unit development and testing. So, whilst groundspeed radar are not novel, the specific procedure adopted within this project (the research, development and production of a commercial product) is. Indeed, specific conclusions drawn from the work performed contradict accepted design thought: these points are described in detail later.

It would be wrong to underestimate the importance of the 'final product': from the company's point of view such an outcome is highly desirable, but the real achievement is the long process of identification and solution of minor problems which prevent the more immediately obvious means of achieving the desired result. Such problems are discussed at numerous points in the text, but can include such factors as: a lack of truly relevant data on the types of radar utilised, the circumstances of their use (including environmental factors, specific application data etc), and the effect of rigid design parameters and limited resources on the desired outcome. Consequently, the reports written as part of (and as a byproduct of) this project, do form, in terms of information, the central body of the thesis. Examples of such information are: new knowledge, data gathering, collation, processing and utilisation.

This chapter will first examine the project methodology, considering such aspects as timescales, compatibility and test schedules; and then continue by reviewing the achievement of objectives, including an assessment of the information presented to the company, a detailed examination of the final product, and an estimate of the potential financial savings.

	October – January	January – April	April – July	July – September
YEAR 1 1982	Familiarisation with company Project definitions	Project redefinition Doppler radar familiarisation Patent search	Project redefinition Literature search	Examine existing design of sensor Prototype mods Literature review
YEAR 2 1983	Ground return measurements Beacon design Prototype sensor designs	Examination of spectrum effects Site tests Circuitry redesigns	Spectra plots Modify prototype Full site tests	Build recording equipment Make measurements Design PCB's
YEAR 3 1984	Design PCB 2 Design configurable sensor system	Build modified horn prototype Locate component suppliers	Construct pre-prodn unit; test and modify Select final prodn components	Test production unit on-site. Select final component suppliers

A full chronology of project progress appears as appendix 3.
Extended field trials were commenced until March 1985.

PROJECT PROGRESS: MAIN LANDMARKS AND DATES. FIG 10.1

10.2 PROJECT METHODOLOGY.

10.2.1 Measurement and test.

Due to the limited resources of OEL (see fig 3.1), all measurements, design, calibration and testing of all equipment often presented problems. Such difficulties were overcome by the adoption of carefully selected cost and resource-saving procedures designed to minimise any detrimental effect on either the measurement accuracy or on the time required. Such methodology does not lend itself to easy description on paper: its very nature is one of adapting to circumstance. The outcome of the application of the method can, though, be more tangible. For example, in order to measure signal amplitude whilst travelling in a vehicle, a data recording system was constructed by using a home-designed interface unit (see report Int P11, volume 2, section 2), a control box modified for autocancel operation, an old briefcase, an analogue meter and a stereo tape recorder. In order to account for this rather basic experimental arrangement, two reports (P6 and 26) were produced to explain and illustrate the means of data interpretation. Calibration curves and example outputs for the recording system appear in section 1.1 of volume 2. Fortunately a spectrum analyser was available at the time of processing this data, and the technical manager possessed a UV recorder. Thus, an outlay of just over £100 provided the capability to record the returned radar signal simultaneously from the preamplifier, Schmitt stage, post-PLL etc, and to reproduce meaningful data in either spectrum format, averaged signal amplitude plots, or frequency tracks.

Further tangible outcomes of maintaining an awareness of available resources were the form of the test specifications produced for the sensor unit. These two specifications were designed to require only that equipment available; the full development test spec (report P23) allows unit faults to be identified and repaired; and the production test spec (report P30) provides a short, although comprehensive, final check for post-assembly QA. Both use a 'sequential inclusive' philosophy whereby equipment reconnections during performance of the tests are minimised. Such a technique was adopted partially because time is saved with no commensurate compromise in measurement accuracy, but mainly due to the oversensitive nature of the available laboratory equipment which regularily decalibrated itself at the slightest opportunity. Due to these problems, an acceptable tolerance range for each measurment is specified on both test procedures. The full environmental test (int P24) includes a full specification assessment.

At several points within the thesis text, reference is made to JMS, and OEL in the early days, failing to appreciate the need for realistic in-situ testing. The work throughout this project was, at every available opportunity, tested by means of car and site trials. If, as was often the case, these are infeasible, suitable carefully designed laboratory simulations were devised (for example, the vibrator test bench: report P13). Such simulations require assumptions to be made concerning the nature of the situation to be reproduced. The assumptions in this project were derived from an amalgam of site experience and 'theoretical assessments and evaluations'. So, for example, to ensure laboratory tests catered for the environmental problems encountered on-site, time was spent ascertaining the extent to which such problems can be quantified. The ensuing report (int P24) thus allows reasonable laboratory simulations to be constructed, taking into account factors such as appropriate temperature and humidity ranges, voltage fluctuations etc.

10.2.2. Timescales

Throughout the duration of the project, emphasis was placed on acquiring resources in such a manner that each resource was available as, and when, required. As a small company cannot afford 'look ahead' resource allocation, this procedure was carefully, indeed sensitively, handled. For example, components were purchased in small batches one week before their utilisation. With the number of orders for sensor components totalling around one hundred per year, timing in the placement of orders was crucial. Attempts to convince OEL of problems induced by delayed component orders was not fully successful: this topic is covered later.

The general problems of planned versus actual timescales were apparent throughout the duration of the project: much of the time, balanced progress derived from a combination of the writer's overenthusiasm and the industrial supervisor's overcautiousness: looked at positively, this was indeed a symbiotic relationship. However, both attitudes were equally affected by external events, and for example, a delay of three months for a certain crucial component had a major impact on planned progress. Such an event does not merely shift project milestones back by the duration of the delay, but forces parallel activities out of step, and diverts attention and resources. Many such delays occurred during the course of the project. For example, a delay in the placement of an order for the new sensor PCB meant both that the new unit could not be developed further, and that more time had to be allocated to the maintenance of the old PCB's. Development work thus ceased until the delivery of these boards.

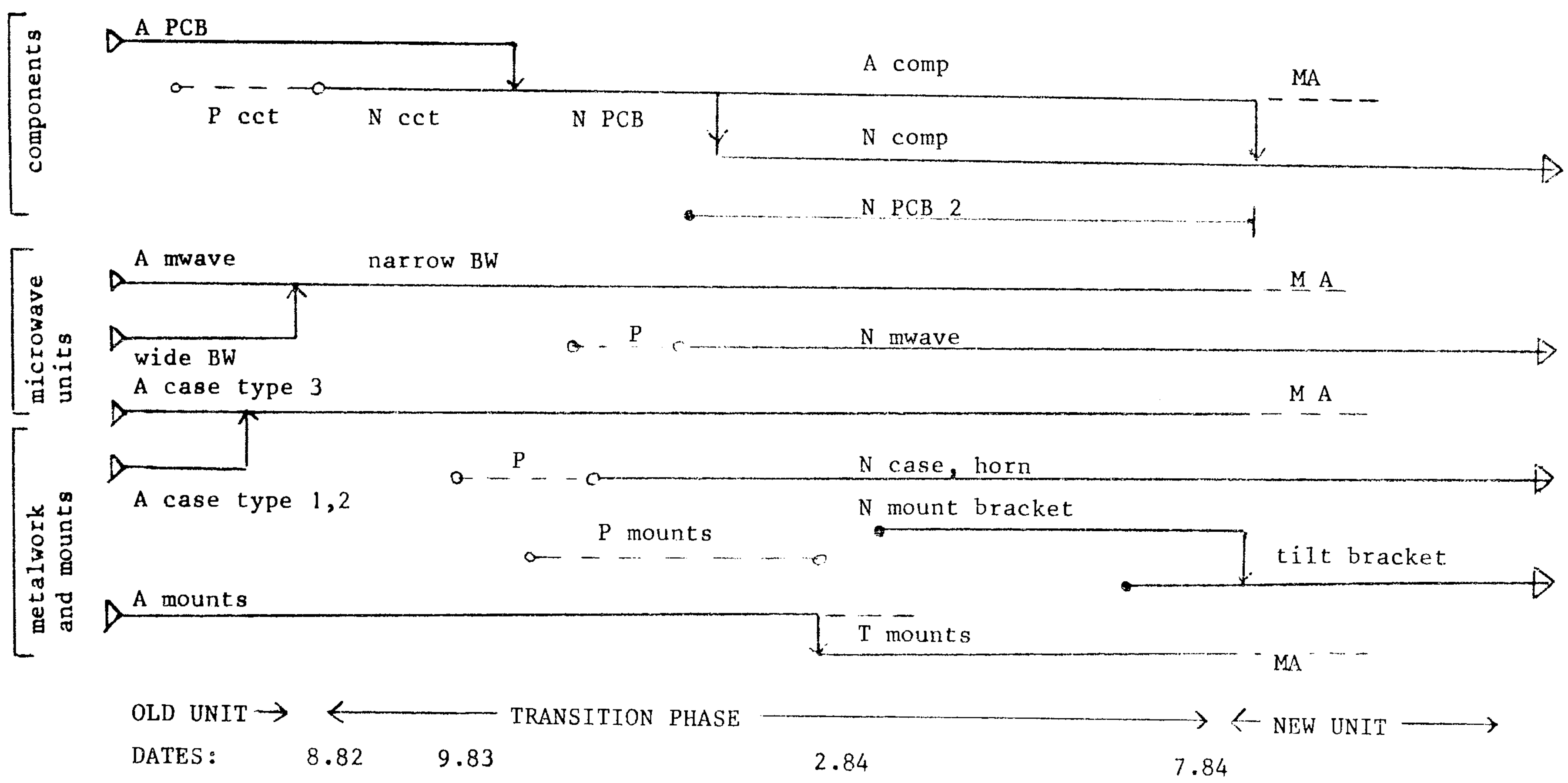
Within the heading of timescales is also included methods of reducing development and production delays. The company possesses large stocks of electronic and mechanical components, but mainly suited for unused, or even obsolete, products. No general reservoir of development components were held. As explained in chapter eight, the procedure for ordering components was lengthy, often extending to several weeks. The writer's attempt to introduce a stock of suitable components was met with some resistance, so as a compromise a basic stock was built up over several months. In the event this stock became depleted during the first prototype development stage, and the long process of continually renewing these stocks began.

This problem was not limited to development stocks: production components also proved difficult to obtain. As discussed in chapter eight, the writer resorted to his personal credit card in order to ensure the supply of urgently required components. The same attitude pervaded development and test equipment: during the course of the work, no such equipment was purchased, even though some basic and cheap facilities were urgently required; for example, a test meter.

Mention was made above of the attempt to convince OEL of the need to maintain credit accounts with suppliers, and to possess adequate equipment and component stocks. Such attempts failed. Stocks are still not kept, and no suitable test and development equipment is available at the time of writing. Perhaps the use of the credit card, ironically , assisted this state of affairs: that is, although OEL accepted in theory that orders must be placed and paid-for, they happily allowed the writer to circumvent their involvement in the ordering process. And similarily with equipment: as any planned laboratory work had to be organised using only that equipment available, OEL would seem to have adopted the view that therefore the available equipment, effectively, was adequate!

10.2.3. Compatibility and timing.

A small company producing one product, be it comprised of several modules, is in a difficult position when redesigning one module: product integrity must be maintained throughout the transition. Thus, at all times, great emphasis was placed on ensuring compatibility of past, present and prototype designs. As explained in section 8.3.3, this often involved taking one 'backward' step in order to achieve two 'forward'. For example, all test circuits had to perform, at least outwardly, in a manner identical to the old design: this meant reproducing some failings of the old design. For example, the velocity-to-frequency ratio of the old unit had to be simulated in order to maintain consistency of alarm speed. This was achieved using a sec-



Abbreviations: A: old unit (Aro) comp: components T: temporary cct: c ircuit mwave: microwave transceiver M: maintenance of... P: prototype N: new BW: beamwidth

<u>THE TRANSITION FROM THE OLD SENSOR DESIGN TO THE NEW HORN UNIT: TIMESCALE AND INTER-RELATED DEVELOPEMNT PROCESS.</u> The necessity to maintain the old units whilst both designing and testing the horn unit resulted in a complex problem of timing development and allocating resources. <u>FIG 10.2</u>

ondary circuit board incorporating a frequency multiplier fitted to all 'transition phase' sensors (ie all old units upgraded with the new PCB, and all prototype horn units). Further, this new circuit board had size constraints dictated by the case dimensions of the old design, its componentry had to be compatible with both types of microwave transceiver, run off the same power supply etc. A further example is that of fitting compatibility: the new case had to be capable of location into the mounting holes of the old design, although such a position was not ideal.

Indeed, the test of the successful outcome of this procedure was that the customer on the test site was unaware that the production design had changed until the final preproduction unit was fitted.

A further aspect of unit compatibility is that of development timing. The stocks of old units depleted rapidly during the course of the project: one by one its constituent components could not be replaced: the component boards failed, followed by the microwave heads, mounts and cases. At each point the contingency plans for ensuring continuous supply of old units had to incorporate the present and future state of the new design. Thus when stocks of the old component boards had been depleted, the new PCB had to be available and be compatible with the old and new designs (although specific components and values differed). Fig 10.2 illustrates the development timescales: this indicates the interrelationship of the various design stages during the transition period.

10.2.4. Future options.

It is inevitable that, in the course of the commercial product development process, alternative outcomes will be considered. Any fully exploited development process will probably have many such outcomes: only by balancing these alternatives can the correct one be selected. In the case of this project the required outcome was predetermined and specific. However, variations on the theme are possible, and several were considered in depth. The three most useful are the 'minimal sensor system' (report P28): a stand-alone sensor that does not require a control box; the 'configurable sensor' (report P17): a sensor with variable alarm settings, either preset or automatically switched by beacon (report P7 and P32). The latter system has been tested in prototype version and would seem to function according to requirements. The MSS system is a reduced version of the full system, and thus not surprisingly, works well. General improvements and modifications to the sensor unit are detailed in report P36.

10.2.5 Company Structure and Attitude.

The management structure of OEL pervaded both day-to-day and policy decision-making during this project to a significant extent. Chapter eight deals in some depth with the problems met by the writer, and attempts to provide both an insight into the difficulties caused by this structure and attitude, and a review of possible measures to remedy such problems. This work will not be repeated here; but it is pertinent at this juncture to briefly review the generalised conclusions of this work.

Throughout the course of this project, it became clear that successful product development relies on more than a 'sympathetic' company structure and attitude: it requires active management and resource support. Further, the exact form of this support must be specific to the company product, management and resources. In consequence it is crucial that a company such as OEL, formed to manufacture a specific product, must possess a technical and commercial management structure that uncompromisingly reflects the optimum format for that product. Innovation inevitably requires, indeed demands, a great emphasis on the acquisition and allocation of resources. In the case of this project, such backup was not forthcoming. This is not a criticism: as highlighted in section 1.1.3, OEL had little choice but to abruptly adopt the role of a development unit; and the fact that the company is still in existence bears testimony and tribute to it's commitment and ability. Perhaps this very determination to survive precluded further adaptation. The outcome of this situation, however, from the viewpoint of this project, was to limit both the scope and depth of the innovation process.

The problems of innovation in a small company are reasonably well documented (refer to chapter eight). But such case-studies and analyses do not include situations in which the company format and attitude are unsuited to the product development and/or manufacture. Indeed it has not been possible to compare and contrast the progress of the company, the product, or the course of this project with similar case-studies. Comparisons, however, would be of limited use: company/product scenarios differ greatly; and OEL is certainly unique in several aspects (eg possessing no direct competition, there exists a great demand for the intended product almost irrespective of the asking price). Indeed, the more generalised difficulties of innovation may well cast light on exactly why no competitive product exists. Conventional developmental procedures based on theoretical design and laboratory assessment are simply not adequate for off-highway radar and electronic applications, as insufficient data exists to provide a suitable starting point. The only solution in such circumstances (and the one adopted for this project) is the time-consuming process of on-site data gathering allied with literature searches and extended laboratory evaluations. For a company of any size and structure, the available resources must be planned carefully to allow such a developmental procedure to continue smoothly. Such resources include access to test sites, and knowledge of the intended application: resources that OEL possess. Hence data gathering and laboratory work can commence. It is conjecture perhaps, but a larger company would lack this information, and hence expend time and money in a fruitless, although comprehensive, laboratory development programme.

How does company structure and attitude affect project development? A detailed answer would require a full chapter; so in brief, both direct and indirect consequences are apparent. Timescales, for example, become dependent upon factors such as the lack of component stocks, delayed procurement decisions and scarcity of suppliers offering credit. Development progress is determined by the availability of test equipment and resources. Value engineering regresses to cost-cutting etc. Such bare conclusions, it is acknowledged, are contentious, and should be considered as the compression of the salient findings of this project's progress.

This thesis, then, provides a reasonably detailed case-study of the progress of product design and development in a non-optimal commercial environment.

10.3 ACHIEVEMENT OF OBJECTIVES.

10.3.1 Introduction

The main objective of this project was the development to production readiness of a commercially and technically viable product within the constraints imposed by the company's existing product range, technical understanding and resources (in terms of equipment, finance and manpower). This has been achieved. Development of the end-product, however, has served as a vehicle for a far broader project objective: the passing on of information. Within the definition of information is included the necessary drawings and data required to reproduce the sensor design, the information needed to best utilise the design, details of variants and modifications, servicing, repair and test (the documentation package for the sensor is listed in fig 9.4). But further, this information also covers such topics as details of competitors' products, literature reviews of directly and indirectly related topics, details and results of experiments performed in the course of the project, general information relating to the project background, and importantly, reporting to the company on perceived problem areas in management, etc; and the timescales viewed and compared from 'at the time' and with hindsight. This seemingly complex mass of information falls into three broad categories: general information to the company, the product, and data analysis. These categories will now be examined in greater detail.

10.3.2 Information to the company

As discussed in section 3.3, one intention of the project was the presentation of information to the company throughout the period of the project on almost all aspects of speed sensor design. To some extent this was a process of collating existing knowledge: no previous discipline or single body of knowledge covers even a minor part of the required information, and indeed this collation may be said to generate areas of knowledge. Examples of such areas are: the environmental testing of off-highway electronics, low-cost signal processing etc. However, gaps in this collation process were very apparent. No work could be traced, for example, on microwave windows, suitability of transducers in adverse environments, means of rationalising pulse-trains cheaply etc. Such topics thus became the basis of the reports presented to the company. This section provides a resumé of the contents of these reports (located in volume 2), and indicates very briefly possible contributions to knowledge.

Reports P3 and 7 deal with returned signal processing, and by examining a typical signal and categorising the main factors having a bearing of the quality of the signal, show how several factors cannot be eliminated at source and why a means of both rationalising such return and of preventing invalid or missed valid alarms must be sought. The former paper proposes a simple technique utilising a PLL IC which improves signal consistency. The latter reviews several techniques of invalid alarm prevention and highlights one simple method using a few logic and timing components. A combination of both techniques is shown to interpret corrupted data very accurately. Report P11 lists the design requirements for a unit capable of demonstrating the sensor circuitry and modifications, and of allowing recorded data playback for laboratory simulation. The simulation of site shock and vibration is covered in report P13, which also describes the nature of site shock loading, and evaluates the effectiveness of several mount types.

Reports P15 and P26 deal with the derivation and utilisation of data: the former derives expressions for scanning and fluctuation noise and provides a graphical interpretation of the consequences of each for a given beam and platform geometry. Scanning noise is shown to be negligible for typical systems, and that fluctuation noise increases with tilt angle. P26 summarises the need for quantifiable data on sensor return signals and lists those factors thought to affect the quality of these signals. Following the description of means of collecting suitable data, the methodology of data processing is described in detail, and a simplified example given.

Several reports review circuit or unit features. P17 outlines the requirement for a frequency translation module and describes a technique for realising this function using cheap, readily available IC's. A means of remotely selecting preset frequency shifts is given, with example circuitry. The compromises necessary for site use are discussed, as is the requirement for such use. Report P32 describes several means of realising a practical beacon system for remote speed selection, concluding that coded infrared or logic ultrasonic systems show most promise. Report P18 establishes the theoretical and practical design considerations for microwave horn, transceiver and case design. Several means of optimising horn gain and beamwidth are given, with a proof of optimum design being a large azimuthal and narrow elevation beamwidth, based on isodop constructions. Several textbook definitions of beamwidth and gain are compared in practice, and a suitable design compared. Means of improving horn performance by selecting vertical polarisation and antenna/lens additions are discussed. It is shown that a cheap and simple dielectric wedge can significantly improve sidelobe suppression. Factors to be considered in horn casting and material selection are also reviewed.

Simple means of altering transceiver beamwidth are also identified in report P19, which evaluates the effect of numerous lens types on beamwidth and power using an Aro unit, and concludes that cheap, practical lenses are both possible and desirable.

Report P20 lists the considerations in selecting a microwave window, and describes tests suitable to ascertain the optimum design and material. Positioning and construction of the window were found to be crucial for best performance, although it is shown that a cheap half-wavelength plastic slab is a good compromise.

Report P24 examines the off-highway environment in terms of temperature, humidity, shock and vibration, and electrical parameters; and illustrates the difficulties in the application of radar and electronics in such an environment. It is shown that extremes of operating conditions must be considered, and means of achieving protection are given. The effects of terrain and truck geometry on speed measurement are quantified: such effects are shown to contribute up to 25% error. A full environmental test schedule is given. Report P21 shows that measurement error using magnetic sensors is unacceptably high, and such techniques are ill-suited to the site environment.

Report P12 examines products that pose competition to the complete system, and reviews the market potential of such a system. No real competition is identified, and potential sales are seen as vast. An altenative sensor configuration is suggested in report P28, which outlines the benefits of speed enforcement without using the truck retarder, including cost and safety. Report P27 examines legislation concerning microwave radiation safety levels and recommends measures to improve safety with specific respect to the speed sensor.

At the time of writing, several reports have been used by the company for design work on other products: P18, 20 and 27 formed the basis of the design for a new man-detect horn unit and window; P19 was used to assess the re-wiring of old Aro units; P22, 23 and 30 were used as a guide for the writing of a test specification for the man-detect unit.

The documentation packages provided for both the modified Aro sensor and the Horn unit are summarised in Fig 9.4. Included are a full set of general, production, diagnostic and environmental specifications, circuit diagrams and drawings, and complementary data on associated topics.

10.3.3 Data Analysis.

Chapter six discusses the findings of the data analysis both in terms of directly useful information, and in comparison with 'accepted' research findings. Specific findings will not be repeated here, but a comparison of findings with the 'body of knowledge' and a general resume of findings thought to contribute to this field will be given.

All figures referenced in this section bearing no chapter prefix can be found in volume 2, section 1 (data recording graphical results: prefix 'D').

10.3.3.1 Backscatter. The findings of spectrum, amplitude and phase null changes with tilt angle correspond with the general consensus in appropriate literature (exact assessments of the relevant literature can be found in chapter five and twelve). They are also in agreement with Cook (1972), DeLoor (1974) and Lundien (1966) etc who found backscatter to be dependent upon surface moisture. Vertical polarisation was found preferable, in agreement with Hyltin (1973) and Cosgriff (1959). The relative importance of surface and subsurface on the quality and quantity of returned signal is, as stressed in the literature review, not reported by the major researchers. Several references, however, note the consequence of 'moisture saturation': Clarricoats (1977) reported that wet sandy soil produces a signal one-twentieth of that from the same material when dry. This, and other similar findings, is in contradiction to the results of this experimental work. Indeed the writer found no surface material that returned less signal when wet.

Backscatter amplitude from typical off-highway terrain cannot be compared to any reviewed work, as none was traced. Several writers give amplitude versus tilt angle results for tarmac, concrete, and sand (eg Cosgriff, 1960: see fig D13), but the terrain is considered in a macroscopic manner. Nevertheless their findings correspond well with the results of this chapter to the extent that the returned amplitude diminishes with a shallowing of tilt angle,with minimal amplitude deviation in the 30 to 50 degree range. Fig D59c provides an indication of the general trend of tilt angle versus amplitude and spectrum centre frequency; and fig D59b exemplifies the general trend of spectrum shape for a range of terrain smoothness.

<u>10.3.3.2</u> Beamwidth The narrowing of the spectral peak with decreasing beamwidth is a well-documented effect for homogeneous terrain. This relationship was borne out by the experimental results. However, the general consensus is that both E and H plane beamwidths should be made as narrow as practicable. Results from such a philosophy are illustrated by the TRW spectra and waveforms (figs D44 and D70): the main spectrum peak is indeed narrow, but the beam 'hunts' discrete regions within the nominal footprint. The H plane beam widening, as illustrated by the prototype and production horns, show a smoother, more defined spectrum and significantly less beam hunting, due to an averaging of return in a plane where deviation from the nominal beamwidth centre does not detrimentally affect the ratio of target velocity to returned frequency. It should be stressed that this 'hunting' phenomenon is not the same as scanning noise, which, although

producing a similar result, is generated by a different mechanism. It was found that this widening of the azimuthal plane, far from increasing fluctuation noise as predicted by the texts, reduced out-of-beam interference to almost zero. This is, in part, due to the suppression of E plane sidelobes by the foam wedge, whilst other proprietary and reported units utilise an E/H plane lens.

In conclusion, the production horn unit represents a favourable compromise between size and performance. It compares well with both other production units, such as the TRW design, and experimental results in the literature.

10.3.3.3 Velocity Measurement Accuracy. The accuracy obtained by the major researchers is tabulated in fig 5.11. Before comparisons are drawn with the results derived using the production horn, it must be stressed that most researchers quote results for laboratory condition test runs only. Thus, comparing like with like, the accuracy of 21+-0.5mph compares well with the +-1mph FCC standard. It also equals or betters the typical accuracy of other researcher's prototypes. Indeed, when other worker's designs are examined, it is found that many use, for example, transmission frequencies of 60GHz. This allows the horn dimensions to be reduced by a factor of six for no decrease in performance (this frequency is illegal in the UK at present). Bearing this fact in mind, the production prototype unit measurement accuracy exceeds those of comparable units.

10.3.3.4 Site Terrain Simulation. No literature is directly comparable here. Simulators reviewed in the main literature review are all laboratory-based. However, the test trailer was confirmed to be a laden truck on a typical site haul road. It is conceivable that if more 'solid' tyres could be fitted, the trailer may simulate an unladen truck on rough terrain successfully.

Simulation of terrain material types is not possible, although approximations can be made. There are, however, no generalised rules in this simulation. If, in certain weather, a specific section of non-site terrain performs similarily to the required type of site terrain, then measurements can be made. The fact, from experience, that this is not always possible, makes the existence of a library of typical, generalised, data recordings (from all types and conditions of surfaces) an essential facility for the company.

10.3.3.5 Discussion. It is crucial, for speed measurement by radar, that subsurface irregularities are acknowledged as contributing as much, if not more, to the returned signal characteristics as the visible surface. Indeed, in many circumstances the subsurface construction is the overriding influence. The problems associated with non-homogeneous subterrain are best cured, as are terrain macro-feature effects, by a narrow elevation and wide azimuthal beamwidth. For optimum accuracy, sidelobes must be suppressed as much as possible. Tests to ascertain correct signal amplification and filter characteristics must be performed on terrain as near as possible to the intended application terrain. Micro-derived effects are handled by optimum selection of polarisation, transmission power and frequency, and tilt angle. Test results confirmed generally accepted findings of the consequences of terrain surface moisture on the returned spectrum: wet terrain shifts spectrum centre frequencies downward in frequency (similar to the effect of smooth terrain); and the returned amplitude from wet terrain is significanty higher than that from dry.

Care must be taken in selecting 'worst case' conditions in any evaluatory regime: for this project such conditions are: a radar placed on an unladen truck travelling over a combination of undulating rock and dry sand (providing poor signal amplitude and significant spectrum spread and signal breakup); and an unladen truck travelling over a combination of undulating rock and a very wet, dense mud with a heavy rainfall covering (providing large amplitude fluctuations and significant spectrum spread).

Associated with, although not directly related to, spectrum width are signal nulls. The technique of reducing phase-induced nulls is identical to that of spectrum width reduction. Nulls associated with lack or excess of returned signal amplitude require processing electronically: no real benefit can be derived from alteration of beamwidth or frequency etc.

By combining beam geometry with suitable processing it is possible to produce a spectrum derived in 'real' circumstances that resembles a laboratory calibration curve (ie a spot frequency curve usually obtained from a 'pencil beam' beamwidth). It is worth stressing that the factors of geometry and of processing must both be incorporated in a complementary manner: design optimisation of one aspect will not produce a viable design.

Test conditions for prototype assessment must take into account ALL circumstances prevalent in the environment of final use. Hence the test vehicle geometry, suspension, electronic interfaces etc must all be carefully selected. A rigid trailer towed behind a car over pot-holed tarmac was found to present a suitably difficult test for the system, although for meaningful results only one section of such terrain must be used such that the unpredictable consequences of subsurface reflections and surface microprofile are minimised.

The dependency of returned signal on highway and off-highway terrain profile and wetness is poorly covered in the general literature: the published work provides an inadequate basis for the development of a unit such as that required by this project. Factors such as transmission frequency and polarisation are better covered in the literature: the general findings correspond with those of chapter six. Similarily the relationship of tilt angle and amplitude/spectrum was also confirmed.

As discussed in section 10.3.3.3, widening of the azimuthal plane beamwidth provides optimum averaging of return, whilst the elevation plane beamwidth is best narrowed.

The need for antivibration mounts, as demonstrated by the Aro unit, was found to be limited to the compensation of the intrinsic design faults of this type of transceiver. Whilst this unit ceases to peform if the mounts are removed, a more rigid design of horn, case and transceiver highlights no significant difference in performance or longevity when so mounted.

10.3.4 THE FINAL PRODUCT.

10.3.4.1 Unit Performance. This section deals with the more tangible outcome of the project: the new sensor unit. Data recordings on car and site trials have shown the unit capable of relative velocity measurement accurate to within the reading error of the car speedometer. It is thus capable of providing an alarm signal to an accuracy of 21 +-0.5mph over a wide range of terrain types and conditions. By examination of frequency tracks, the accuracy obtained is typically 21 +-0.2mph for 95% of the time. This compares favourably with other reported work (see fig 5.11). Trials conducted over the worst site terrain have shown a frequency output accuracy resembling that theoretically possible (see fig 9.1). Thus, both long and short-term accuracy approaches that attainable in theory.

Extended field trials have shown the unit to be mechanically robust: a rock impact that badly damaged the outer casing and mounting bracket left the unit functioning correctly. No component, external or internal, has shown any adverse reaction to shock or vibration; and the lack of antivibration mounts allows the unit to require no site calibration or maintenance. The unit shape and flush microwave window (see pic 7) also assists in the extension of periodic maintenance by preventing oil, mud or ice to collect on the horn mouth. Further, the driver's trick of disabling the unit by placing mud over the unit window is made very difficult.

The unit is straightforward to manufacture and simple to construct, consisting of two castings, sides, PCB and transceiver. No machining is necessary within the company, and no careful alignment or calibration is required during or after assembly. The two-piece casting design allows the machining of both critical surfaces (the join between castings and the horn throat mounting surface) in one operation. The separate mounting bracket arrangement allows ease of mounting in the conventional position on the truck rear bracket (see Pic 2) or alternative placement in any suitable place using an appropriate mounting technique.

A heavy-duty socket allows both easy unit replacement and test, and prevents ingress of dirt or water. Spare pins are provided to allow future upgrade or modification or offered facilities; connections being available to the power supply, Schmitt output, pre and post PLL, and spare socket pins.

Although much reference has been made to the lack of calibration required, if this is deemed necessary, all internal components can be accessed in-situ by the removal of the upper casting. Thus, the microwave unit bias and Gunn voltage can be measured with no disturbance to the microwave unit or horn. However, this should not be necessary: the horn-window match with the transceiver is excellent (reflecting only 0.25% power, absorbing between 0 and 0.06 microwatts, and pulling the bias voltage down by 0.03 volts) and can withstand a significant mismatch without any perceivable degradation in unit performance.

Access to the circuit boards is provided by removal of one side; and the unit can be stripped down to its constituent modules in approximately four minutes. Exchange of any one module (eg the PCB, transceiver, socket, or wiring loom) can be achieved in less than two minutes. Completion of the production test schedule takes five minutes. Consequently, turnaround time should be minimal both for production and repair.

<u>10.3.4.2</u> Cost savings. One critical aspect of any commercial product is the cost of manufacture. For this project a wider financial view was taken, and the savings made as a result of incorporation of the new sensor design into the company's product range will be assessed. Such figures can only be factual in a historical context, but it is reasonable and useful to estimate the probable savings made over two years. Any such estimate can take account of purely direct financial savings: such intangible and unquantifiable returns as goodwill, increased sales, company image etc cannot readily be assessed. Hence these estimates cater for manufacture and service costs only. As discussed in section 10.3.4.1, disassembly and calibration time of the horn unit is minimal, thus releasing valuable manpower and resources for more pressing needs. Such savings are also not considerd in these calculations.

The savings are calculated in two ways: taking account of present component stocks (components redundant to the existing company product range), and assuming no such stocks. In both cases a cost is derived for quantities of 1, 30 and 100. The estimates are given in fig 10.3. From this table it can be appreciated that the manufacture cost saving is around 35% and the two year upkeep life saving is approximatly 70%.

The component listing for the basic sensor is reproduced as appendix 3.0. This provides ordering information and component pricing, as well as alternative suppliers and current prices.

	QUANTITY MADE	ONE				THIRTY				ONE HUNDRED	
	UNIT TYPE	ARO		HORN		ARO		HORN		ARO	HORN
	INC STOCK (*1)	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO
INITIAL COST	mwave unit	43.50	43.50	30	0	37.00	37.00	28.00	0	33.50	26.00
	PCB	4.00	4.00	4.00	4.00	3.00	3.00	3.00	3.00	2.00	2.00
	components	7.00	7.00	7.00	7.00	6.00	6.00	6.00	6.00	5.00	5.00
	plug/skt	0	0 -	2.00	0	0	0	2.00	0	0	2.00
	antivib mounts	5.00	5.00	0	0	5.00	5.00	0	0	5.00	0
	case + machining(*2)	25	20.00	40.50	40.50	25.00	20.00	36.50	36.50	25.00	30.50
	labour	10	10	10	10	10	10	10	10	10	10
	TOTAL	94.50	89.50	93.50	61.50	86.00	81.00	81.50	55.50	80.50	75.50
FUTURE COST (*4)	new antivib mount	30.00	30.00	0	0	30.00	30.00	0	0	30.00	0
	new mwave unit	43.50	43.50	0	0	37.00	37.00	0	0	33.50	0
	rewiring	3.00	3.00	0	0	3.00	3.00	0	0	3.00	0
	labour (*3)	38.00	38.00	0	0	38.00	38.00	0	0	38.00	0
	TOTAL	209.00	204.00	93.50	61.50	194.00	189.00	81.50	55.50	185.00	75.00
save	unit savings £			115.50	142.50			112.50	133.50		109.50
	unit savings %			56	70			58	70		59

NOTES:

*1Stock Items: refers to those components in stock and not used in any current or planned future product.

*2. Future horn designs would incorporate a cheaper manufacturing technique: figures quoted here are 'worst case'. The casting pattern is also not accounted, being a 'one-off' cost.

*3. Sites are at present located 180 and 250 miles distant from the fitter base. Travel times and costs are not included

*4. The costs are calculated for a two-year upkeep. Calculations based on longer life would siggest even greater savings for the horn design.

ASSESSMENT OF LIKELY SAVINGS TO THE COMPANY IF THE NEW SENSOR DESIGN IS ADOPTED. A PERIOD OF TWO YEARS UPKEEP IS ASSUMED.

FIG 10.3

CHAPTER ELEVEN

FURTHER WORK, RECOMMENDATIONS AND RECAPITULATION.

"Scientific theory only carries
further a process which
scientific common-sense has
already begun. "

C H Whiteley
Philosophy, Vol 34, 1959

CONTENTS

SECTION

11.1 INTRODUCTION

This chapter examines future work that may be of benefit to the sponsoring company, and briefly highlights gaps in the project's contribution to the body of knowledge. Means of improving the 'saleability' of the speed sensor unit are discussed, as although the development unit has proved itself on extended field trials, certain aspects warrant further consideration. The chapter ends by proposing a set of recommendations to the company, and summarises the main achievements of the project.

11.2 FURTHER WORK

11.2.1 Speed Sensor: Optimum Design?

The proposed sensor design fulfills the criterion of accuracy, longevity, practicality and cost. But although it is satisfies the product brief as required by the company, this brief was based on the commercial experience of liaising with only one site operator. No data is available on the specific needs of other potential customers. Such information is necessary either to optimise the design for specific user needs, or to generalise the design based on a representative cross-section of user needs. Specifically, information is needed on factors such as alarm speed, type of sanction, alarm cancel speed, method of cancel, speed switching (automatic zonal or manual), truck type (available space, location or mounting bracket, cable lengths etc).

But even assuming that the unit developed during the project fulfills such needs, alternative designs that achieve the required result are possible, and even desirable. For example, positioning the sensor at the truck centre of gravity offers significant benefits: vertical accelerations are reduced and the unit is protected from adverse environmental effects such as rock damage, oil, dust etc. The unit can be made immune from truck tilt by adopting a Janus configuration, whereby two mircowave units, forward and rear-facing, act so as to cancel the effects of such tilt (cosine bias shift) . The present project could not pursue either idea: central chassis positioning is not compatible with the present mounting shelf and wiring looms, and the Janus technique would place the cost and size of the unit above the present limit.

The possibility of reducing the sensor cost by replacing the aluminium casting, and indeed the whole case, with a metal-plated plastic moulding was considered: such a measure would reduce unit cost by over 25%. Much work would be needed to ensure the selected material and design was both electrically and mechanically adequate, but in principle such a design would seem to be commercially feasible.

Reprot INT P24 includes an extended environmental test. Such a schedule is beyond the resources of OEL, but the writer considers at least part of this test as necessary for both market acceptance of the unit, and to boost company confidence in the unit's ability to survive the arduous conditions. However, due to the cost of contracting out such a test (estimated at around £8-12000), the decision to allocate the resources for a full commercial launch must precede the test schedule. For smaller production quantities, certain licensing is still required specifically Home Office radio frequency approval. For export, the appropriate FCC regulations should be adhered-to. Only after such tests have taken place can further unit development take place, but let us consider several eventualities as examples: if the impact test shows that the outer casing is easily damaged but the internal components still function, the possibility of packaging the internal space inside the case with silicon-impregnated foam should be considered. Thus, even if the outer case is badly bent, allowing the ingress of water and dust, the internal components will be temporarily protected. If the EMI/RFI susceptibility/emmission tests are failed, this foam can be carbon impregnated. If temperature sensitivity is exhibited, however, all components emmitting heat should be moved so as to be in close proximity with the thick casting section of the outer case.

The remote speed switching option has been built in prototype, and whilst the design functions adequately in car trials, a full site test would be necssary to prove the design satisfactorily. Such tests have not been performed to date as the company does not require this facility at the present time. The techniques found to be most promising in laboratory trials, infrared and ultrasonic, have fundamental limitations in the site environment, but the more obvious choice of radio linkage is ruled out at present by both Home Office legislation and site regulations. This situation may change in the future, however, so a close watch should be kept on such legislation.

Further information may be derived on suitable horn designs by the measurement of cross-polarised sidelobes; crude measurements have shown the horn prototype to possess minimal cross-lobing. However, such lobes are of measurable amplitude, and thus this topic should be investigated further using calibrated laboratory equipment.

11.2.2 Data Recordings

Although the recordings discussed in chapter six cover almost all terrain/weather/platform combinations, several inconclusive areas remain. First, no site trials have been performed with a snow covering. It is reasonable to assume, however, that the results will be similar to a heavy water covering. Second, and of greater concern, anomalies concerning fluctuating average amplitude returns are still apparent: this effect is believed to be related to the relationship between absorption and reflection of the surface and subsurface layers. No work could be performed on this topic due to problems with site access and difficulties in test condition repeatability.

It was also hoped to produce a frequency-track recording of a prototype Janus configuration sensor in order to ascertain the contribution of platform tilt to measurement accuracy. Unfortunately, time, money and lack of opportunity prevented this.

11.3 RECOMMENDATIONS TO THE COMPANY

This section briefly lists recommendations to the company. Several of these points are covered in depth in other sections of the thesis.

DEVELOPMENT RESOURCES

- hold a working stock of development components and sub-modules,
- Form an associateship with the local university library, and register with technical, commercial and patent computer databases and information services,
- Purchase the laboratory equipment necessary to provide basic test, repair and development facilities. For sensor work, such a list is: 30V 2A variable metered PSU, sine/sq oscillator with 0.1mV output, 1mV 5MHz 2 channel 'scope, microwave frequency meter (10GHz, 10mW). All other equipment is possessed by OEL.
- Recommission the sensor test trailer and modify the test unit so the vehicular power supply anomalies form part of the unit test procedure.

THE PRODUCT

- Construct a further fifteen units to replace half of the units currently fitted at Butterwell, as a comparative field trial,
- Verify the production schedules (component supply lists, construction details, test and production schedules and specifications) on a production test-run,
- Forward to an approved establishment a sample unit for full environmental testing (including conformance to BR14, FCC 15, SAE J1211, ASTM 117-73, MS217C, IEC44 etc).
- Redesign the control board circuitry (F/V etc) to allow the theoretically correct ratio of speed to input frequency

to be used. Remove the present alarm speed select circuitry

- Assess the possibility, both technical and commercial, of utilising alternative construction techniques (eg plastic horn and casing, Janus configuration sensor etc).

THE MARKET

- Carry out a survey of potential customers and their requirements with regard to the relative importance of cost, size, maintenance, alarm speed, zonal system, speed selection, sanction etc
- Seek new areas of sale eg military, meteorological (rate and speed of rainfall), agricultral (particulate velocity and liquid flow). Further areas look promising, and may be the subject of patent applications.

MANAGEMENT

- Establish and enforce a technique of documenting development, production and test work. Perform data analysis on unit failure modes, repair progress etc.
- Hold regular progress meetings to coordinate optimum utilisation of manpower and resources.

11.4 RECAPITULATION

The aim of this project has been to:

1. Assess the existing radar speed sensor and sanction unit; design and implement an experimental regime intended to extent the unit's longevity and measurement accuracy, pending the design of a suitable replacement unit.

2. Examine the whole topic of irradiation of terrain by X band radar, and radar in vehicular and off-highway applications; electronics in off-highway vehicles, non-automotive Doppler radar, non-radar velocity

measurement and radar parameters. Collate and interpret this information into a practical and useful form.

3. Examine those areas of research that do not appear in the general literature, and perform experimental work in order to provide detailed yet comprehensible information for the company to use in future product development.

4. Examine the company history, past and present management structure, product range etc, and assess the effect of such factors on the progress of the project.

5. Design, develop and prepare for production, a new radar-based speed sensor unit compatible with the company's existing product range, future requirements, commercal and resource constraints.

In conclusion:

The overall result of the project has been the successful development to production stage of a speed sensor unit and the provision of a problem-free transition to full production of this unit.

SUFFIXES

"We cannot identify science with truth;
for we think that both Einstein's and
Newton's theories belong to science;
but they cannot both be true, and they
may well both be false. "

K R Popper
Objective Knowledge (Oxford 1972)

CONTENTS

SECTION

1. INTRODUCTION.

This section contains lists of references for both volume one and two, and a general bibliography. Due to lack of space, the bibliography lists only those books and papers which, although used for a specific purpose during the project, were not directly referenced.
To assist the reader with locating other pertinent information, a list of major journals in each of the major topic headings is given below.

Vehicular Electronics: SAE Journal; IEEE Transactions (Vol VT); ISTA Proceedings (Sweden)

Antennas and propagation: IRE Transactions (Vol AP); IEEE Transactions (Vol AP)

Microwaves: Microwave Journal; IEEE Transactions (Vol MTT)

Airborne Doppler: IRE Transactions (Vol ANE); IEEE Transactions (Vol AES)

Backscatter/terrain: IEEE Transactions (Vol GE); MIT Lab reports; MEXE Lab reports.

LIST OF REFERENCES

Abbreviations found in this section are reproduced below.

ACRONYMS:

ANSI	American National Standards Institution
ASAE	American Society of Agricultural Engineers
ASTM	American Society for Testing Materials
FCC	Federal Communications Administration
HMSO	Her Majesty's Stationary Office
IEE	Instiitute of Electrial Engineers
IEEE	Institute of Electrical and Electronic Engineers
IMechE	Institute of Mechanical Engineers
IRE	Institute of Radio Engineers
IHD	Interdisciplinary Higher Degree
MEXE	University of Mexico Engineering Experimental Station
MIT	Massachussetts Institute of Technology
NEL	National Engineering Laboratory
NRL	Naval Research Laboratory
OEL	Ogden Electronics Limited: the sponsoring company
OGC	Ogden Group of Companies: OEL's mother group
SAE	Society of Automotive Engineers
SPRU	Science Policy Research Unit
UOA	University of Aston: runs the IHD scheme
USASI	USA Standards Institution
USDD	United States Department of Defence

ABBREVIATIONS

admin	administration
aerosp	aerospace
ant	antennas
aeron	aeronautical
BS	British Standard
conf	conference
cong	congress
corp	corporation
dept	department
diss	dissertation
elect	electronics/electrical
expt	experimental
EP	European Patent
GB	Great Britain
inc	incorporated
inf	information
inst	instrumentation/instruments/institute
jnl/j	journal
met	meteorological/meteorology
mil	military
navig	navigational
no	number
org	organisation
phys	physics/physical
proc	proceedings/procedure
pub	publication/publishing
sci	science/scientific
spec	specification
symp	symposium
stn	station
trans	transactions
univ	university
veh	vehicle, vehicular
Am	America
appl	applied/applications
biomed	biomedical
comms	communications
ch	chapter
cons	consumer
cp	conference proceedings
def	defence
ed	edition/editor/editorial
eng	engineering
expo	exposition
geosc	geoscience
hbk	handbook
ind	industry/industrial
int	international
meas	measurement
mwave	microwave
nat	national
occup	occupational
opt	optical/optics
pat	patent
prop	propagation
res	research
sect	section
soc	society
std/s	standard/standards
syst	systems
tech	technology/technical
US	United States
vol	volume

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Mil Sped 202E	tests on electronic components, series 100		
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		103B	humidity, Aug 1963
		104A	immersion, Sept 1956
		105C	barometric pressure, Aug 1963
		106E	moisture resistance, Apr 1980
		107E	thermal shock, jan 1981
		108A	elevated temperature, Sept 1963
		110A	sand and dust ingress, Apr 1973
		112C	sealing, Apr 1980
	tests on electronic components, series 200:		
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		202D	shock, Apr 1973(also 205E and 213)
		203B	random drop, Apr 1973
		204D	high freq vibration, Apr 1980
		207A	high impact shock, Sept 1963
		212A	acceleration, Apr 1973
		213B	pulse shock, Apr 1973
		214	random vibration, Nov 1966
		215B	solvent resistance, Jan 1981
		(311)	low level switching, Apr 1969
Mil P5425	plexiglass spec		
Mil P2242	teflon		
Mil P997GSG	silicon fibreglass		
Mil P8184	acrylic sheet		
Mil C14550	copper electroplating		
Mil G45204	Gold electroplating		

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		2871, 3839 and 1035;	alloy spec
		6231	insulated cables
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