GEC REVIEW

Volume 8 No. 3

GEC REVIEW

Front cover

Cordless telephones are now providing a superior alternative to pagers, at the right price. The paper by Goodman explores the existing situation and looks into the future for cordless telephony.

Ten Unipak II motors manufactured by GEC ALSTHOM Large Machines Ltd. and supplied to Frank Mohn of Norway for driving dewatering pumps in a dry dock in Japan.

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A Process of Programmed Renewal

GEC ALSTHOM Large Machines Limited has recently been awarded the 1992 UK Manufacturing Effectiveness Award following the completion of a programme of cultural and physical change at their Mill Road factory in Rugby. The project involved the complete redesign of the factory layout, the introduction of new products, equipment and concepts resulting in dramatically improved leadtimes and sales per employee. The success of the project is shown to be attributable to a properly balanced programme addressing cultural and physical issues in a holistic approach to overall business improvement.

Keywords: restructuring; total quality management; just in time; design for manufacture, reorganization; world class manufacturing.

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SCHWARZENBERGER, P. M.

Lasers for Space-Based Wind Monitoring

There is a need for detailed mapping of wind speeds around the world in order to improve the accuracy of weather forecasts and for the modelling of climate change and global warming. Such information can be provided using a frequency-stable, eye-safe laser, mounted on a satellite together with a receiver to collect the return signals, and directed towards the Earth's surface. This paper presents an overview of GEC-Marconi's activities in developing a laser for space-based wind measurement, to a very demanding specification, carried out in support of both NASA and European Space Agency programmes.

Keywords: laser; CO_2 laser; LIDAR; wind; space; NASA; ESA; LAWS; foil.

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GOODMAN, J. E.

The Cordless Office

Much has been written over many years about the use of cordless connectivity in the office. The use of infra-red to link data terminals was proposed by IBM in the late 1970s and, more recently, the replacement of the ubiquitous wired telephone by the use of radio techniques has been an intense area of study. The question has to be asked whether technology now provides a mobile solution attractive to the user or is there some way to go? This article explores the existing situation and also looks into the future for cordless telephony – widely regarded as one of the most important changes in the working environment since the introduction of the word processor.

Keywords: cordless; PABX; mobility; CT2; telephony.

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SCANLAN, M. J. B.

Chain Home Radar – A Personal Reminiscence

This paper was written to celebrate the author's 50 years involvement in the field of radar, concentrating mainly on his experience of the Chain Home (CH) radar system in operation in 1943. The paper attempts to give a broader picture than that provided by the technical accounts to be found in the literature and draws heavily on the author's personal recollections. After reviewing the 'Daventry experiment', in which radio direction finding (R.D.F.) was first demonstrated, the author discusses the technical outline, operation, calibration, maintenance, anti-jamming, security and training aspects of CH radar. References to more detailed technical descriptions of CH radar are given.

Keywords: radar; Chain Home; CH; radiolocation; CH transmitter; CH receiver.

A Process of Programmed Renewal – Renaissance at Rugby

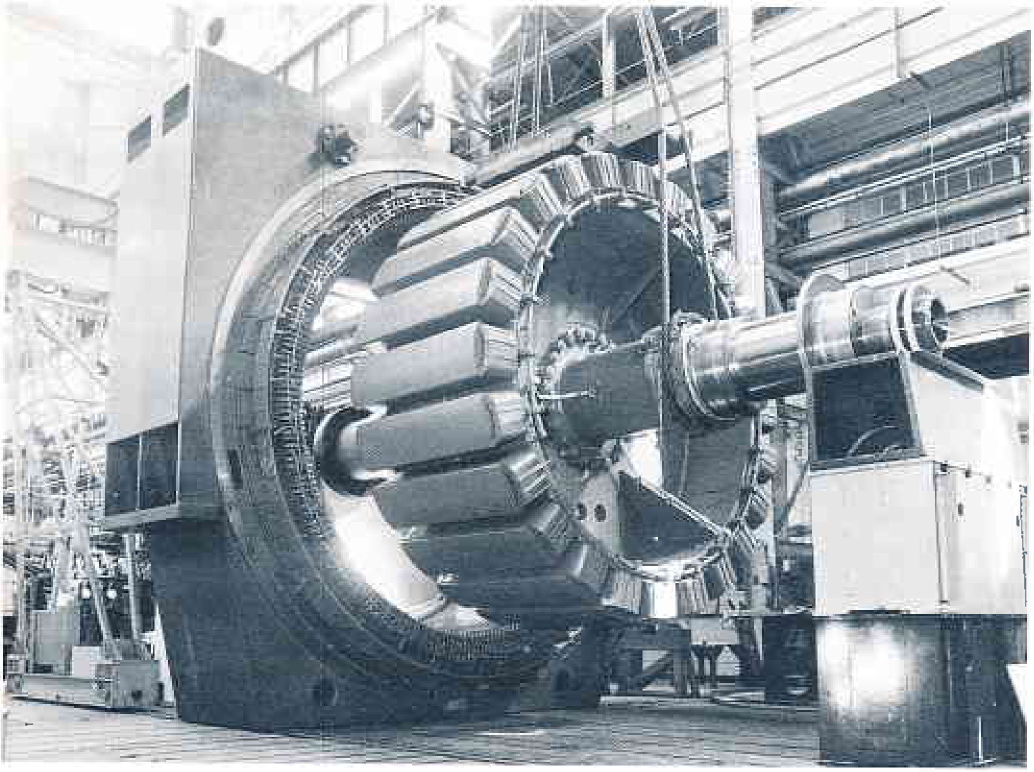
by Eur. Ing. M. R. LLOYD, B.Sc., Ph.D., C.Eng., F.I.E.E.
and M. MASON, C.Eng., M.I.E.E.
GEC ALSTHOM Large Machines

M. R. Lloyd graduated in Electrical Engineering from the University of Southampton in 1971. He gained his Ph.D. on the topic of electrical machines at the same university in 1977. He was initially employed as a Machine Design Engineer with Laurence, Scott and Electromotors Ltd. in 1974, progressing within that Company to become (in turn) Chief Electrical Engineer, Head of Research and Development, Chief Engineer, Engineering Director and Production Director. In 1987 he joined GEC ALSTHOM Large Machines as Engineering Director and, subsequently, Managing Director. In 1993 he moved once more to become Managing Director of GEC ALSTHOM Traction.

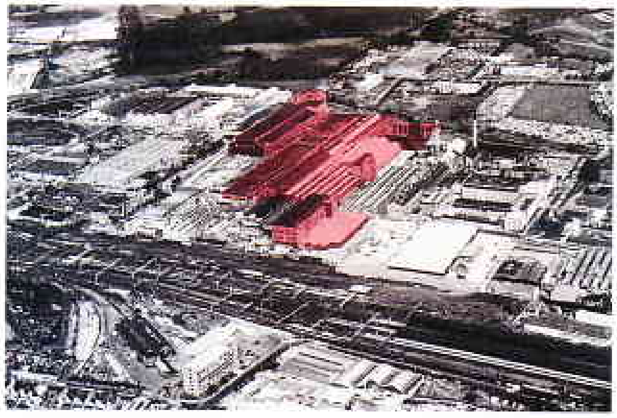
M. Mason joined the Associated Engineering Group in 1965, being responsible for the manufacturing development of the aluminium radiator. He then joined Stuart Davis Machines in 1976 as Design Manager, and moved to GEC ALSTHOM Large Machines as Manager, Production Engineering, in 1983. He is currently Project Manager of the Programme Renewal Project.

GEC ALSTHOM Large Machines Limited is a medium-sized engineering company specializing in the design and manufacture of large bespoke electric motors and generators (fig. 1) in the power range 100 kW – 300 MW. The Company's major markets encompass power generation, marine, oil, petro-chemical and process industries, and over 60% of the products are exported. The Company is located at Mill Road in Rugby and employs 1 000 people, with annual sales of approximately £55 million. Since 1989 the Company has been part of the GEC ALSTHOM group of companies formed by the merger of GEC Power Systems in the UK and Alsthom in France.

The Company started on the present site in 1902 (fig. 2) as the British Thomson-Houston Company with facilities to cater for a wide range of diverse products, including light bulbs, trains, turbines, domestic appliances and transformers. It was also



1 ***10.6 MW, 60 rev./min. synchronous motor***



2 ***Aerial view of the Mill Road site indicating present utilization (red)***

the site where the jet engine was developed and holography discovered in the UK. The factory grew in line with the labour-intensive technology available and the extensive facilities were arranged in the accepted functional layout of that era. Following a number of business reorganizations throughout the 1970s and 1980s the majority of products were moved to smaller well-equipped sites utilizing modern technology, leaving the manufacture of motors and generators with inappropriate facilities amongst many separate buildings and a surplus of old and inefficient equipment.

By 1987 it was clear that a major restructuring of all sectors of the business activities was essential if the Company was to survive in the fiercely competitive international market. It was also clear that the opening up of the European Markets in 1993 would provide excellent opportunities for the export of the Company's products.

However, to achieve any significant improvements, the facilities and company working culture had to be totally redesigned to compete against world-class competitors. This would require many years of commitment and investment in equipment, product, factory layout, culture, training and people to introduce the most appropriate technology for the product. These changes were introduced in several phases to ensure uninterrupted and increasing production, the most significant and lengthy phase involving the remodelling of the entire manufacturing facilities. In addition to this physical relocation, the introduction of JIT (Just in Time), TQM (Total Quality Management) and DFM (Design for Manufacture) philosophies involved a substantial training programme in order to benefit from investment in new equipment and ensure ongoing improvements through heightened employee involvement.

The Project

The target of attaining a world-class capability required the co-ordination of a number of parallel actions across all business areas, which resulted in doubled sales per employee, halved factory space and significantly increased return on capital employed and operating margins in a process of programmed renewal.

In order to achieve the progress necessary by the target completion date of January 1993, a multi-disciplined project team of up to 40 people was seconded to achieve the co-ordination of production with the following activities:

1) a complete rebuilding of the manufacturing and production testing facilities to bring about reduced leadtime; removal of surplus facilities; investment in new equipment and enhancement of working conditions,
2) replacement of centralized site services by modern distributed systems, and improvement of the environment by elimination of environmentally damaging processes and removal of all redundant buildings,
3) the review of all component manufacture against a 'make *versus* buy' philosophy; and the building up of a preferred supplier base and reduction in inventories through a JIT programme,
4) ensuring a company-wide training programme for all employees to generate a culture of delighting the internal and external customer to improve quality,
5) introduction of company-wide TQM projects to eliminate non-value added waste and ensure a culture of ongoing improvements supported by a single status workforce,
6) streamlining of the organization and shortening of all process leadtimes by 50% throughout by the introduction of manufacturing cells,
7) introduction of a full CADCAM and system support structure to reduce product development times and costs by DFM projects,
8) introduction of new products to take advantage of the new facilities and emerging technology, in particular motors for electronic variable-speed drives, and
9) re-orientation of the marketing efforts to increase exports, particularly to support the move from large to small power station building programmes.

The total budget of £21 million capital and £5.4 million revenue over the five year period was justified on the basis of operational benefits and increased sales, matching increased depreciation during the period of change. Hence the planning and phasing (fig. 3) of the physical relocation without disruption to customer commitments was fundamental to the success of the project.

Each move was planned in meticulous detail to ensure support for increasing production and was timed so that the maximum spare capacity was released early in the programme to enable retraining of personnel to resource further moves and prepare for the new operating practices.

A total of 130 person-years of planning and project management was required for the successful completion of the exercise.

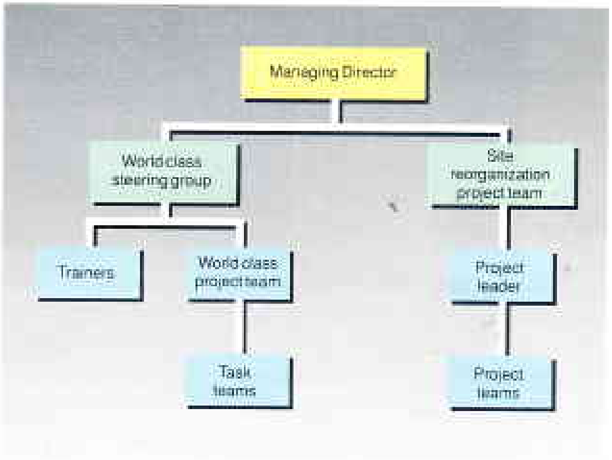
Considerable ingenuity was required to keep within the capital budget. Capital expenditure on new equipment was limited to those areas where new technology was required to fulfil the space reduction requirements or support the reduced leadtime programme. Such investment in the press and machining cells totalled approximately £5 million. The remaining capital expenditure on machine tools was used to upgrade, enhance or extend the capabilities of existing equipment.

It was estimated that a new facility on an alternative site would cost approximately £47 million to build and hence such an option was disregarded at the outset.

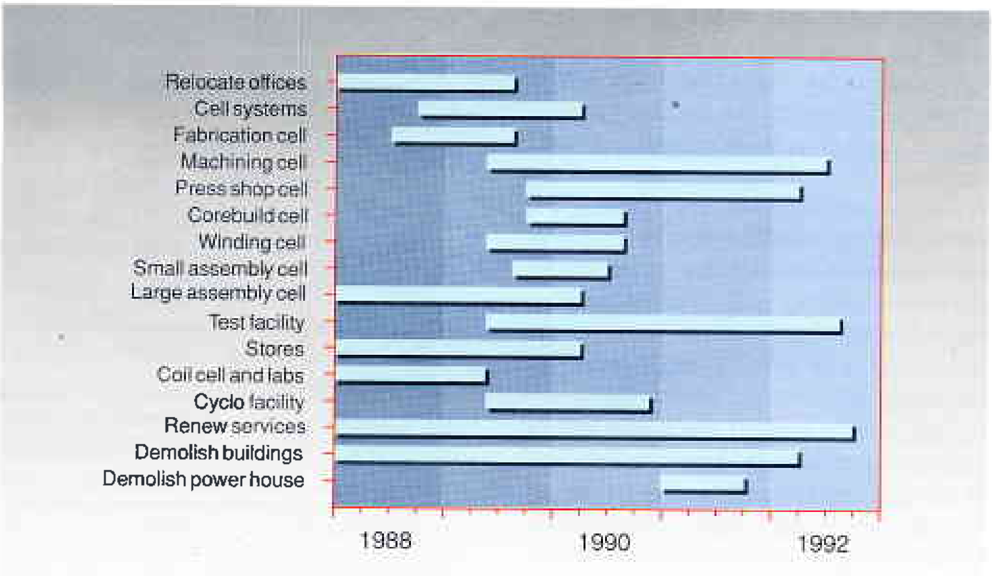
Project Management

To ensure day-to-day control whilst maintaining increasing output proved a major logistical problem. Two full-time project teams and a steering group were formed to progress the project. These teams reported independently from the operational management structure (fig. 4).

1) *Site Reorganization Team* – responsible for planning and executing the physical relocation, refurbishment, new equipment



4 ***Project management structure***



3 ***Phasing of major site relocations***

purchase and installation, including the co-ordination of test plant installation.

2) *World-Class Steering Group* – responsible for overseeing the introduction of JIT, TQM and DFM concepts into the Company. All activities relating to systems were also co-ordinated from this group with the aim of gaining Third Party ISO 9001 accreditation by the project completion date. All training was also co-ordinated from this Group.

3) *World-Class Project Team* – responsible for introducing best practice and co-ordinating TQM projects across functions where necessary. This full-time team was fundamental to the success of the project as the benefits from the physical changes could be brought about only by the acceptance of changes in working practice.

Workflow

To increase overall effectiveness it was necessary to reduce dramatically the leadtimes and inter-operational times. This was achieved by concentrating manufacturing operations into a smaller number of self-sufficient manufacturing cells operating in one building. In order to reduce leadtime further, a programme of set-up time reduction, total preventive maintenance and improved scheduling was also undertaken.

Whilst inter-operation times had not traditionally been considered a major direct cost element, it was recognized at the outset of the project that leadtime should be considered as a major influence. This was because the total sales capability of the Company would depend on reducing non-value added costs such as queueing, set-ups and transportation times.

Fig. 5 indicates the sequence of operations for a medium-sized machine stator frame within the facilities in 1987, a direct comparison is shown in fig. 6 in 1992, representing a 52% reduction in distance travelled. Even more dramatic savings have been achieved with other components, as summarized in table 1.

However, to achieve a logical arrangement of cells to minimize inter-operation times and fit into the required areas, considerable ingenuity in layout and investment in new technologies was required. A summary of the space reduction achieved for all major manufacturing areas is shown in table 2, with an overall reduction of 39% in floor space and a reduction of forty buildings. The most dramatic reduction was achieved in the machine shop and press shop areas. This necessitated the vacation of several buildings and temporary siting of existing equipment while new equipment was manufactured to exacting specifications.

TABLE 1

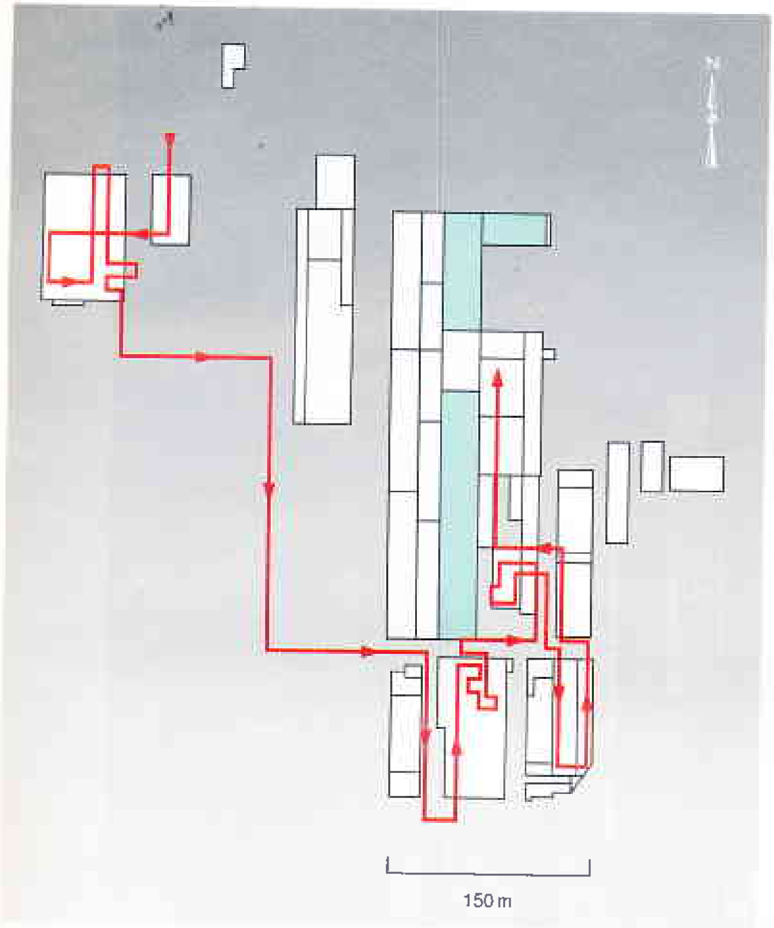
Major Component Routeings

Component and route	Distance in 1987 (m)	Distance in 1992 (m)	% reduction
Fabricated frame to final assembly	2005	957	52
Stator core, laminations to final assembly	1010	341	66
Rotor core laminations to final assembly	773	341	56
Field coil manufacture to poling up	3000	184	94
Segmental lamination manufacture to core build	1220	134	89

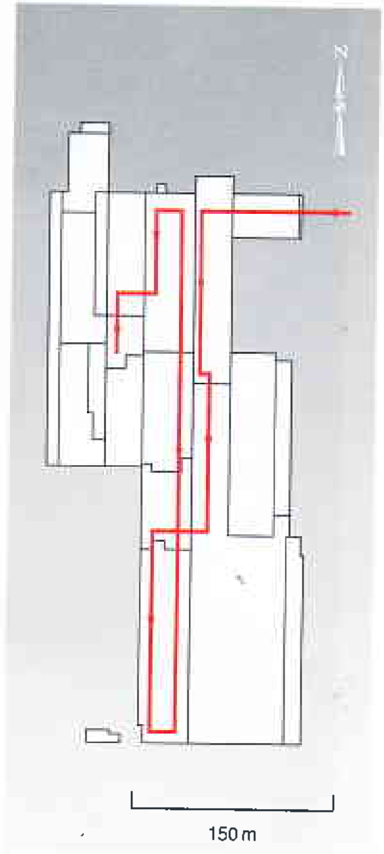
TABLE 2

Manufacturing Areas

Cell	Cell area		Reduction (%)
	1987 (m^2)	1992 (m^2)	
Fabrication	8047	4100	49
Machining	10293	4330	58
Press	6273	2410	64
Core building	2859	2230	22
Coil & insulation	9777	9850	–
Winding	4623	4220	9
Assembly	7655	6430	16
Test	9841	3860	61
Despatch & transport	4062	1480	64
Total manufacturing covered above	63430	38910	39
Office services	41803	24547	41
Total Company covered area	105233	63457	40
Total Company land area	335818	133518	60



5 ***Frame workflow pattern 1987***



6 ***Frame workflow pattern 1992***

Manufacturing Cells

Manufacturing was reorganized into twelve self-sufficient manufacturing cells, each cell placed into its logical position in the workflow to minimize inter-operation times.

Manufacturing costs were reduced by the following techniques:

1) amalgamation of several areas originally separated because of differing but similar operator skills, for example medium and large winding departments,

2) creating a business unit culture and capability within the cell to shorten lines of communication,

3) multi-skilling amongst support trades (for example: maintenance, self-inspection, housekeeping, crane driving) to reduce overheads,

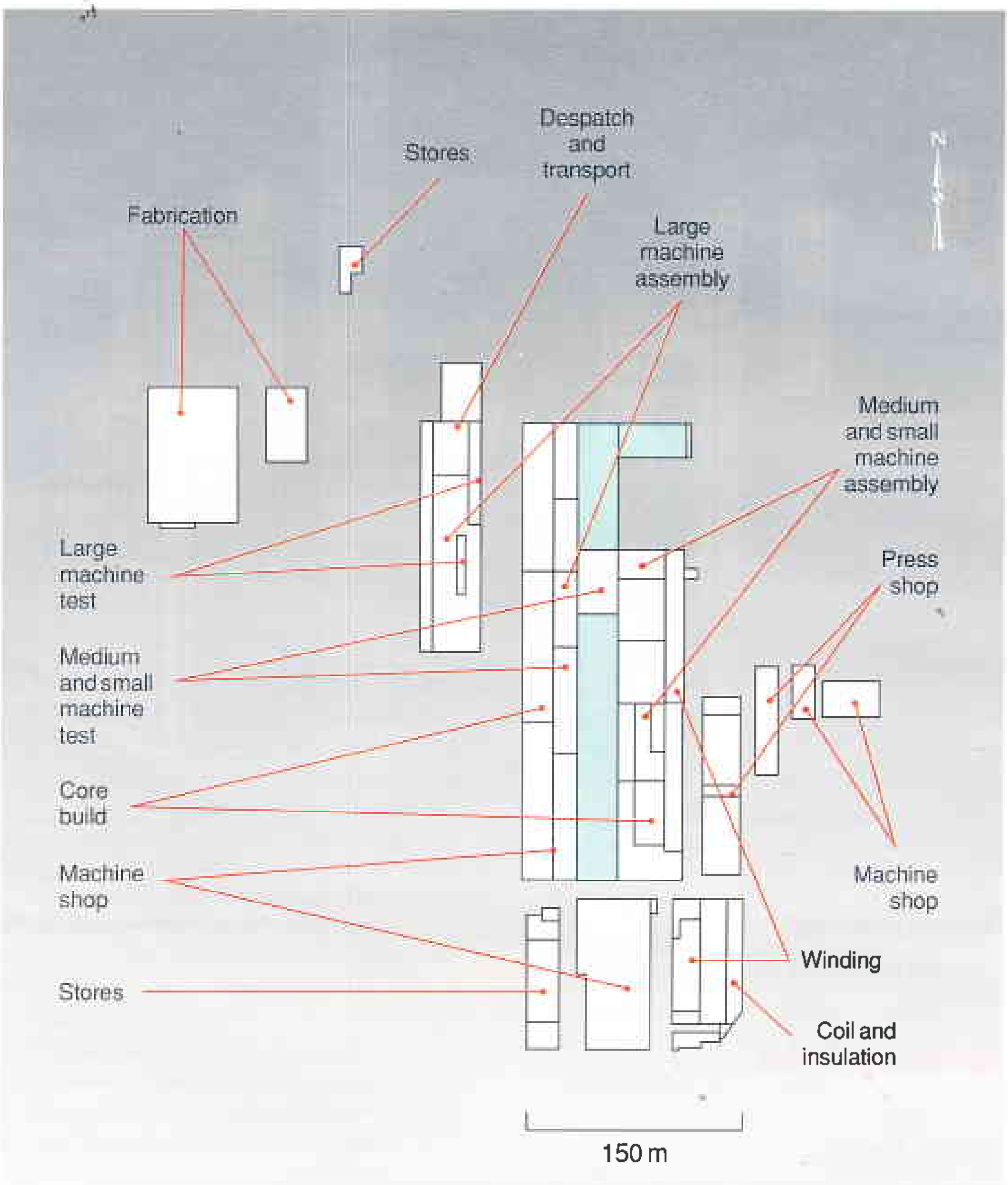
4) provision of floor-operated cranes in all areas to enable operators to be independent of external services for moving work when required (forty-one cranes were uprated or replaced), and

5) modernization and refurbishment of existing equipment and investment in purpose-built equipment where existing equipment was incapable of supporting JIT philosophies. All new equipment was specified to combine operations.

The layouts of manufacturing facilities in 1987 and the manufacturing cells in 1992 may be compared in figs. 7 and 8.

The manufacturing improvements achieved by the introduction of manufacturing cells, improved workflow and enhanced production logistics are summarized in table 3.

In order to optimize capital expenditure against revenue benefits the manufacturing facilities were grouped into cells in the following way:



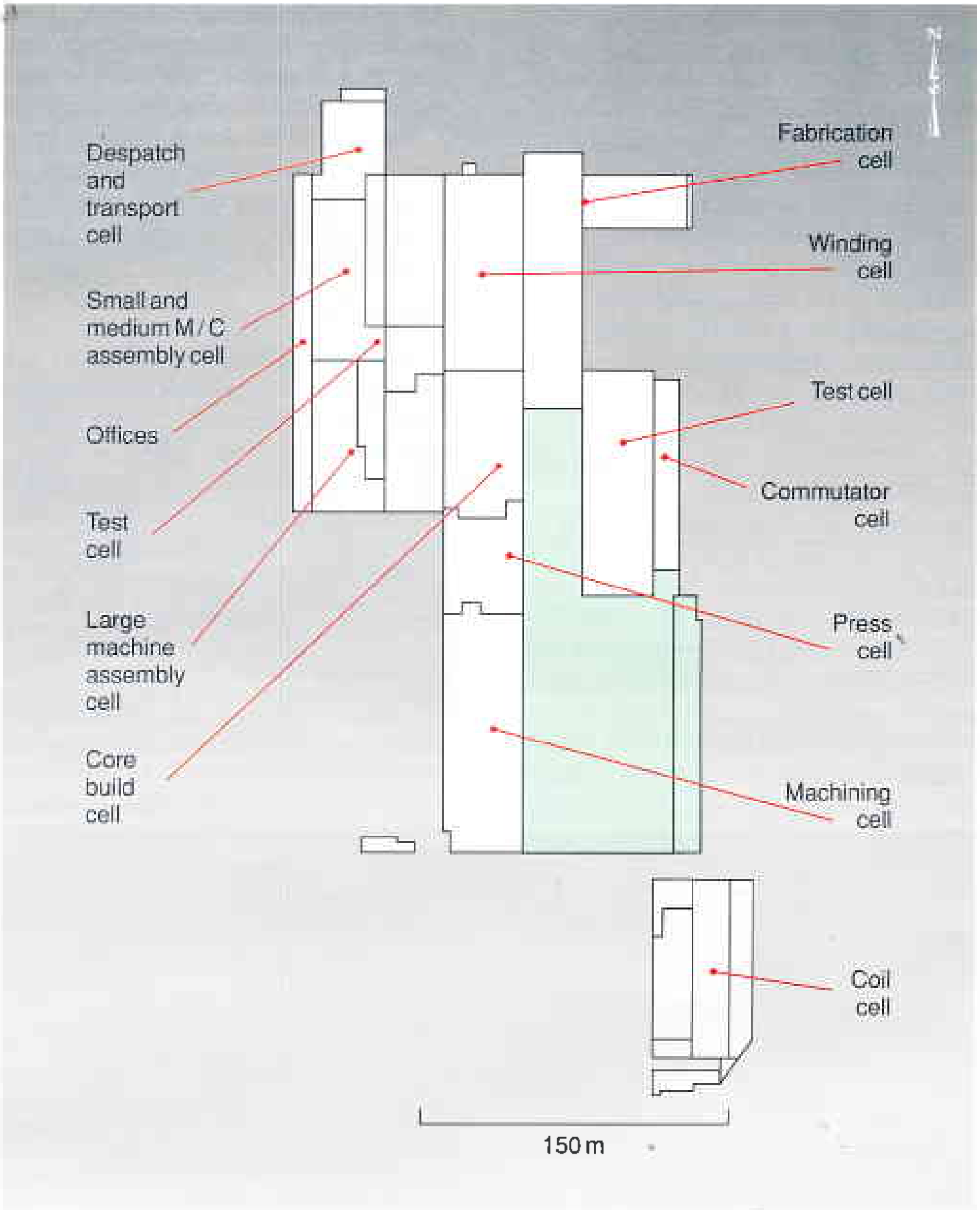
7 *Manufacturing areas 1987*

1) feeder cells based on process, that is, fabrication cell and machining cell,
2) strategic items based on major component cells, that is: press, core building, coil and winding cells, and
3) assembly and test cells based on product size, that is, small machines assembly and large machines assembly.

Such an approach enabled the support facilities (cranes, stores, engineering, etc.) to be optimized to the relevant cell with the minimum capital outlay. However, duplication of certain facilities was still beneficial to leadtime reduction and was used in some cases, for example, separate test facilities for coils and for windings.

Reduction of process times in the winding and coil cells was achieved with a CNC (Computer Numerically Controlled) 'self teach' robotic taping machine, 16-axis bar pressing machine and a single process wedge cutting machine. These investments enabled accuracy and quality to be considerably enhanced whilst reducing lead-times.

Major investment was necessary in the Machining, Press and Test cells to achieve the reductions required, in all cases the capital equipment was designed to the Company's exact specification.



8 ***Manufacturing cells 1992***

Machining Cell

A combination of new equipment and enhancements to existing equipment resulted in a 58% reduction in floor area. Enhanced effectiveness has enabled a 60% reduction in the number of machine tools to deal with the increased workload by the utilization of the following techniques:

1) capability of some existing machine tools extended to include in-progress gauging and probing. All CNC machines upgraded to DNC (Direct Numerical Control) linking,
2) machine tools arranged in product sub-cells to ensure unidirectional workflow,
3) single hi-tech machine tools acquired to replace several separate machines,
4) major set-up time reduction programme, including pallet system and magnetic work-handling to allow rapid batch changeovers,
5) rationalization of tooling, introduction of a computerized tool management system, automated head, pallet and tool changers,
6) a rigorous planned maintenance programme following re-siting of the Maintenance Department into the Machine Shop, and

TABLE 3
Manufacturing Productivity Summary

Annual performance	1987	1992	% change
Output/area (hours/m^2)	8.7	13.6	+56
Output/employee (hours)	861	1 160	+35
Production (hours)	438 156	458 181	+4
Area/employee (m^2)	98	85	−14
Employees	509	395	−23
Production area (m^2)	49 527	33 570	−32

7) resiting of major machine tools to enable one operator taking responsibility for several machines.

In addition, three major DNC linked CNC single hit machine tools, including a 3 m shaft lathe, a universal machining centre for 2 m cube components (fig. 9) and a 1 m cube machining centre for disc type components were introduced, replacing eight previous machines.

The above methods and equipment, together with the single order processing, 'Kanban'* and flexible working arrangements have enabled average floor-to-floor times for major components to be reduced by 33%.

Press Cell

New technology has enabled a dramatic 64% reduction in floor area. The new cell consists of two new CNC hydraulic blanking presses with NC roll feeders and two new CNC tool-changing notching presses. All four presses are integrated with robot systems that load raw parts and deliver finished items. The new plant was particularly chosen to combine previously separate operations and

*Kanban is a system introduced from Japan whereby a visual indication – such as a card, bin, container or space on the floor – is used as a signal to take action. For example, an empty stock bin is the signal to replenish stock. For further information, see reference (1) for example.

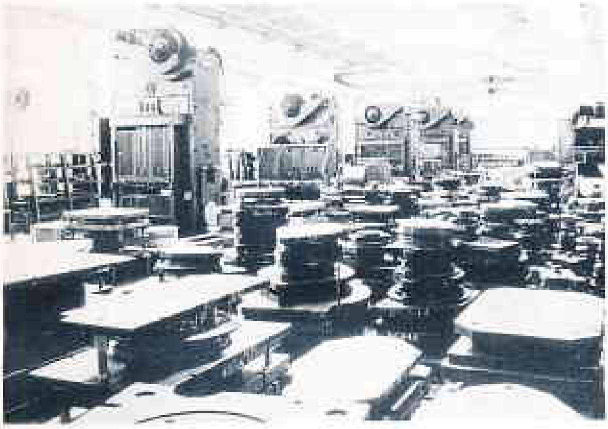
9 ***Two metre cube, 7-axis machining centre***

allow rapid batch changeovers (fig. 10 and fig. 11). Cell manning was reduced by over 60% and set-up times reduced in some instances from 8 hours to 8 minutes.

Test Cell

Five separate test areas were concentrated into two locations. The largest test bay was totally modernized to enhance capability and power ratings. New equipment includes the total replacement of switchboards, control panels and test stations. All metering control was made 'off-floor' and linked via data loggers to the engineering system of 'Sun' workstations.

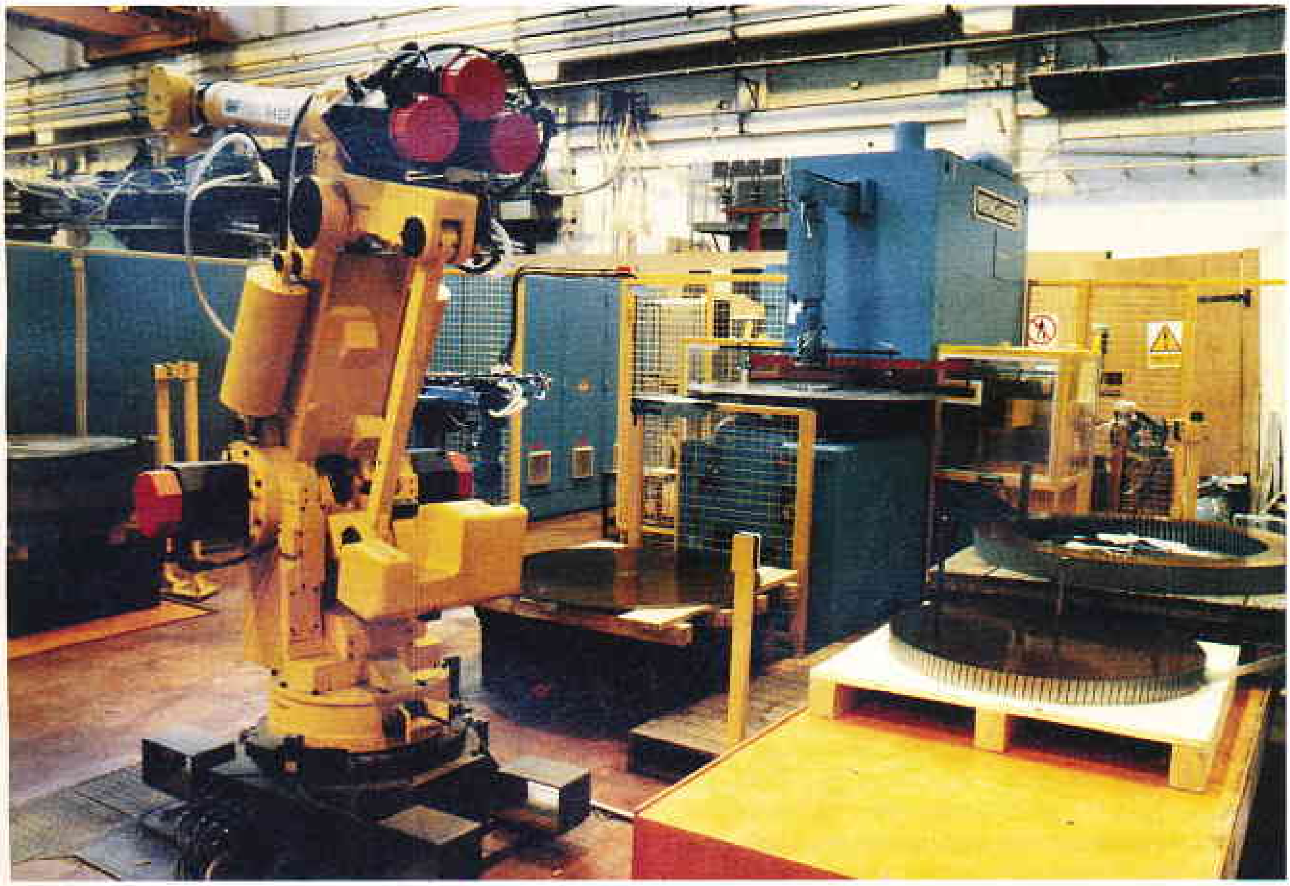
An important enhancement included the uprating of the capability to test motors and generators at 60 Hz for export markets. For synchronous machines the power threshold was increased by 400%. Novel features in the test cell included an epicyclic gearbox arrangement and electronic converters to limit power consumption drawn from the electrical supply to a minimum.



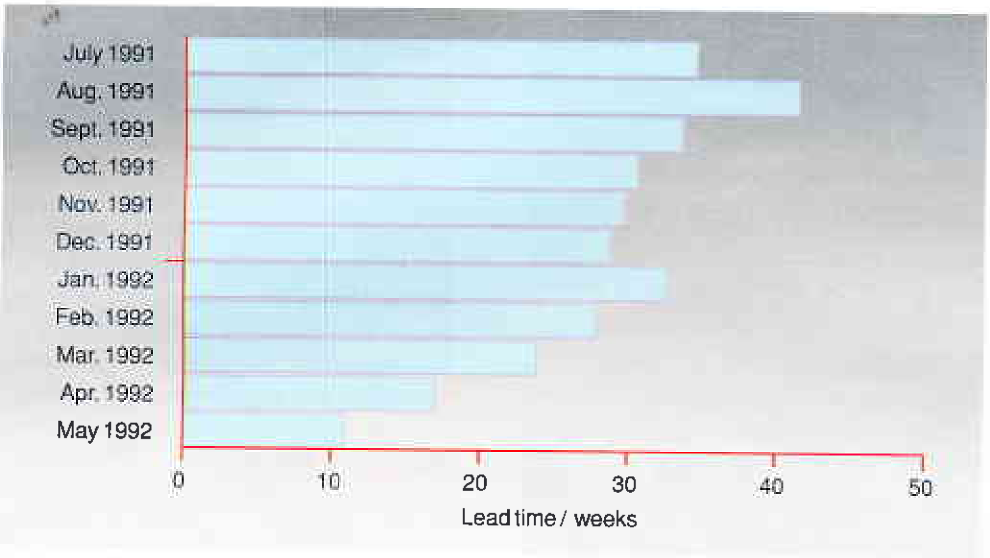
10 ***Manual lamination presses 1987***

Scheduling

All manufacturing cells operate as autonomous units where flexibility within the cell is paramount and has been achieved by multi-skilling. Work is synchronized between cells on a 'pull' system using 'Kanban'. Flexibility of resources between cells is controlled on a day-to-day basis by cell supervision utilizing information from the TRACK-STAR RCCP (Rough Cut Capacity Planning) system. This system and the MRP (materials requirement planning) manufacturing system are



11 ***Automatic handling and NC presses 1992***



12 *Achieved leadtime (weeks)*

updated via data pens taking information from bar-coded process control cards.

Orders are all processed as single machine orders, enabling de-batching throughout the facility and all items are made to order with no stock. The use of 'Kanban' techniques enables synchronization of components with the minimum of inventories whilst still reducing leadtimes.

The use of the above techniques has provided the most dramatic results on the lower power industrial induction motor range, as can be seen in fig. 12 that covers the sales period July 1991 – May 1992.

Suppliers and Inventories

In order to reduce the leadtime and ensure minimum inventories, all major suppliers have been organized on a 'preferred supplier' basis. The number of suppliers has been reduced from 883 in 1989 to 409 in 1991 and it is planned to reduce to 350 by March 1993. The floor space of the incoming stores area has been reduced from 4 902 m^2 to 1 730 m^2 in the same period by the systematic reduction of design variability and number of suppliers. The new stores area consists of a high density racking area for medium-sized components serviced by a 'manriser' truck connected to the computer via an infra-red link. A robotic silo storage area is used for smaller components, which is also linked to the computer to enable synchronization of kit marshalling. Certain suppliers have been put on 'Q' status (indicating no goods inwards inspection), with direct delivery to the point of use enabling manufacturing cells to call off deliveries when required.

In addition, all components made in-house were reviewed against competitive prices from outside the Company and a number of components were out-sourced. Particular criteria were procurement leadtime and quality of supply. Local suppliers were actively encouraged to take up the challenge, as is evidenced by sheet metal supply now being manufactured by a company set up by ex-employees.

Key achievements in the purchasing area are indicated in table 4.

TABLE 4
Materials Department Changes

	1987	1992
Number of suppliers	883	409
People employed	28	21
Number of computer terminals	10	18
Supplier partnerships	0	12
Material spend/factory cost	50%	43%

Buildings, Services and Energy

In 1987 distributed services comprising heating, compressed air and process steam were provided by a steam-operated boiler house and distributed across the 42 hectare site by a network of pipes. Steam was generated from coal-fired boilers with consequent chimney emissions, coal stockpile and use of water treatment chemicals.

As these infrastructure costs represented a significant proportion of the total product cost, it was decided to improve and modernize the site services with

- energy management, and
- cost reduction

as key elements, whilst also eliminating any processes that were environmentally damaging.

Heating is now provided by 600 high efficiency gas-fired radiant heaters in the factories, and low pressure hot water modular atmospheric boilers for office areas. Local gas fired generators provide process steam at point of use. Local electrically-driven air compressors are operated under computer control. DC rectifiers have replaced old rotary converters; modern 350 MVA fault-rated switchgear has been installed and electricity substations reduced from 23 to 6. Computer-controlled energy management of heating, compressors and lighting is in operation, with automatic meter reading. Old lighting systems have been replaced with high efficiency fluorescents in offices and Sonplus lighting in factories. A programme to replace completely the use of town water by treated river water for process cooling has resulted in an annual saving of 59% in volume use.

The overall energy utilization and savings are summarized in table 5. The 40% annual energy savings achieved resulted in the Company being awarded the highly commended category in the 1991 UK Energy Awards.

TABLE 5
Energy Utilization Improvements

Contribution to energy usage	Energy utilization (therms × 10^3)*		Improvement (%)
	1987	1992	
Site distribution energy loss	890	50	95
Space heating and associated services	1 185	710	40
Energy used for manufacture and test	1 400	1 340	5
Total energy purchased	3 475	2 100	40
Water consumption ($m^3 \times 10^3$)	219	90	59

(* 1 therm = 10^8 J)

Working Conditions

To encourage the removal of internal barriers, harmonization of terms and conditions of office and factory employees has resulted in identical contracts of employment and cashless monthly pay. All work areas have been refurbished to encourage pride in the workplace and individual responsibility for house-keeping and quality (fig. 13).

Training

Training to support the programme of change was phased to match progress of the physical relocation.

Phase I External training of senior management group by exposure to best practice, seminars and workshops. Establishing a steering group for further training and train the internal trainers required for phase II – a total of 228 person-days training + 58 person-day visits to reference sites.

Phase II Company-wide awareness seminars, to complete workforce, each employee receiving 10 hours in two half-day sessions – total of 1 094 person-days + 64 person-day visits to reference sites.

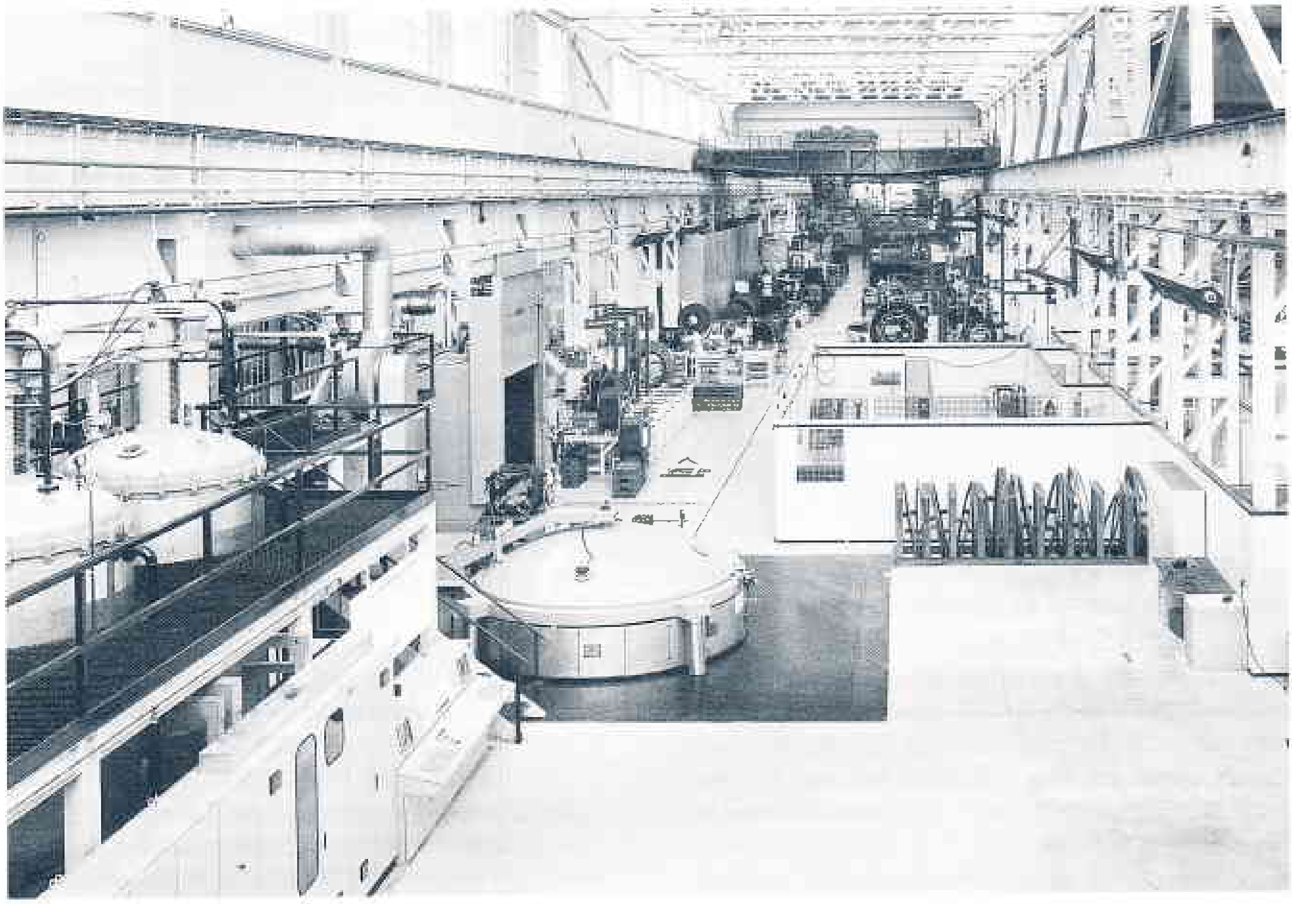
Phase III Further structured training focused at those more directly involved in the process, with the use of simple techniques. This included CEDAC (Cause and Effect Diagrams with the Addition of Cards), DFM, TQM and Action Planning seminars and workshops – total of 886 persondays to June 1992 with an ongoing visits programme to build on this.

Further details of this training programme are given in reference (2)

Communication

At the outset it was understood by all concerned that manpower would be reduced, but the reduction would be planned and those employees affected would be retrained. Given the radical nature of the changes proposed, communications were extremely important and handled in the following way:

1) daily meetings at functional head level to co-ordinate working information to ensure rapid response to questions and to quell rumours,



13 *Winding cell*

2) weekly meetings at departmental level to encourage discussion and generate input to planned moves, and

3) monthly briefing sessions, carried out by the Managing Director, to communicate the business position and other relevant information to a cross-section of the workforce, and then down through a cascade structure.

Against this network of communications, reinforced with a company newspaper, extensive use has been made of information boards detailing performance measures and project progress.

Flexibility

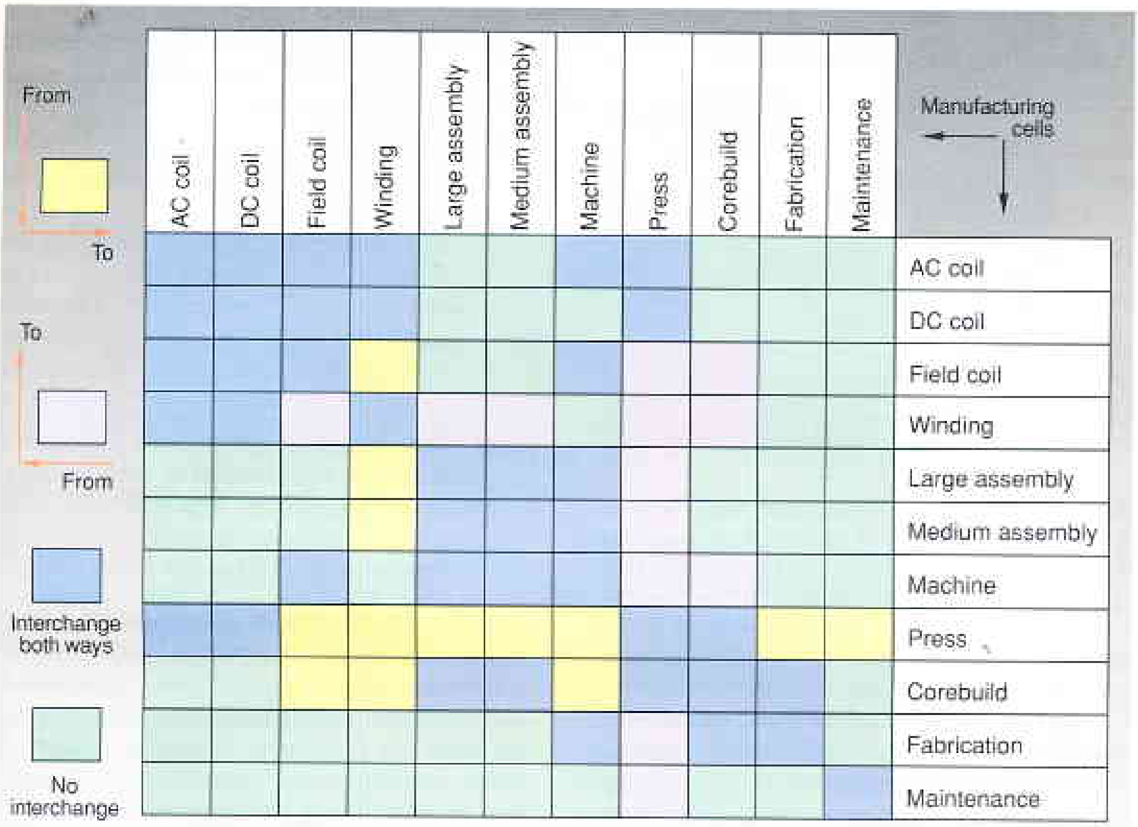
As a direct consequence of the need to encourage flexibility of skills, employees have annual individual appraisals, measured against agreed objectives. Skills matrices are actively encouraged; gaining increased numbers of skills is a means of career progression and development. A number of cross-functional teams were set up to encourage problem solving. The aim has been to involve 50% of the workforce in such an exercise by March 1993. The present flexibility arrangements between the skills is shown in fig. 14.

Quality Assurance

The move from a culture whereby quality was thought to be inspected into the product, to a culture where all employees contribute, has been difficult. But the change of emphasis as can be evidenced from a comparison of the 1987 and 1992 position (table 6) has been effective in reducing defect costs and encouraging the concepts of the internal customer chain.

All employees have undergone training in TQM techniques in addition to operator certification in manufacturing areas.

The Company has additionally updated all QA procedures and systems to reflect the new working practices and, in June 1992, was awarded Third Party Accreditation to ISO 9001 by Lloyds Register Quality Assurance Limited.



14 *Diagram indicating the interchangeability between staff in manufacturing cells. Arrows reflect the direction of mobility.*

TABLE 6

Quality Assurance Changes

	1987	1992
Third party certification	None	Lloyds register quality assurance
Second party certification	CEGB MoD defence contractors list	National Power National Grid Powergen
Hazardous area certification	BASEEFA surveillance	EECS licence QUASCO†
Documentation structure	Quality manual Company instruction letters Quality control routines Machine production routines	Quality manual Company procedures Department routines
Quality control	Chief Inspector 34 Inspectors	Quality Control Manager 4 Quality Controllers 13 Cell Inspectors
Operation certification	None	269 of 308 total

† The quality organization covering the oil industry – Quality Appraisal Service Company Limited

Technology

Whilst the heavy electrical engineering industry has relatively long product development cycle times, there is an increasing need to incorporate specific customer requirements into individual orders on an ever-decreasing timescale. Hence reduced leadtime and DFM philosophies were essential to the success of this project. This was tackled in the following way.

Systems

A MEDUSA draughting, GNC (Graphical Numerical Control) part-programming and in-house engineering design system was introduced on an Ethernet network with the aim of reducing pre-production leadtimes. A total of 75 'Sun' work-stations were introduced over a four year period and manual draughting eliminated. The engineering and draughting functions were merged with the manufacturing pre-production areas into a 'manufacturing support' group which, coupled with DFM training and projects, has done much to eliminate non-value added waste in this area.

The introduction of the CAD system enabled the redevelopment of six product ranges to be carried out in parallel with the physical changes within

TABLE 7
Engineering Department Changes

	1987	1992
Number of Engineers	52	49
Number of Draughtsmen	49	41
Office area (m^2)	3168	1682
Number of draughting workstations	21	41
Number of drawing boards	70	5
Number of engineering workstations	0	34
Product ranges developed in 5 years	2	6

the factory, enabling the full benefit of the DFM programme to be available at the time of product introduction. Table 7 summarizes some key changes in the 1987 – 1992 period.

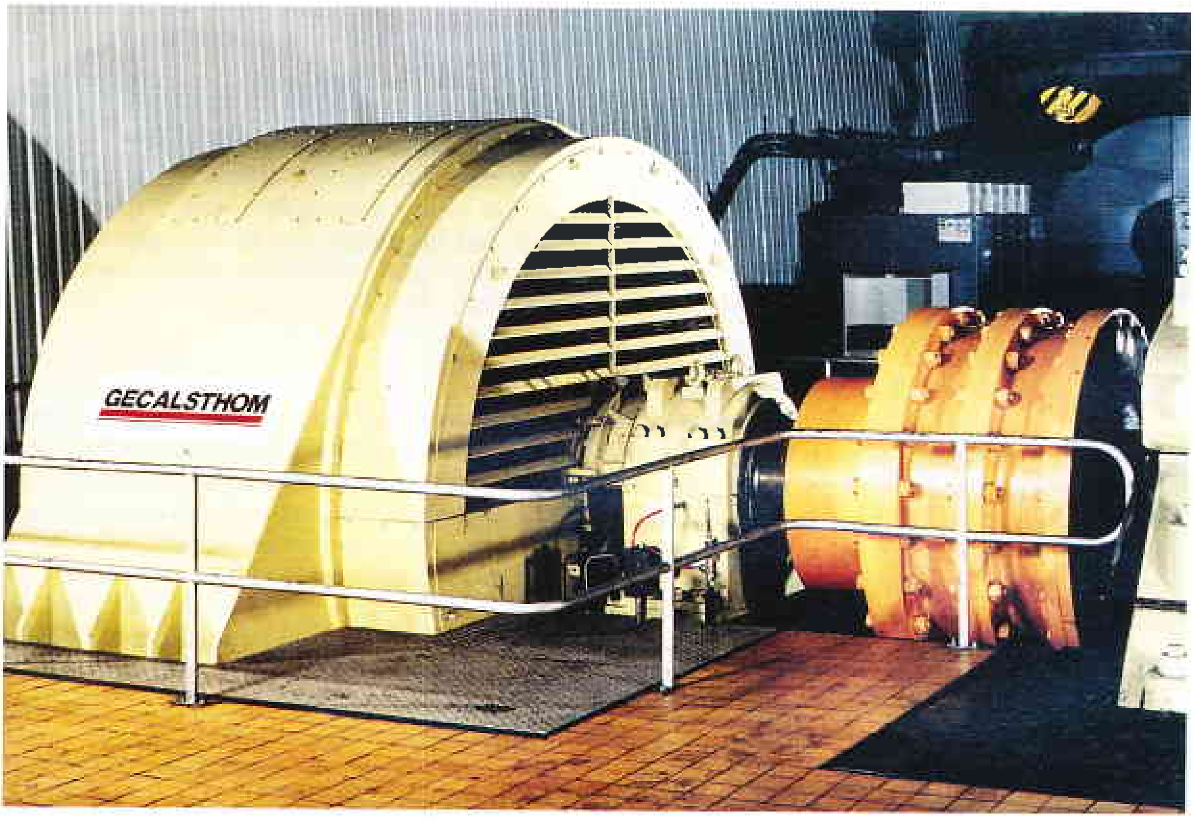
Products

a) The market for DC motors was predicted to decline as large multi-MW electronic AC drives emerged as the new technology (fig. 15). A new range of large induction motors was developed to take advantage of this potential market. This led to the introduction of the 6MW Cycloconverter production test facility that is the largest facility of its type in the world.

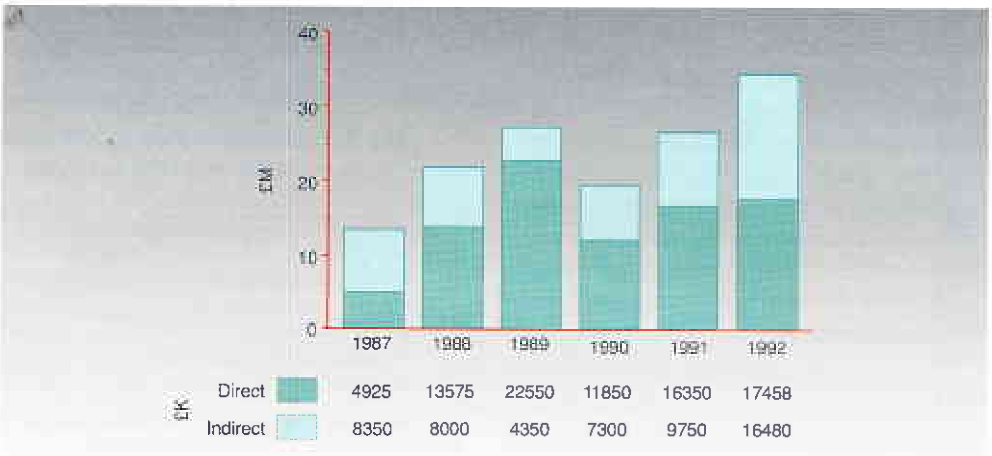
b) The industrial range of induction motors was totally redesigned to take advantage of the new facilities and, using DFM techniques, a 30% part count reduction was achieved. The new range went from concept to full production in 18 months. This compares with the original introduction of the range in 1981 that took three years to develop.

c) The range of generators for gas turbines was also redesigned to take benefit of part count reduction, together with increased use of supplier partnerships to reduce leadtime.

The new products, facilities and increased competitiveness, particularly for the power generation markets of gas turbines and hydro turbine applications has enabled the company to increase its sales, in particular those for export. Annual sales have increased by 42% with export orders (fig. 16) increasing from approximately £13million in 1987 to £34million in 1992.



15 *Cycloconverter driven induction motor*

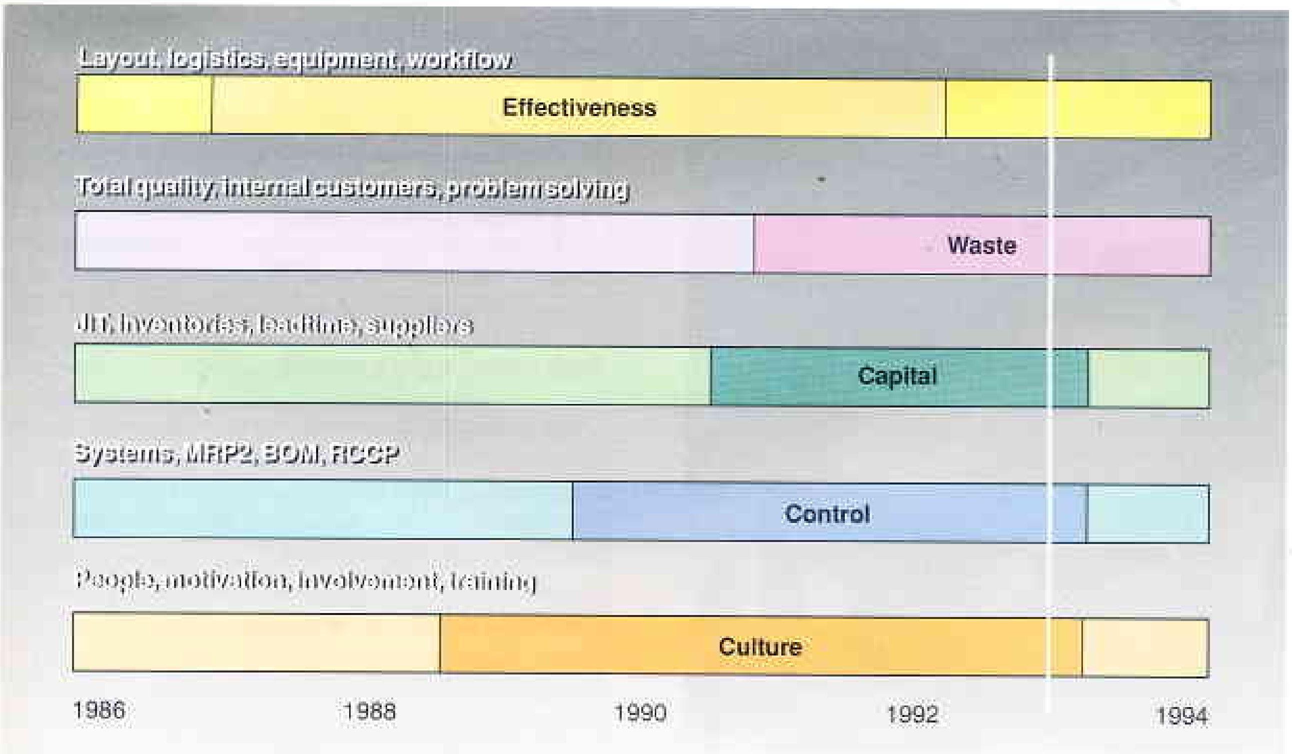


16 ***Export orders 1987 – 1992***

Management of Change

Whilst the changes in the business created many logistical problems throughout the five year period of change, the Company not only managed to operate effectively and profitably, but also doubled sales per employee during the process. Whilst good project management was fundamental to the execution of the project, the final outcome was totally dependent on the wide scope of the original plan.

It was recognized at an early stage that unless parity of performance was achieved in all functions and processes within the Company, progress towards world-class business performance would be limited by the weakest part of the business. In a batch manufacturing environment with customer specified variants, all activities are inevitably closely interlinked and, whilst the site layout and manufacturing logistics were the areas of initial focus, the changes were made in the full recognition of the other changes that were necessary. This is shown in diagrammatic form in fig. 17 where the horizontal bars indicate the five prime business areas. The intensity of effort to achieve parity of performance in all areas is shown as



17 ***Synchronization of performance***

darker shading. Having achieved this parity or synchronization of performance, a firm foundation for achieving world-class performance based on continuous improvement in all areas has been reached. However, further progress will be dependent upon adopting the 'learning organization' approach to business improvement: accepting that staff learn as they experience change within the organization, improving both themselves and the Company – sometimes referred to as 'empowerment'.

Conclusion

Following a major reappraisal of the Company's operations in 1987, a five year programme of changes to all the Company's operations has enabled GEC ALSTHOM Large Machines Limited to benefit from the application of the latest manufacturing philosophies and technologies. Considerable care was required to ensure that the new factory workflow and equipment would support the concepts of reduced leadtime in a low volume batch manufacturing environment (fig. 18). It is clear that the degree of improvement achieved was a direct result of changes across all the Company's activities in a far-ranging process of programmed renewal covering both physical and cultural issues. Without this holistic approach, the degree of change would have been more limited and short-lived. A firm foundation for a process of continuous improvement has now been established.

18 *The 44 MW synchronous propulsion motor capable of powering the Q.E.2 at 32 knots*

Comparison of the 1987 and 1992 position includes the key achievements given in table 8.

TABLE 8
Key Achievements from a Comparison of the 1987 and 1992 Positions

Manufacturing cells in logical layout to achieve:	
• Shorter cycle times	50% reduction
• Less occupied space	40% reduction
• Fewer inventories/sales	25% reduction
• Lower overheads/sales	25% reduction
• Higher productivity	35% increase
All achieved whilst increasing volume	
Improved test facilities:	
• Noise test facility	unique in Europe
• Cycloconverter facility	largest in World
• Increased power loading	400% increase
Decentralized site facilities:	
• Energy saving	40% reduction
• Reduced water consumption	60% reduction
• Improved environment	no emissions
Improved products and technology:	
• New products developed	6 products
• Full CADCAM workstations	75 interlinked
Improved marketing and sales:	
• Higher export	150% increase
• More sales/employee	92% increase
Better financial performance:	
• Profit	sixfold increase
• Return on capital employed	fivefold increase
Firm foundation for future:	
• Based on TQM, DFM and JIT concepts	
• Further inventory and leadtime reductions	
• Culture change	
• Realizing people's potential	

Acknowledgement

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Lasers for Space-Based Wind Monitoring

by P. M. SCHWARZENBERGER, M.A.
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P. M. Schwarzenberger graduated in Physics from Oxford University in 1982 as a GEC-sponsored student and, after graduation, joined GEC-Marconi Avionics' Applied Physics Division (now part of Hirst Research Centre). After working on a variety of laser projects, in 1985 he was appointed Project Leader for development of a compact, rugged laser for applications in the United States. From 1989 to date, he has also been responsible for the development of a laser for space-based wind measurement, initially for NASA and, more recently, for the European Space Agency.

There is a need for detailed mapping of wind speeds around the world in order to improve the accuracy of weather forecasts and for the modelling of climate change and global warming. Such information can be provided by using a frequency-stable, eye-safe laser mounted on a satellite, together with a receiver to collect the return signals, directed towards the Earth's surface. This paper presents an overview of the activities of the Applied Physics Division, Hirst Research Centre, in developing a laser for space-based wind measurement, to a very demanding specification, carried out in support of both NASA and European Space Agency programmes.

Climate Change

The world's climate is a complex interaction of atmosphere, sea, ice, land and life which, throughout history, has resulted in natural climate changes such as the Ice Ages, to which life has adapted by migration and evolution. More recently, human activities have grown to the point where they are having a significant effect on the world's climate. In particular, the concentration of 'greenhouse gases' in the atmosphere is increasing, reducing the amount of infra-red radiation that escapes from Earth to space which is thought to result in a warming of the lower atmosphere, land and sea surfaces. The most significant greenhouse gas is carbon dioxide, arising from burning of fossil fuels, and deforestation reducing the conversion of carbon dioxide to oxygen by photosynthesis. Methane, nitrogen oxides and chlorofluorocarbons are also greenhouse gases that are increasing in concentration as a consequence of man's activities.

Scientists are seeking to estimate the expected global warming that will occur because of the increased accumulation of greenhouse gases, and to assess the impact that this will have on the Earth's climate and sea level[1]. Such information is of great importance to the world's governments in order that informed decisions on reducing the production of greenhouse gases can be made.

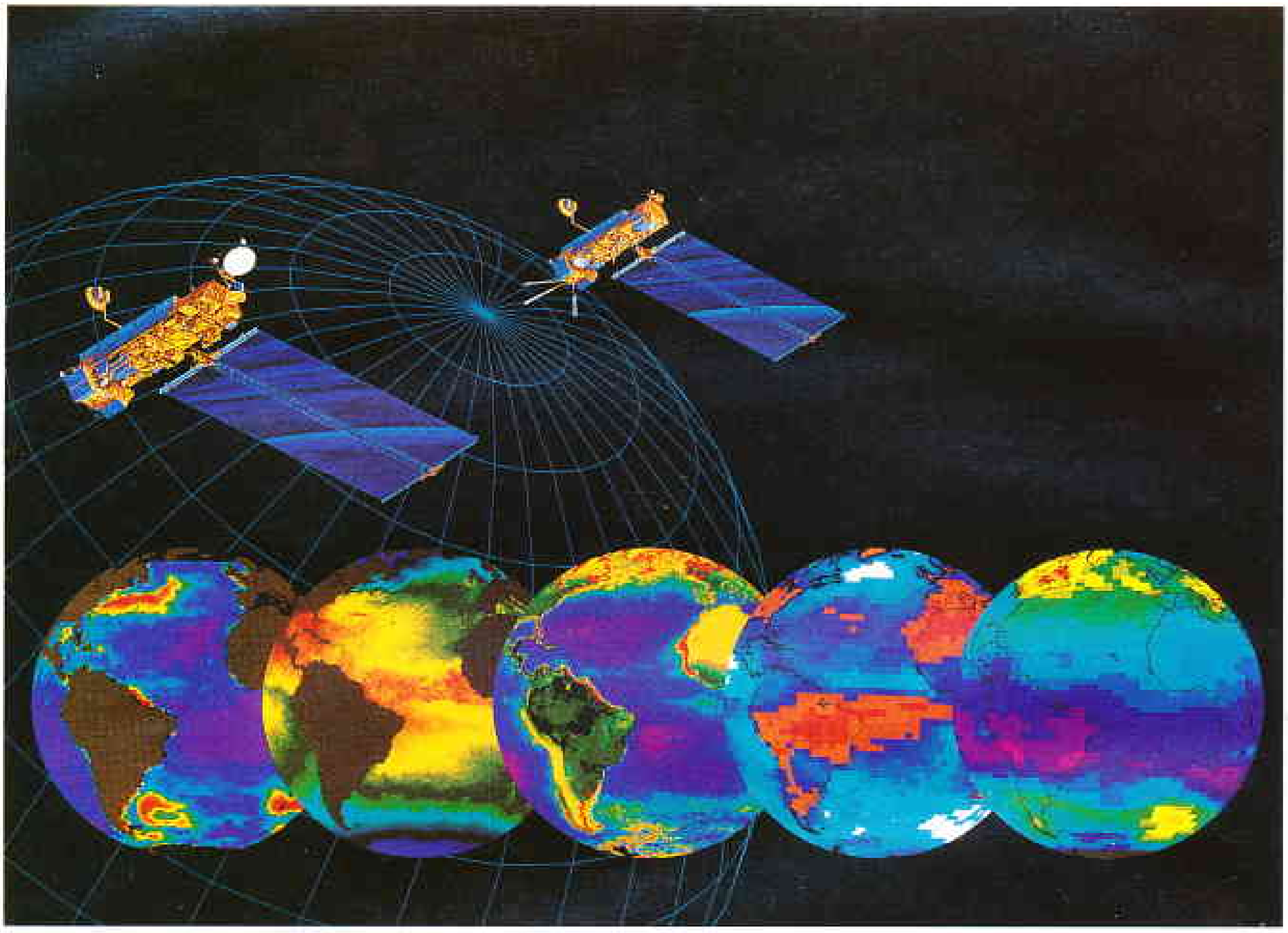
Unfortunately, accurate estimates of global warming are difficult to make as the Earth's climate is complex and sensitive. Feedback processes exist that can amplify or reduce the primary greenhouse effect. It is difficult to predict accurately the effect of clouds on the Earth's climate. The world's oceans act as a giant heat-sink, which may cause a delay in atmospheric warming.

Such complexities can be understood and the theoretical models refined to be consistent with observation, but only by extensive measurements of significant parameters on a global scale. Observations which are needed include measurement of cloud density, direction of evolution, wind speed, direction, turbulence, temperature, ocean circulation, heat flux, forestation, ozone and ice. Such global measurements can be fed into climate models that can be modified until their accuracy is confirmed in the short term. The same models can then be used with confidence to predict accurately longer-term climate change.

For such data sets to be truly global, space-based instruments orbiting the Earth are the most effective solution.

The Earth Observing System

In order to improve our understanding of the Earth's climate and predict more accurately the extent and impact of future climate change, the International Council of Scientific Unions and the World Meteorological Organization have jointly undertaken the World Climate Research Programme. The European Space Agency, NASA, the Japanese and Canadian Space Agencies are all participating in this programme, and an International Coordination Working Group has been established to ensure a co-operative and coordinated approach. The United States' contribution to the World Climate Research Programme includes NASA's Mission to Planet Earth, which consists of a series of scientific studies, satellite and spacecraft flights known collectively as the Earth Observing System (EOS). EOS is an information system with a number of satellite-based instruments providing geophysical, chemical and biological information to further our knowledge of the Earth's climate[2, 3]. Such data will be collected for at least 15 years,



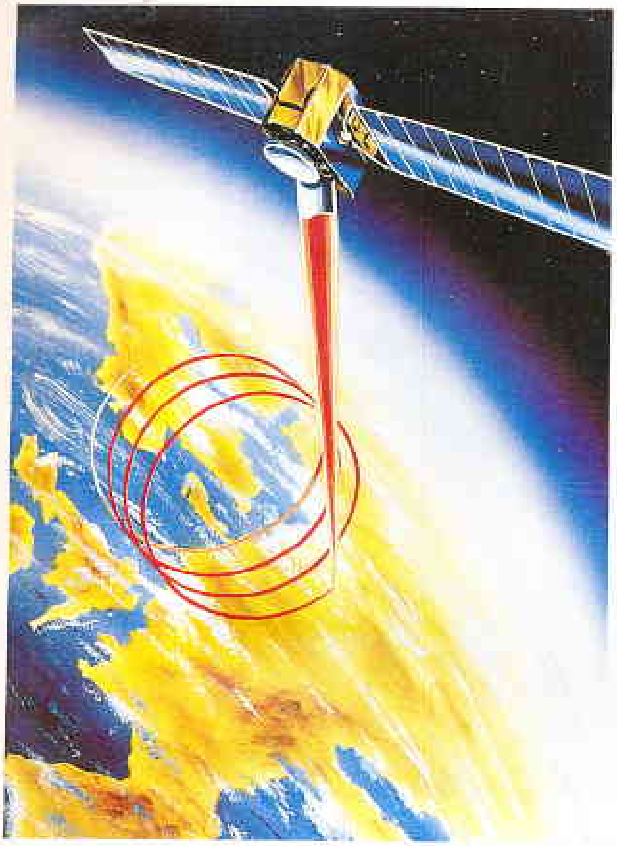
1 ***The Earth Observing System EOS-A (left) and -B (right) polar platforms. The five discs show (left to right) variable sea-surface topography, sea-surface temperature, a composite of ocean chlorophyll concentration and terrestrial vegetation index, mean cloud cover and stratospheric ozone (courtesy NASA Headquarters).***

starting in 1997, in order to allow accurate modelling of climate processes over an extended period. EOS instruments will map ozone, make thermal measurements, determine concentration of chemicals, map clouds and winds, and study water vapour and ice (fig. 1).

Wind measurements around the globe will dramatically improve climate models – in particular, relating to movements of water vapour. At present, direct wind speed data are provided only by land-based Rawindsonde (weather balloon) surface stations and some ship and aircraft reports. Indirect estimates can be made using satellite imagery of cloud motion, but the usefulness of such data is limited. A map of wind speeds and directions at different layers, regularly updated, can be provided most cost-effectively by a space-based wind measurement instrument.

Space-Based Wind Measurement System

The wind measuring system (fig. 2) consists of a frequency-stable, pulsed carbon dioxide laser, mounted on a satellite with its 'eye-safe' beam directed towards the Earth's surface. As the laser beam passes through the atmosphere, some laser radiation is reflected from tiny aerosols carried by the wind and detected by a receiver on the satellite. A measurement of the Doppler frequency shift of the return beam provides accurate information on wind speeds. As the satellite orbits the Earth, a three-dimensional map of wind speeds at different heights and positions can be built up and then regularly updated. As well as direct measurement of winds, the instrument can provide valuable



2 *Space-based wind measurement instrument (courtesy DRA)*

information on aerosol distribution and the positions and movements of clouds.

Such a system is known as a Doppler Wind LIDAR (Light Detection and Ranging) and the concept has a long heritage of ground and aircraft systems and design studies.

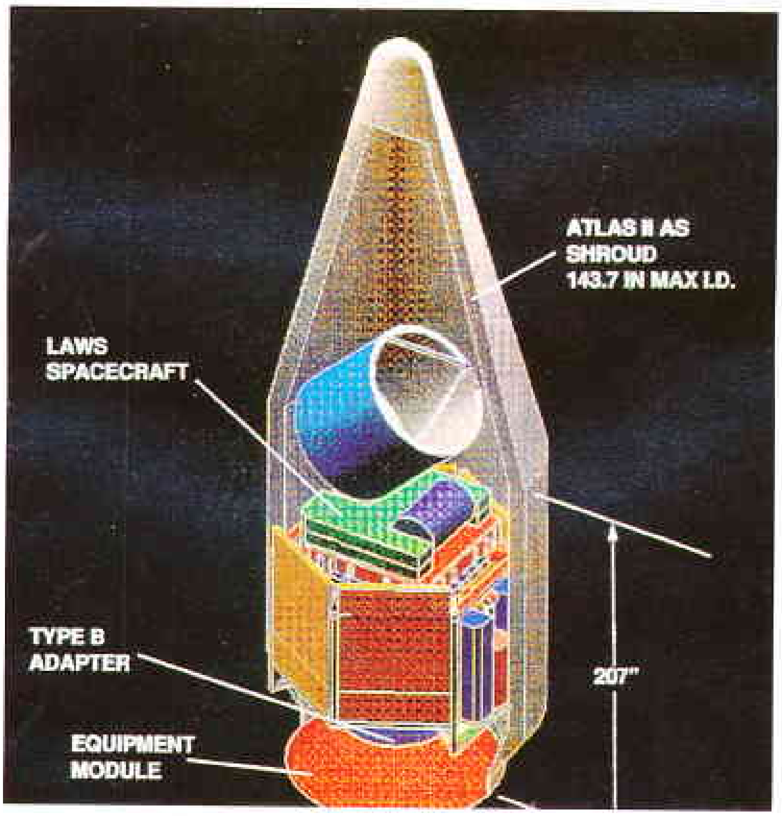
NASA's Laser Atmospheric Wind Sounder

The space-based Doppler Wind LIDAR instrument under development by NASA for EOS is known as the Laser Atmospheric Wind Sounder (LAWS). It is presently planned that LAWS will use:

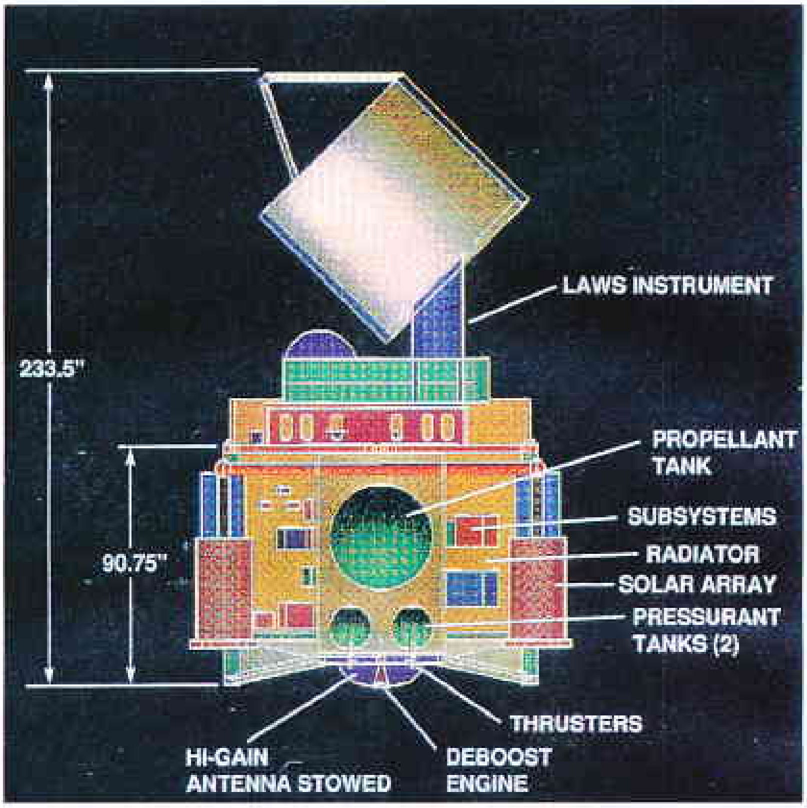
- a coherent Doppler LIDAR with a pulsed, frequency-controlled CO_2 laser transmitter operating at 9.11 μm,
- a continuously scanning transmit and receive telescope,
- a heterodyne detector, and
- a signal processing system.

Figs. 3 and 4 depict launch and pre-deployment configurations for the LAWS system.

The satellite will orbit at an altitude of 500 to 650km and provide measurements of wind



3 *LAWS launch configuration (courtesy NASA Marshall Space Flight Center)*



4 *LAWS configuration prior to deployment (courtesy NASA Marshall Space Flight Center)*

5 L

speed to an accuracy of ±1 m/s, in each 100km × 100km horizontal area, with a vertical resolution of 1km. As the satellite orbits the Earth, it will scan the atmosphere underneath it in a strip that is 1000km wide. Fig. 5 shows the coverage after 13 hours of successive orbits. After 72 hours, virtually complete coverage has been obtained and, from then on, the wind measurements are regularly updated[4].

NASA has now largely established the scientific requirements for LAWS and, since 1989, has funded two parallel contracts to define the LAWS instrument, to carry out preliminary design, and to breadboard critical items. These programmes have now been successfully completed and many of the risk issues resolved[5, 6]

Improvements in Weather Forecasting

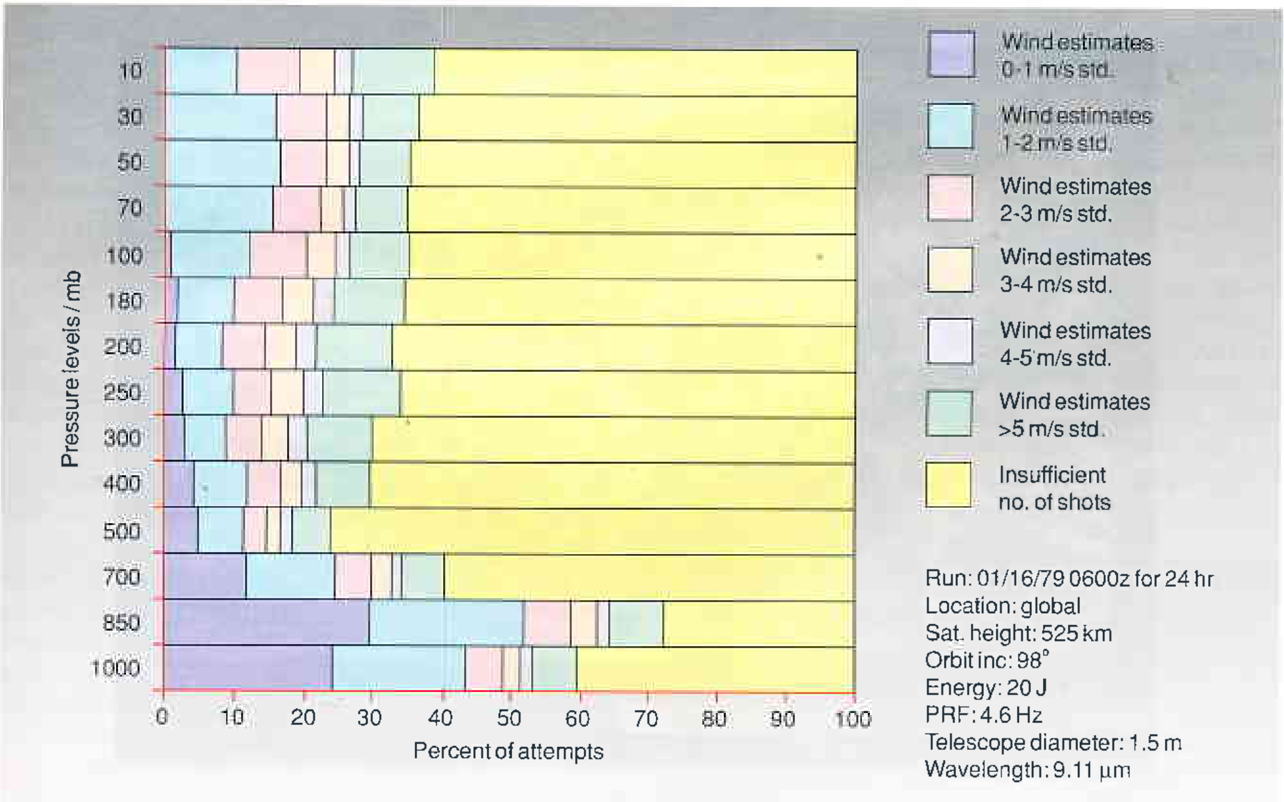
As well as improving our understanding of the Earth's climate system for climate change research, a space-based wind sensor will also significantly improve the accuracy of every-day weather forecasts.

Scientific studies to determine the effectiveness of a space-based wind measurement system have been carried out as part of NASA's LAWS programme and for the European Space Agency. The studies have included extensive modelling of the expected data products from a Doppler Wind LIDAR (figs. 6 and 7). These have been fed into Observing System Simulation Experiments (OSSEs) which simulate the effect of a LAWS instrument on wind measurements and weather prediction. An example, with an explanation in the caption, is shown in fig. 8, demonstrating the significant improvement in wind measurements that would arise from the use of the instruments[7]. Such detailed knowledge of wind speeds and directions will, in turn, improve the accuracy of weather forecasts.

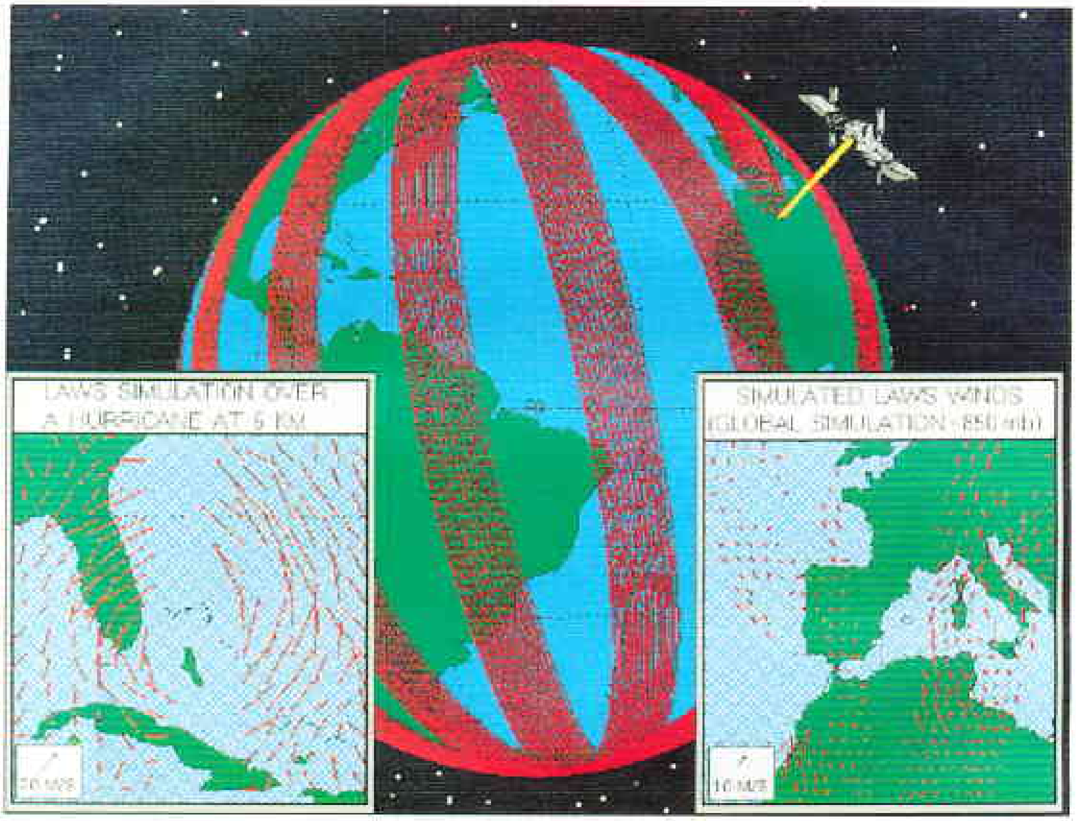
A good example of the positive impact of a Spaceborne Doppler Wind LIDAR is the October 1987 storm in the United Kingdom, that British weather forecasters unfortunately failed to predict. Analysis by the United Kingdom Meteorological Office concluded that a Spaceborne Wind LIDAR would have detected a crucial jet structure near Newfoundland which, in turn, would have led to an accurate prediction of the storm[8].

6

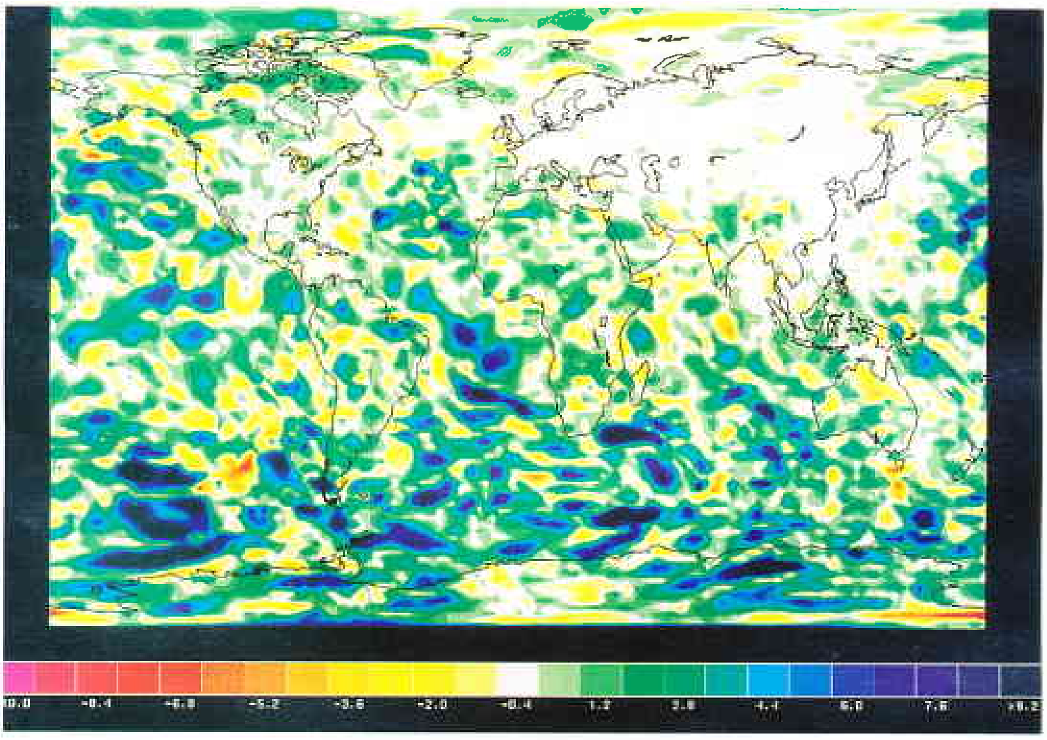
5 ***LAWS 13 hour coverage at a 525 km orbit (courtesy Simpson Weather Associates)***



6 ***LAWS performance profiles (courtesy Simpson Weather Associates)***



7 *Simulated LAWS wind measurements (courtesy Simpson Weather Associates)*



8 ***The impact of a 20 J pulse energy LAWS in polar orbit on the 400 mbar zonal wind, after 24 hours of assimilation. Areas of blue and green denote regions of positive impact, that is, where the assimilation of LAWS data has reduced the wind error. Scale shows reduction in r.m.s. wind error, units are m/s. (courtesy NASA Goddard Space Flight Center)***

The Applied Physics Division's LAWS Phase One Study

The Applied Physics Division's involvement in space-based wind measurement centres around the laser transmitter; the Applied Physics Division (now part of GEC-Marconi's Hirst Research Centre) has been carrying out laser research and development since 1963, shortly after the invention of the laser. Lasers developed by the Applied Physics Division include helium-neon lasers, continuous wave and pulsed carbon dioxide gas lasers, deuterium fluoride, helium-xenon and dye lasers, as well as carbon dioxide and solid-state laser systems.

The Applied Physics Division was selected as a laser transmitter sub-contractor to Lockheed Missiles and Space Company, prime contractor for LAWS under contract to NASA. The Defence Research Agency (DRA), Malvern, acted as consultants to the Applied Physics Division for the study and Matra Marconi Space (UK) provided assistance on space aspects(9).

Selection of Laser Type

The requirements for a satellite-based laser transmitter for wind measurement are demanding. First, the laser must be eye-safe in case anyone on the ground should inadvertently look up at the satellite whilst the laser is transmitting. Any wavelength below 1.4µm is therefore undesirable, as visible and near infra-red radiation is focused by the lens of the eye onto the retina. At the laser pulse energy needed for wind measurement, damage to the retina could occur. The eye safety consideration therefore almost certainly precludes the well-established Nd:YAG laser emitting at 1.06µm. Two laser types were considered for LAWS, an erbium- or holmium-doped YAG solid-state laser, operating around 2.1µm, and a carbon dioxide laser, operating at 9 – 10µm. While the 2µm laser offers potential advantages of small size and high reliability, at present the technology is not as mature as that for a carbon dioxide laser, especially at high energy levels. Therefore, a pulsed carbon dioxide laser, emitting at 9.11µm, was selected for its proven technology, eye safety, good atmospheric transmission and high backscatter from aerosols.

Laser Requirements

The required velocity accuracy of ±1m/s and the vertical resolution of 1km lead to a pulse length requirement of 3 – 5µm and a laser frequency stability of better than 200kHz. In order to obtain an adequate return signal from backscattered radiation, a laser pulse energy of about 10J is required. A 10Hz pulse repetition frequency and a 10^9 pulse lifetime is necessary to obtain full coverage around the globe continuously for three years. Finally, limitations on the size of solar arrays require an overall efficiency of at least 5%.

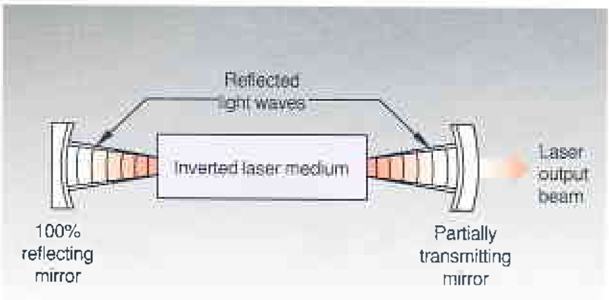
While these performance requirements have all been demonstrated individually in the laboratory (with the exception of lifetime), they had not been demonstrated in a single, compact laser suitable for space use, prior to the LAWS programme. Of all the requirements, the lifetime of 10^9 pulses is the most demanding, as, to our knowledge, the maximum demonstrated lifetime of a CO_2 laser was previously 2×10^7 pulses(10).

Introduction to CO_2 Laser Technology

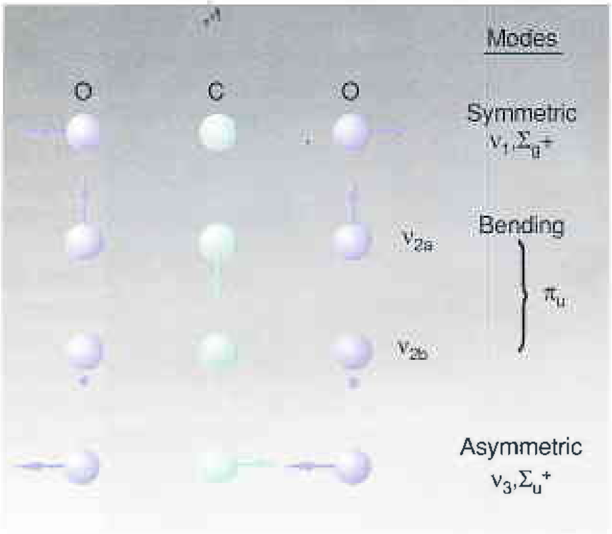
All lasers are based on the principle of establishing a gain medium in which radiation of a certain frequency is amplified. Feedback is provided by reflectors at each end of the gain medium, one of which is made partially reflecting in order to extract radiation (fig. 9).

A CO_2 gas laser takes advantage of the fact that a CO_2 molecule has three atoms, one carbon and two oxygen, which are normally static relative to each other, a condition referred to as 'ground-state' CO_2. If the gas is electrically excited, the oxygen atoms can vibrate relative to the carbon atoms in several possible ways; the molecule can either bend or stretch. Stretching can be symmetrical, that is, both oxygen atoms oscillate away from the central carbon atom at the same time, or asymmetrical (fig. 10).

These various vibrational modes have different energies and are referred to as vibrational states. The CO_2 is excited electrically to a high energy vibrational state, then decays by spontaneous emission to a lower energy vibrational state, in the process emitting radiation at wavelengths of 9.6 or 10.6µm (fig. 11). The molecule then decays back to the ground state, by collisional processes. As well



9 Principle of laser oscillation



10 ***CO_2 vibrational modes***

as carbon dioxide gas, nitrogen gas is added to assist in populating the upper vibrational state of CO_2. This is because of the fortunate coincidence that the excited vibrational state of N_2 has almost exactly equal energy to the upper vibrational state of CO_2. Helium is also added to help provide collisional depopulation of the intermediate CO_2 vibrational level back to the ground state.

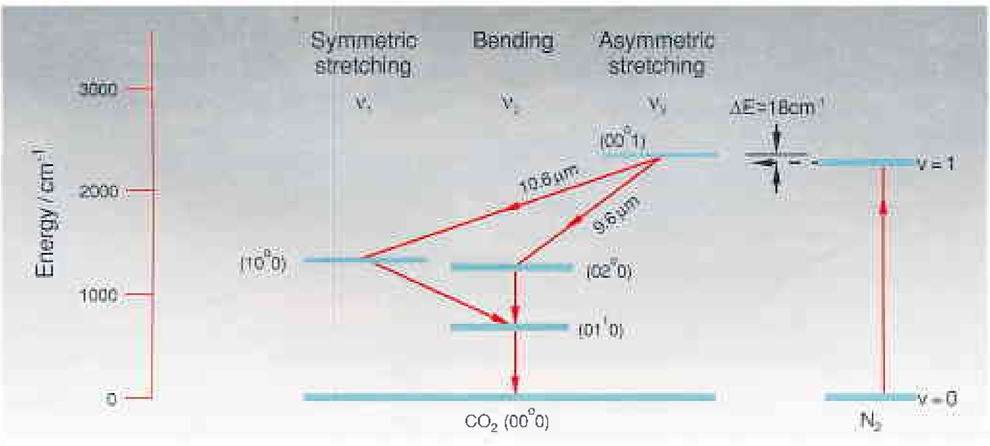
The earliest form of continuous wave CO_2 lasers used a permanent DC voltage excitation of a longitudinal discharge in low pressure gas. Such an approach is still used for lasers in industrial marking, welding and cutting. It provides a continuous beam that can be used for short range, ground-based Doppler Wind LIDAR, but is insufficiently powerful for a long range, space-based laser. A pulsed electric discharge is therefore applied in a transversely excited (TE) configuration. The significance of the transverse nature of the discharge is that, by operating with the electric field of the discharge transverse to the axis of the laser cavity, instead of down the full length, high electric fields can be obtained without excessively high voltages.

A pulsed discharge gives a pulsed laser output that can be a few microseconds long with a high peak power and energy. In turn, a high backscattered signal is obtained and, because the laser is pulsed, range information is obtained. The wavelength produced by the laser will normally be 9.6 or 10.6 µm, as described above. However, any radiation resulting from decay between vibrational states of a CO_2 molecule can, when transmitted through the atmosphere, be absorbed by natural CO_2 in the atmosphere. While this effect is slight, a worthwhile improvement can be obtained by using a rare isotope $^{12}C^{18}O_2$ gas instead of the abundant isotope $^{12}C^{16}O_2$. Using the rare isotope gas gives vibrational states with slightly different energies, leading to a shifted wavelength of 9.11 µm that has improved atmospheric transmission.

Whichever type of CO_2 gas is used, as a result of electron impact during the pulsed electric discharge, some CO_2 dissociates as follows:

$$2CO_2 \rightarrow 2CO + O_2 .$$

Such dissociation is undesirable because it leads to loss of CO_2 and eventually a reduction in laser output energy. More significantly, a build-up of oxygen can be detrimental to the uniformity of the laser discharge, in the worst case resulting in an arc between the electrodes rather than a glow discharge. In the very short term, that is, between laser pulses, the dissociation products need to be swept away by circulating the gas using a fan. In the longer term, the dissociation products must be removed and fresh CO_2 supplied. For industrial



11 ***Energy level diagram of CO_2 laser***

applications and in the laboratory, this is often achieved simply by flowing fresh gas in at a slow rate and removing old gas. For a space-based system, heavy gas cylinders would be impractical and a sealed laser is required. It is intended that a catalyst be used to recombine CO and O_2.

One approach is to use a specially developed solid catalyst, similar to that found in car exhausts but capable of operating at room temperature. Such a catalyst is referred to as heterogeneous, to indicate that reactions take place between a gas and solid. An alternative method of recombining CO and O_2, described later in this article, is homogeneous, and involves purely gas phase reactions.

A side effect of the dissociation and recombination by use of catalyst, in the case of the rare isotope $^{12}C^{18}O_2$ laser, is that the process allows exchange of ^{18}O atoms with any residual ^{16}O atoms in the system that may be absorbed on the surfaces of solid material used to construct the laser. Such an effect, known as isotopic scrambling, is clearly undesirable as it would result in changes to the output wavelength of the laser. It is particularly likely to occur when a solid catalyst is used, as a major constituent is tin oxide, SnO_2, containing ^{16}O atoms. However, processing techniques have been developed to overcome scrambling effects.

Study of Alternative Discharge Technologies

The following CO_2 laser discharge technologies were considered for LAWS:

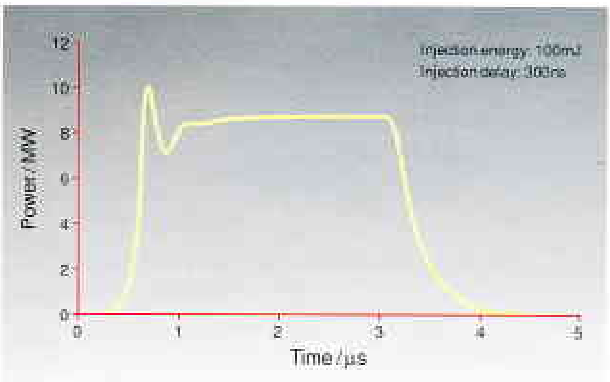
- *Self-Sustained.* A high electric field of 10 – 15kV/cm .atm is used such that ionization balances electron attachment. Pre-ionization, usually ultra-violet radiation generated by a corona discharge, is required to provide initial electrons.
- *Pulser-Sustainer.* A short, high voltage pulse provides initial ionization, often augmented by pre-ionization. A lower voltage long pulse sustains the discharge at around 8 – 12kV/cm .atm.
- *e-Beam Sustained.* The electric field is maintained at a reduced value near 4kV/cm.atm to provide excitation of the upper laser level with maximum efficiency. The gas is ionized directly by a beam of high energy electrons, produced by an electron gun and injected through a thin metal foil.

Trade studies were carried out to determine the optimum discharge technology. An e-beam sustained laser was selected by the Applied Physics Division for the following reasons.

- *Efficiency.* The e-beam sustained laser is inherently more efficient than other discharge technologies as the laser electric field can be optimized independently of the electron source. The requirement for a 5% overall efficiency can therefore be more easily attained.
- *Pulse Shape.* A computerized parametric model was used to predict the LAWS pulse shape and optimize operating conditions. Fig. 12 shows the characteristic top-hat pulse shape of the e-beam sustained laser, with a sharp cut-off that prevents confusion over returns from cloud. This is more suitable for LAWS applications than the pulse shapes produced by self-sustained and pulser-sustainer lasers, which have a sharp peak followed by a long tail.
- *Gas/Catalyst Lifetime.* CO_2 lasers normally use low-temperature solid catalysts to recombine CO and O_2 produced by the gas discharge. The oxygen generation rate for an e-beam sustained laser is effectively 10 to 100 times less than for self-sustained. The e-beam sustained laser therefore requires less catalyst and is ideal for long-term gas control and reduced isotopic scrambling.

Although the e-beam sustained laser has major advantages, it also has drawbacks which were analysed as part of the study:

- *Foil Lifetime.* One potential risk area for an e-beam sustained laser is the lifetime of the thin foil that separates the laser head from the electron gun. Analysis has shown that with conservative foil design, lifetimes of 10^9 pulses should be achievable.



12 ***Pulse shape of e-beam sustained laser***

- *Radiation Issues.* The high voltage electrons produced by the electron gun generate X-rays which could be detrimental to other components on the satellite. Analysis and test results indicate that the levels are less than the background radiation in space for a polar orbit.

Concept

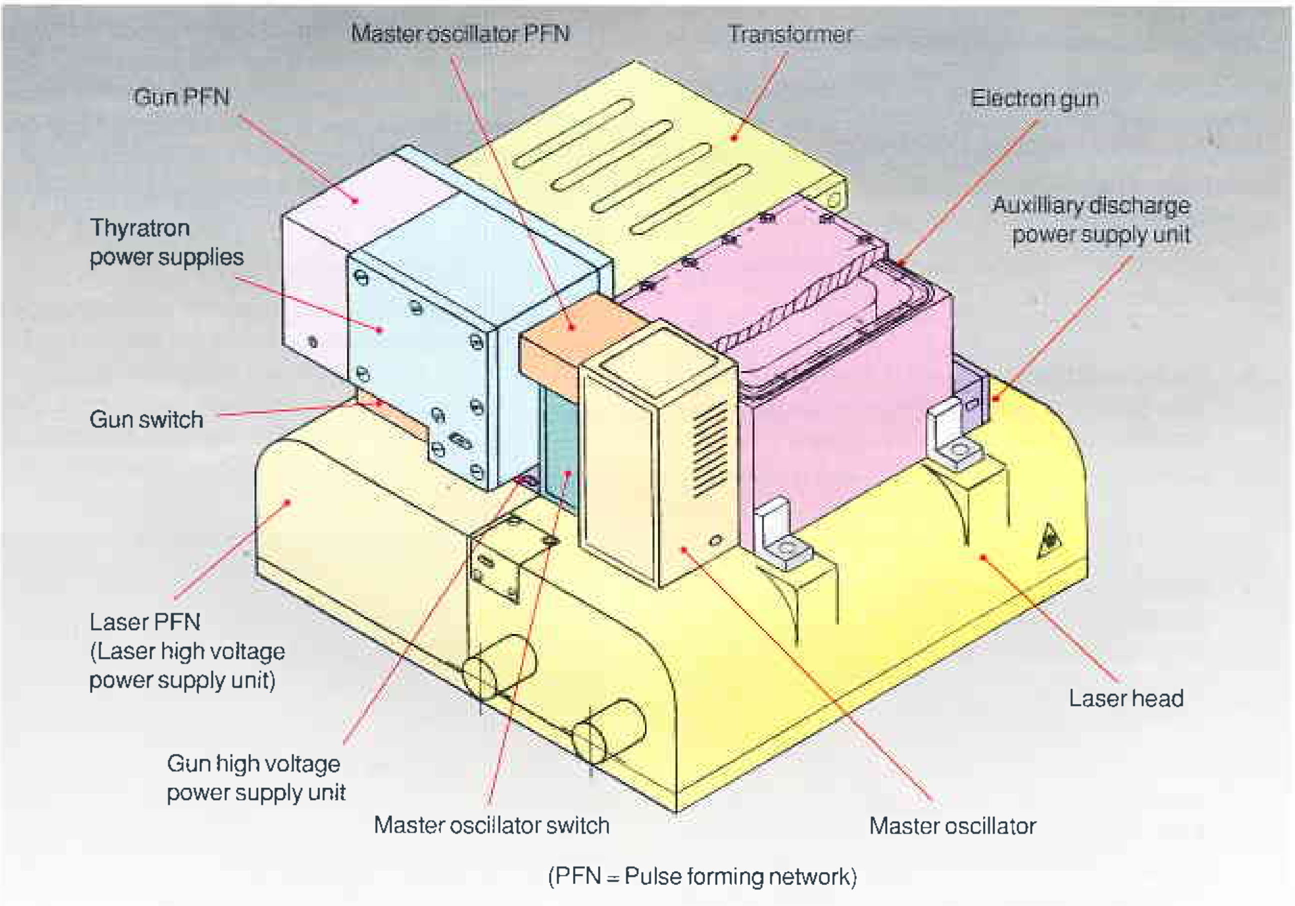
The above trade studies led to the selection by the Applied Physics Division of an e-beam sustained laser for LAWS. Other design considerations are summarized below:

- *Frequency Chirp.* Analysis of the expected frequency stability was carried out by the Applied Physics Division and compared with experimental data from DRA. Laser Induced Medium Perturbation (LIMP) effects can be controlled by the correct choice of a large cavity aperture. Plasma effects require the current during the laser pulse to be maintained constant to about 1%. Cavity length effects are controllable by correct mechanical design of the resonator.
- *Resonator.* An unstable resonator was selected as the baseline concept for good transverse mode selection from a large aperture cavity and high efficiency. Injection from another laser controls the single longitudinal mode of the high-power laser.

Configuration

A laser configuration was established (fig. 13) to provide information on laser power requirements, weight and physical dimensions. These were then fed into Lockheed's preliminary instrument design.

The study has led to the selection by the Applied Physics Division of an e-beam sustained laser for high efficiency, good frequency control, low CO_2 dissociation and a top-hat pulse shape. All NASA's requirements could be met with a compact, lightweight design. The lifetime of the electron transmitting foil was identified as a risk area that required further study and testing.



13 ***The Applied Physics Division's laser transmitter configuration for LAWS***

Foil Lifetime Studies

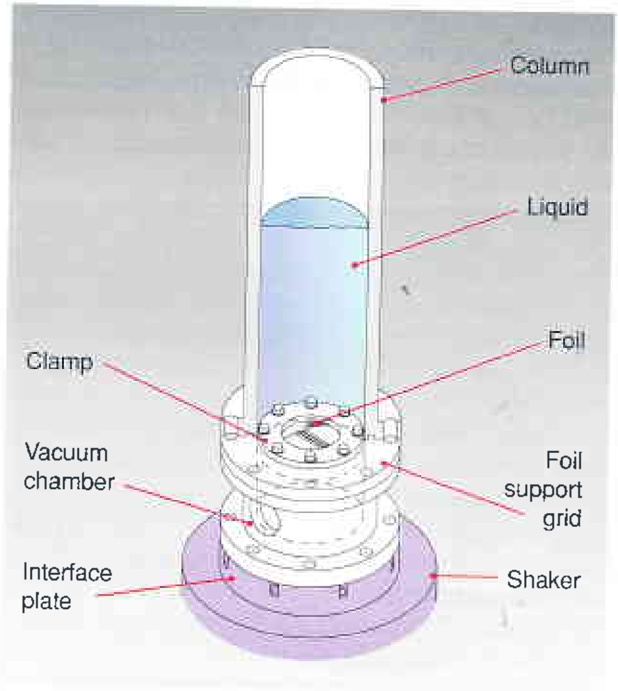
A programme of work has recently been undertaken to identify the optimum foil material and foil support structure for a space-based e-beam sustained laser, and carry out accelerated foil lifetests[11]. The work was undertaken by the Applied Physics Division, with DRA as consultants, under contract to Lockheed Missiles and Space Company, following on from the LAWS Phase One Study Programme.

In an e-beam sustained laser, the electron gun operates at near vacuum, and the laser at between 0.5 and 1 bar. The laser and gun are separated by a metal foil strong enough to maintain a gas seal but sufficiently thin to permit electron transmission. As each laser discharge produces a pressure pulse, it is possible for the foil to become fatigued with repeated laser pulsing, and then break, which would result in a failure of the entire laser.

A simulator has been designed and built to mimic the pressure pulse generated by the laser but to operate at much greater pulse repetition frequencies. The electron transmissions of materials investigated in the simulator have also been determined in an e-beam sustained laser, over a range of operating voltages. The equipment built is shown in figs. 14 and 15.

The simulator is mounted on a powerful vibration testing machine or 'shaker', that vibrates it in a vertical direction at frequencies of up to 4kHz. As the equipment moves upwards, so does the column of liquid contained in the upper section. The force required to move the liquid is provided by the foil which is thus subjected to an equal and opposite reaction. This reaction constitutes the pressure pulse. Changing the height of the liquid column or the density of the liquid changes the amplitude of the pressure pulse applied to the foil.

Initially, a very careful calibration procedure was undertaken to provide confidence in the representativeness of the simulation tests. It was found that the required pressure pulse could be accurately simulated up to a frequency of 4kHz, which allows 10^9 pulse lifetests to be completed in just a few days.



14 ***Liquid is used to simulate the laser pressure pulse and permit accelerated fatigue testing of candidate foil materials.***

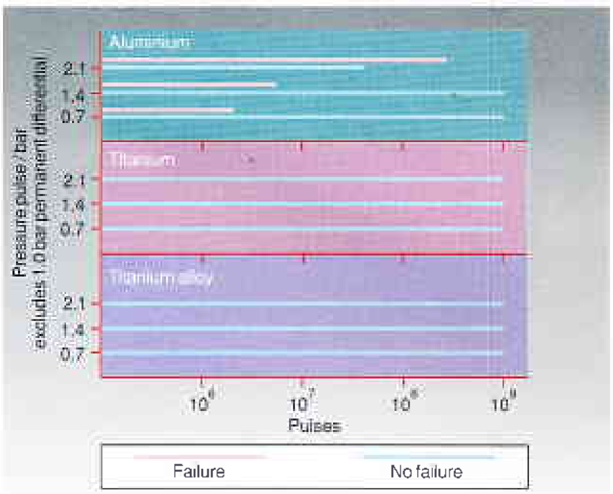
15 ***The Applied Physics Division's laser pressure pulse simulator***

Aluminium, titanium and titanium alloy foils of appropriate thicknesses for use in a laser (25, 15 and 12.5 μm respectively) were all lifetested using the simulator. A permanent pressure differential of 1 bar was maintained and pressure pulses of 0.7, 1.4 and 2.1 bar applied. These test conditions represent one, two and three times the real laser pressure pulse, respectively.

Aluminium foils behaved variably, some foils lasting 10^9 pulses, others failing at 10^6 pulses (fig. 16). The variation in aluminium foil lifetime, and the failures observed, are to be expected, as the material is being used above its elastic limit. The titanium and titanium alloy foils, being used well below their elastic limits, both survived 10^9 pulses at all three test pressures, with no failures whatsoever.

The simulation tests indicate that the titanium or titanium alloy foils are preferable from the fatigue viewpoint, as aluminium is being used above its elastic limit. It is highly encouraging that 10^9 pulse lifetimes have been routinely demonstrated, even at much higher pressure pulse levels than on the real laser.

However, it must be remembered that these tests were carried out at room temperature. Any electrons not passing through the foil (about 75%) are absorbed, resulting in foil heating. Aluminium has a high thermal conductivity, resulting in temperature rises of only five to 10°C at a laser repetition rate of 10 Hz. Titanium has a thermal conductivity an order of magnitude less than aluminium; also a foil of half the thickness is used to obtain electron transmission equivalent to that of aluminium. Temperature rises of 200°C are therefore possible.



16 *Results of accelerated foil fatigue tests*

Titanium alloy is even worse with a thermal conductivity one quarter that of pure titanium. At present, therefore, pure titanium is the preferred choice of foil. Ultimately, a clad metal consisting of a layer of titanium alloy for strength, and aluminium for high thermal conductivity, may prove to be the ideal material.

Development of CO_2 Laser for Spaceborne Doppler Wind LIDAR

The Applied Physics Division, Hirst Research Centre, is a member of an international team carrying out a significant part of the European Space Agency (ESA) programme for development of a CO_2 laser for Spaceborne Doppler Wind LIDAR, with DRA as prime contractor, and CISE S.p.A. and Dornier GmbH as the other sub-contractors. The work is being funded both by ESA's Technology Research and Development Programme and by its Earth Observation Preparatory Programme.

The system requirements for velocity accuracy, data coverage and instrument lifetime lead to a laser specification of: 10 J pulse energy, 10 Hz repetition frequency, a 5 μs pulse width, frequency stability of 200 kHz, an efficiency of 5%, and a lifetime of 10^9 pulses. The eventual wavelength will be 9.11 μm, obtained with $^{12}C^{18}O_2$ but, during the current programme, a wavelength of 10.6 μm or 9.25 μm will be demonstrated using $^{12}C^{16}O_2$, because of the high cost of the rare isotope gas.

During earlier phases of the project, an e-beam sustained laser concept was selected, with a novel, DRA designed, compact electron gun. The present programme, which started in July 1991, is of three and a half years' duration. Experiments with existing equipment, critical component analysis, and the laser, electron gun and resonator design, have been carried out in the first year; construction of equipment commenced in the second year, and testing is to take place in the third and final years.

The Applied Physics Division's role has been to undertake validation experiments using an existing e-beam sustained laser, and to design a compact breadboard laser, working closely with DRA who are also designing the electron gun, and CISE, who are designing the optical resonator. The Applied Physics Division has procured components and assembled the laser, and will soon integrate the laser with the DRA-built electron gun, and then carry out test and analysis, including frequency stability measurements and monitoring of output characteristics over a period of extended operation.

Gas Lifetime Experiments

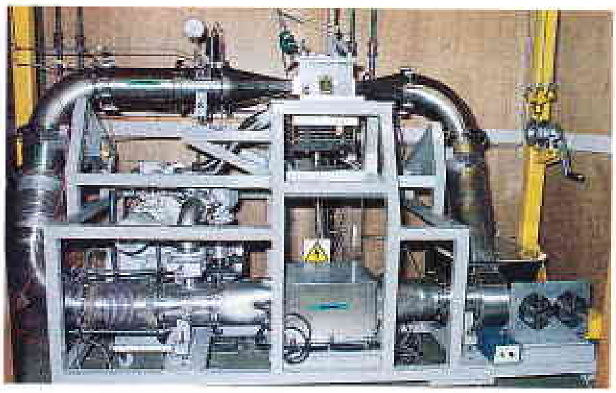
One particularly promising area being explored is that of homogeneous catalysis[12]. DRA have recently discovered an effect present in e-beam sustained lasers in which the primary electron beam from the electron gun directly 'burns' the CO back to CO_2, under correct conditions. It may therefore be possible to dispense with a solid catalyst altogether, with significant advantages of no flow impedance, no particulate shedding, no additional mass, lower cost, and elimination of isotopic scrambling. Even if solid catalyst is required, it will be a very much smaller quantity than that needed for an equivalent self-sustained laser.

The experimental work that the Applied Physics Division has undertaken to date has included modification of an existing e-beam sustained test-bed (fig. 17) to use representative operating parameters for a Spaceborne Doppler Wind LIDAR, and carrying out lifetests of up to 10^7 pulses to determine the long-term effectiveness of homogeneous catalysis[13]. Oxygen and carbon monoxide concentrations and discharge current – which correlates closely with laser pulse shape – were all monitored throughout the test. O_2 and CO build up rapidly at the start of the first test and then reach an equilibrium level because the recombination rate, caused by the primary electron beam, increases with CO concentration (fig. 18). There is a slight fall-off of oxygen over the 10^7 pulse run, because of oxidation of surfaces. A second lifetest of 10^7 pulses is shown in fig. 19 in which CO was deliberately added at the start of the run to maximize recombination and hence prevent oxygen formation. The achievement of demonstrated 10^7 pulse lifetimes for a full-scale laser is notable, even though they are two orders of magnitude less than the ultimate lifetime requirement. It is intended to extend the lifetests further towards 10^8 pulse lifetimes in the near future.

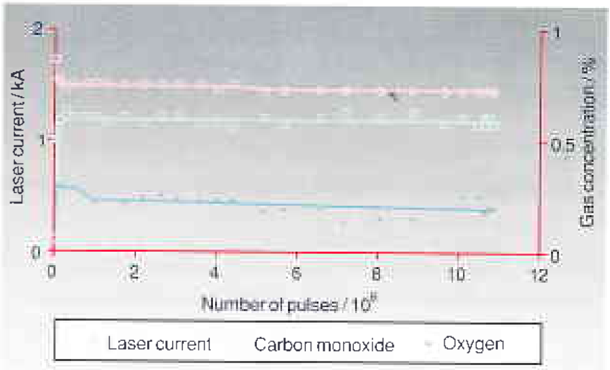
Laser Design

The objective of the laser development programme is to design, construct and test a laser breadboard with the necessary performance parameters for Spaceborne Doppler Wind LIDAR, which will require no major re-design for eventual space use. In other words, it must operate satisfactorily and have a similar physical configuration to the space hardware, but need not use space-qualified components or light-weight materials.

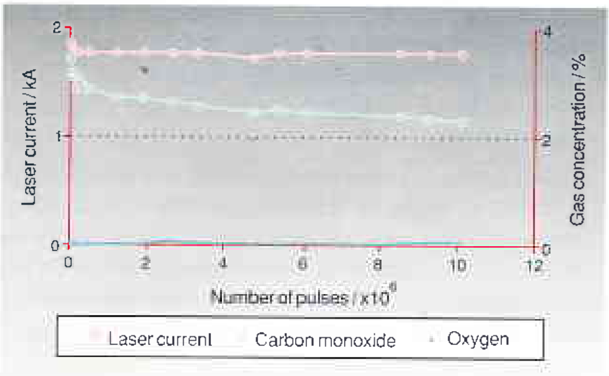
An important part of the design approach was, therefore, the dramatic reduction in size of the gas flow loop from that of the e-beam sustained test laser, leading to a compact, light-weight design.



17 *The Applied Physics Division's e-beam sustained laser test-bed*

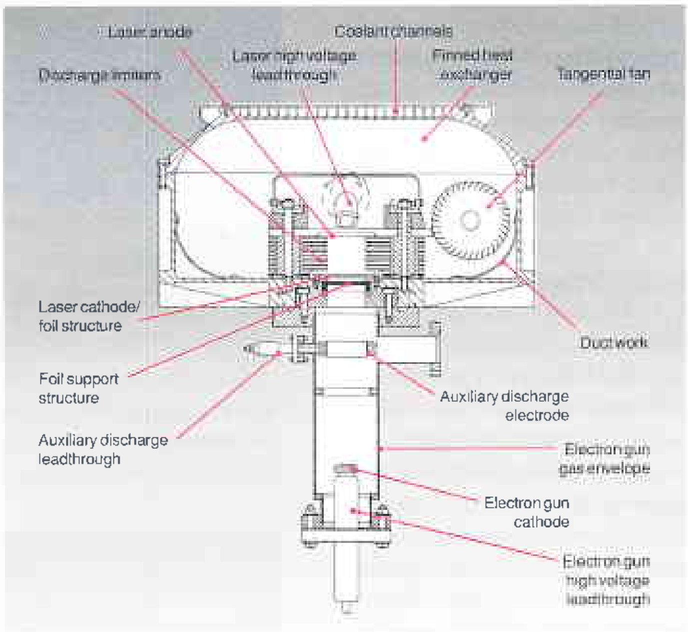


18 *10 million pulse laser lifetest*



19 *Second 10 million pulse lifetest, with CO added at the start of the run to prevent build-up of O_2*

An ability to tolerate the severe launch vibration was also a major consideration. A cross-section of the laser design is shown in fig. 20. The laser gas discharge itself is formed in a volume of gas whose square cross-section can be seen in the centre of the diagram, between the electron gun and an



20 *Cross-section of the Applied Physics Division's breadboard laser*

electrode to which a 10 – 20 kV pulse is applied (the laser beam is normal to the plane of the diagram). Ionization to sustain the discharge is provided by electrons from the pulsed gun, transmitted through the foil. Either side of the discharge are ceramic monoliths to act as discharge limiters, thermal and flow equalizers, and acoustic attenuators. Above the electrode is a ceramic insulator to isolate the high voltage electrode. Gas is circulated around the laser by a tangential fan along the full length of the laser discharge. The gas is then ducted to an integral heat exchanger (to remove the 1.2 kW of electrical energy that is not converted to laser output) and then back to the fan, resulting in a closed-cycle system. The overall size of the gas loop is a fraction of the size of the large external ducting of the e-beam sustained test laser. The gas envelope comprises a case and heat exchanger/cover, both machined from solid aluminium for high vacuum integrity and rigidity under vibration (figs. 21 and 22).

Other important design factors are:

- *Gas Contamination.* All materials must be vacuum compatible, eliminating rubbers and plastics.
- *Vacuum Integrity.* The gas envelope must be helium leaktight to prevent leakage of gas in space.

21 *Laser case with tangential fan installed.*

22 *Integral heat exchanger/cover machined from solid aluminium*

- *Opto-Mechanical Stability.* The laser cavity optics must be kept parallel to within five arc-seconds.

23 Breadboard laser with stable resonator mount

This last consideration has led to the design of an external resonator structure on which the laser optics are mounted. It is vibration-isolated from the laser itself to prevent coupling of fan vibrations and laser pressure pulse effects to the resonator; its length is maintained by three low-expansion invar tubes (fig. 23). The resonator structure is mounted on an aluminium honeycomb breadboard that also carries the injection and local oscillator lasers, fold optics, and detectors.

At the time of writing, the laser has been assembled and is currently undergoing initial tests.

Conclusion

A Spaceborne Doppler Wind LIDAR will have a major impact on climate change modelling and numerical weather predictions. The Applied Physics Division, Hirst Research Centre, has been developing a laser transmitter for this application to a demanding performance and lifetime specification. In the LAWS Phase One Study, it has been shown that the e-beam sustained laser has many advantages for Spaceborne Doppler Wind LIDAR, but foil lifetime was identified as a risk area. The Lockheed-funded programme addressed this risk area, and foil lifetimes of 10^9 pulses were routinely demonstrated. In the European Space Agency programme, a 10^7 pulse lifetime has been achieved using a full-size test laser and gas phase catalysis. Finally, a compact, rugged e-beam sustained laser breadboard has been designed and is currently being tested.

Acknowledgements

I would like to acknowledge many of my colleagues from the Applied Physics Division, Hirst Research Centre – in particular, M. J. Brown, W. E. Holman, R. C. Leybourne, R. J. Robinson, I. M. Smith and S. Wallace. Many other organizations have played an important part in the developments described in this article, and I would like to express my thanks to a number of individuals at CISE S.p.A., Dornier GmbH, DRA, the European Space Agency, Lockheed Missiles & Space Company, Matra Marconi Space (UK), NASA, NOAA, Simpson Weather Associates and the University of Alabama, Huntsville for their assistance and the provision of photographs and diagrams. Funding for the work described in this article has been received from the European Space Agency, Lockheed Missiles & Space Company and NASA, and is gratefully acknowledged.

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The Cordless Office

by J. E. GOODMAN, BSc, FIEE
GPT LIMITED

Much has been written over many years about the use of cordless connectivity in the office. The use of infra-red to link data terminals was proposed by IBM in the late 1970s and, more recently, the replacement of the ubiquitous wired telephone by means of radio techniques has been an intense area of study. The question has to be asked whether technology now provides a mobile solution attractive to the user or is there some way to go?

This article explores the existing situation and also looks into the future for cordless telephony – widely regarded as one of the most important changes in the working environment since the introduction of the word processor.

J. E. Goodman graduated in Electrical Engineering at Manchester University in 1960 and, after a short spell in the aviation industry, moved to Marconi Radar Systems at Great Baddow to work on displays and signal processing. He joined what was then Plessey Telecommunications in 1973, based at Beeston, Nottingham. Apart from a period of two years with Nexos Office Systems in Bristol, he has been involved in private switching systems and networks ever since. His interest in the use of radio in the office began in 1982 when the first cordless telephone products began to appear in the domestic arena. He was on the original working party specifying CT2 as well as the British Standards Institution (BSI) committee for cellular phones. He is now heading the hardware development department of GPT Business Systems Group in Nottingham.

The Marketing Case – or 'Why do I Need a Cordless Connection?'

Communications can be broadly divided into three categories: voice, video/image and data. The most important of these at present is voice, followed closely by facsimile, which can be regarded as a combination of image and data.

Voice communication is vital because most actions are initiated by people after consideration of information which is held either by the decision-taker or in the mind of someone else, not in some data bank. No doubt this will change as machines become more sophisticated to the point where they can initiate actions reliably. Until this is possible, people will continue to rely on voice contact to amass information in determining a course of action. Personal contact is the only trusted mechanism.

There are, however, many obstacles to direct communications between people, especially in the office situation. Meetings, enforced absences from the desk and sheer bad luck result in up to 70% of business calls not reaching the intended person first time. How many times have you answered a colleague's telephone only to have to give those lame excuses:

'His (or her) coat is here',
'He/she can't be far away', or
'I'm sure he/she'll be back in a moment',

ending of course with that defeatist:

'May I take a message or get him/her to ring you?'

This is the starting point of the telephone tag syndrome – an endless cycle of left messages and missed calls – which can mean that it is several days before contact is made. Given this need, why is it that, up until now, the use of portable telephones at the workplace has not been widespread?

The answer lies in achieving the right balance between technological solution and cost. In the case of the cordless office, a practical solution has not previously been available and definitely not at the right price.

Paging has gone some way to satisfying the need, but it does not provide full two-way speech which is required for business applications. Second generation cordless telephony, however, now satisfies this requirement and, moreover, was specifically designed to do so.

The Technologies

Fundamentally, cordless telephony consists of a portable handset which is connected by radio to a base-station connected to an incoming telephone line. The radio power used is very low – typically 10 mW – and therefore distance is limited, even in open space, to around 200 m.

Most readers will be familiar with the domestic cordless telephone. These CT 0 models have proved the convenience of mobility in the home. Cordless Telephone Generation 0 (CT0) phones operate on eight fixed channels at around 1.8 MHz in the base-to-handset direction, and 47 MHz in the handset-to-base direction.

To clarify any confusion, the more secure version – with security coding to stop anyone else making calls on your base station – was called CT 1. However, this designation is more universally applied to a 900 MHz product specified by CEPT

(Committee European Post and Telephone) and used mainly in Germany.

The use of CT0 in the office is severely limited by the number of channels and the lack of encoding of the speech and signalling. Any other CT0 telephone on the same frequency will directly interfere with a user, creating noise and lack of security. These problems are overcome with later systems such as CT2 and DECT (Digital European Cordless Telecommunications standard). CT2 is now a European standard and is being rapidly adopted in the world – not just for the office, but also for Telepoint public services (described later).

DECT is another standard which, with CT2, is being adopted in Europe. DECT will emerge later, and products will be commonly available by mid-1995, by when the two standards will jointly satisfy requirements for cordless telephony in the office environment.

A comparison table is shown in fig. 1 which summarizes the characteristics of both standards. It is worthwhile noting that CT2 operates at a frequency of 864 – 868 MHz, whereas DECT is at the higher frequency of 1.8 GHz.

With either system, the handset must be registered on the base station before the user can make and receive calls. Unique identities are programmed in during manufacture, so that handsets have PIDs (portable identities) and base stations have BIDs (base station identities). By recognition of these identities in the signalling between handset and base station, the correct call can be set up.

System / standard	CT2/CAI	DECT
Owner	ETSI	ETSI
Applications	Residential Business Public	Residential Business Public
Access method	FDMA/TDD	MC/TDMA/TDD
Bandwidth per RF carrier	0.1MHz	1.728 MHz
Number of carriers	40	10
Channels per carrier	1	12
Total number of channels	40	120
Radio spectrum	4 MHz	20MHz
Bandwidth per channel	100kHz	167kHz
RF output power peak	10mW	250mW
RF output power peak (mean)	5mW	10mW
Traffic channel bit rate	32 Kb/s	32 Kb/s
Speech coding	ADPCM	ADPCM

1 *CT2 and DECT compared (ETSI is the European Telecommunications Standards Institute)*

The Cordless Concept

If we look at the benefits of cordless connectivity to various occupations we can picture the requirement as a matrix (see fig. 2). There is a range of users, varying from a requirement for very low functionality given by a single cordless telephone extension, all the way through to the multi-site business, in which many users move around. Somewhere in between is the single, but larger, site where a number of coverage areas are required, including small offices which may still require high functionality and be part of a larger network.

We can illustrate this using fig. 3, where the radio coverage is represented by the areas covered by the 'circles'. In any of the circles a user can be given radio coverage; but only where numerous circles overlap (as at top right) does the user obtain true total coverage and mobility.

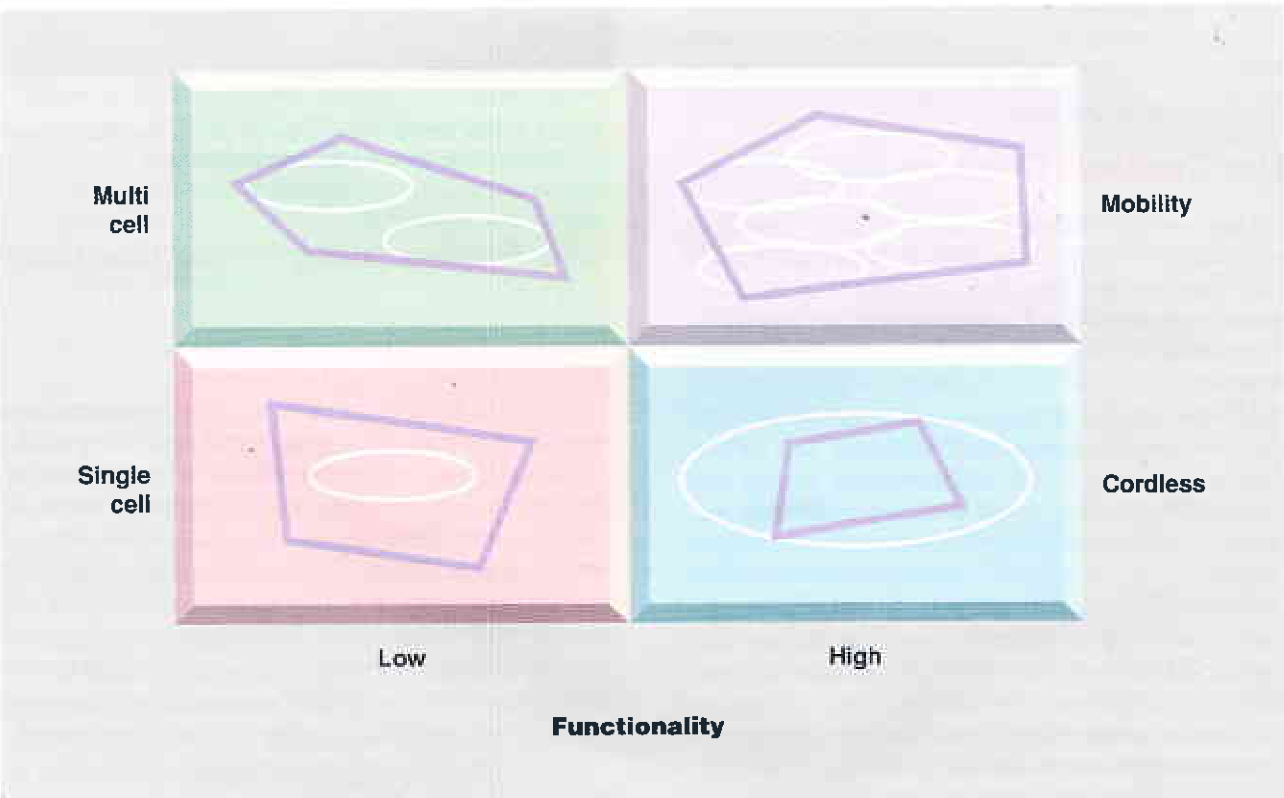
The functional user aspects are summarized by fig. 4. Obvious cost benefits flow from increased contactability.

CT2 Applicability to the Cordless Office

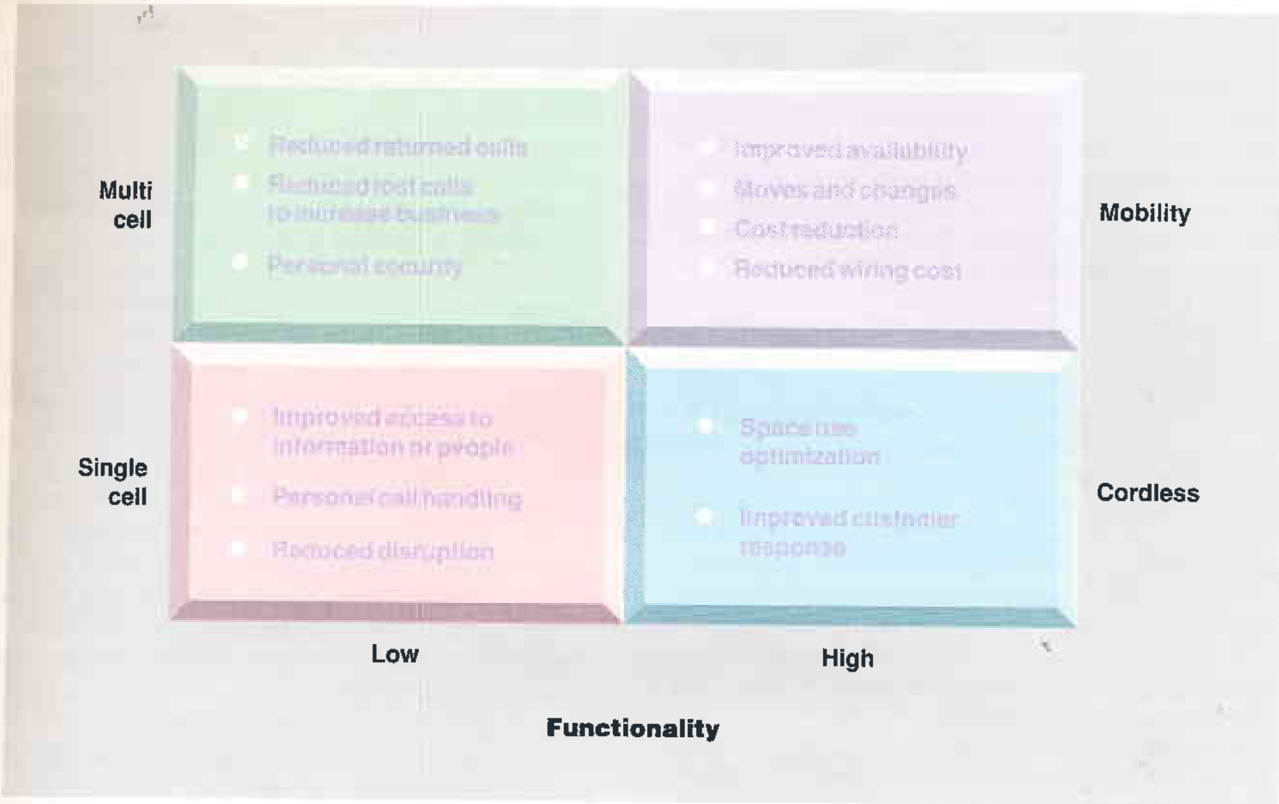
In the office environment, most people require a telephone, but only some will have cordless handsets. Most will be connected to the office telephone system or Private Automatic Branch Exchange (PABX). Some users will have both a wired telephone and a handset. It is necessary, therefore, to integrate the radio aspects with the usual PABX functionality. This is generally done by the use of separate radio controllers (called Cordless Concentrators by GPT) connected by several speech and signalling paths into the main switch.

Why, then, are the new cordless technologies so suitable to both business and domestic applications? Again, looking at fig. 1, we can see the similarities of CT2 and DECT. The technical

2 *The benefits of cordless telephony to various occupations*



3 *Radio coverage*



4 ***User benefits***

attributes of CT2 that make it suitable are apparent.

The first reason is the number of channels available (40) so that potentially, in a given radius, 40 simultaneous users could be supported, which would give a practical figure of well over 100 users where each one makes average use of the telephone.

The second reason is that CT2 (and particularly the Common Air Interface protocol) dynamically allocates channels as they are required. That is to say that the handset finds a suitable channel on which it can transmit and agrees this with the base station, whereupon a call can be made. This eliminates the need for a very large Mobile Switching Centre (MSC) which controls the channels. The need for an MSC is one reason why cellular radio systems cost so much. It also means that there is no need for frequency planning when laying out the cordless office coverage which, for economic reasons, needs to be a short and simple exercise.

The third reason is that the burst mode transmission eliminates the need for an expensive diplexor filter at the RF front end, making cheaper solutions for radio parts possible. This 'ping–pong' technique, technically known as Time Division Duplex, means that the handset takes up 1 ms and the base station also takes up 1 ms of the 2 ms message period. The complication here is that it is much better if all transmissions are synchronized, that is, all transmissions from base stations start at the same time so handsets respond at the same time, otherwise handsets in close proximity may interfere with each other.

These three advantages therefore enable CT2 to satisfy the needs of the office user. No list of technical benefits would be complete without dealing with the user, who will wish to move from floor to floor while using his or her handset.

The ability to make and receive calls at any point depends upon the system recognizing an identity, and its ability to track the user from location to location – known as roaming. It is perfectly possible for users to be registered on the system in such a way that they can move from site to site. If these sites are all part of the same private network, users can make and receive calls at any of the locations. Once a call is in progress, a user may wish to move from one coverage area to another. Provided that the areas overlap, this move can be made without dropping the call. This process is called handover and is perfectly feasible with CT2 or DECT.

The System Concept

The introduction of a radio connection in the office requires changes in the PABX. Calls must be routed to the appropriate radio base station communicating with the handset. In larger systems, polling to locate handsets must be done to ensure that the incoming call can be sent to the right area. The last known location, as well as the normal 'home' location, needs to be stored.

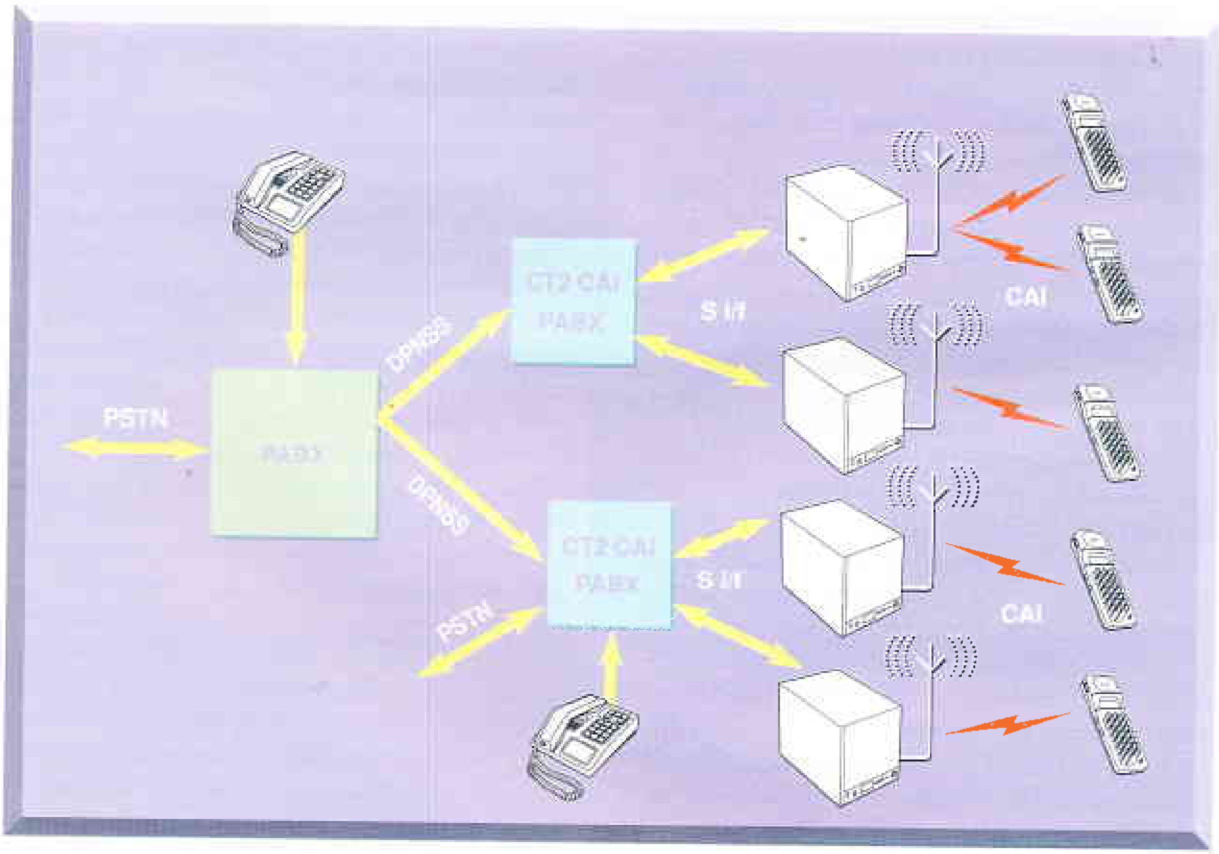
In a network such as fig. 5, sophisticated inter-node signalling needs to be employed – as in, for example, a Digital Private Network Signalling System (DPNSS) used for private networks in the UK. Records of valid handset identities need to be kept and, as each one is treated as though it were a normal extension, they must be included in the numbering scheme. Sophisticated interfaces such as the ISDN standard S Interface (S i/f) need to be used in order to ensure a fully-integrated signalling capability between nodes in the system.

Provision needs to be made for an alternative answering point for situations when the handset doesn't answer because the user has moved out of range (off site, or simply switched off). Having once 'lost' a handset, the system must expect it to 'arrive' anywhere in the network and must therefore be continuously trying to locate it unless, of course, the user makes a call, thereby telling the network where he or she is.

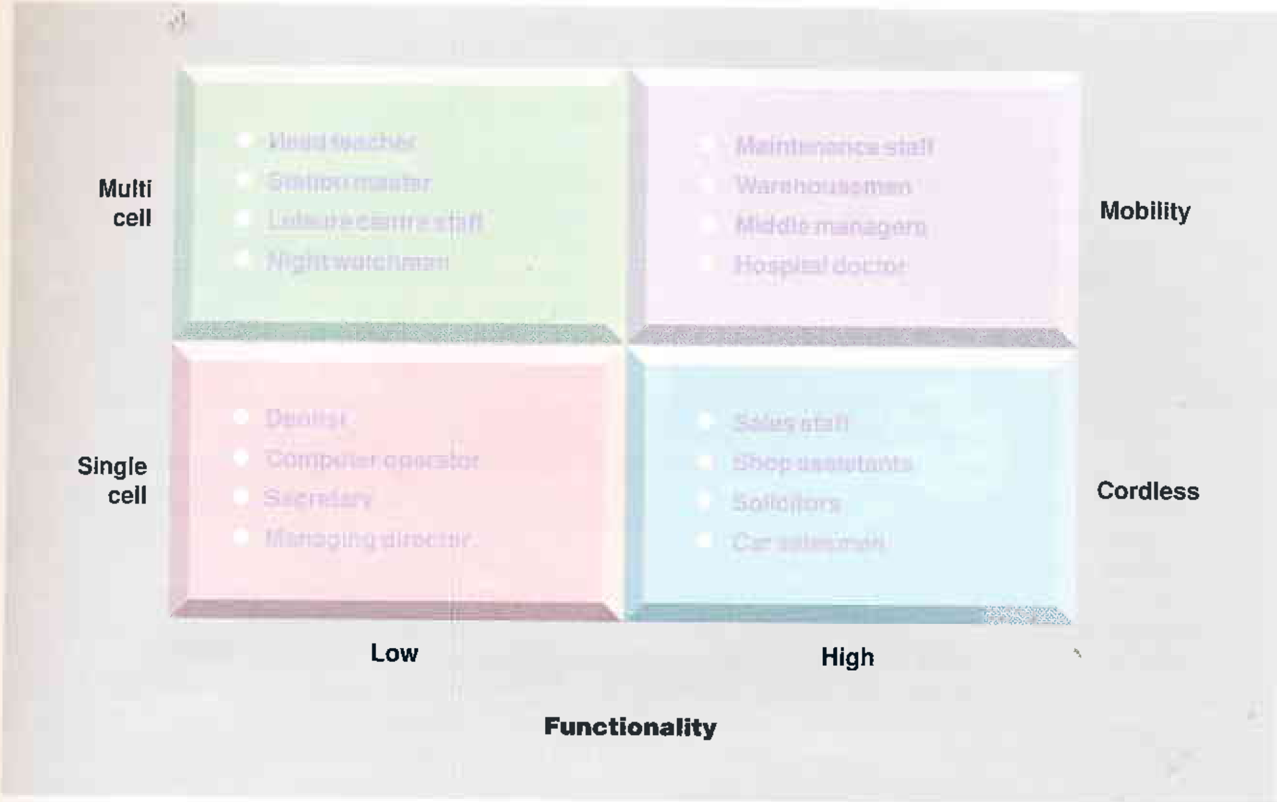
User Benefits

The principal benefit to the user is increased contactability. There is the freedom that comes from knowing you won't miss a call simply because you are not in earshot of the telephone. Cordless communications will change the working habits of a lifetime. It is now possible to pick up a cordless handset and walk to the task in hand or towards the person you wish to see. Secretaries and receptionists are no longer chained to one location, and the pattern of work will change to reflect this new-found freedom. Other benefits referred to earlier in fig. 4 can be seen to relate to the occupations illustrated in fig. 6.

Experience bears this out. In early field trials, people soon found the ability to move around the office while in conversation with a caller was a considerable advantage. Mobility not only makes communication more flexible but also more personal and, hence, of a higher quality. Some users found that to be able to walk across the room while talking and asking questions provided a much better personal service than the hold-and-enquiry facility provided by conventional PABX services. The off-hook telephone lying on top of a vacant desk quickly becomes a thing of the past.



5 *Cordless working in a private network*



6 *Use of cordless telephony in the workplace*

Below are some examples of use.

- A person working in a confined location, such as a dentist, can answer the telephone anywhere in the surgery, or be handed the portable phone by the receptionist should the call be urgent.
- Cordlessness in schools overcomes the problem of directing calls to teachers as they move from class to class. It also does away with the need to provide static telephones, which may be stolen or vandalized.
- In the factory environment, the role of the production manager may extend to several areas of the plant. Equipped with a cordless handset, he or she can go anywhere and still be reached when the need arises.
- The freedom to move about the office considerably improves the effectiveness of critical business activities and enhances all aspects of customer relations. The cordless PABX is, without a doubt, very good for business.

User requirements make other demands on the system and terminal. The mobility of users within private networks has required that special attention be paid to the user interface with PABX services. As handsets become personal items, users will demand that the same interface be presented, regardless of the host PABX. Similarly, the multiple applications nature of the cordless handset requires that handsets have common interfaces between public Telepoint and PABX applications.

There are of course times when users, or the people around them, may not wish to be disturbed; in this case they always have the ability to switch off the unit.

Radio Propagation in the Office

One of the major problems facing the developers of cordless PABX products is achieving integration of the cordless elements (radio fixed parts) into the overall architecture of the PABX. For the very small, single-cell, cordless PABX this is relatively simple, as the radio fixed part and antenna may be collocated within the PABX central unit.

Larger systems that need to encompass large areas or higher traffic volumes require multiple, strategically-located antenna systems and radio fixed parts to achieve the necessary service characteristics. However, large PABXs are typically hidden in back rooms and basements, along with network connection apparatus. As the architectural convenience of collocation cannot be achieved, designers of integrated cordless PABX systems rely on digital connection and signalling methods to allow the PABX to control the operation of the radio fixed part properly.

It is interesting to note that this is one application that benefits from the needs for ISDN-like signalling and access protocols. In order to integrate the cordless facilities closely into the operation of the PABX, while supporting user mobility patterns across several radio coverage areas, a high-speed transmission system is required which is capable of handling sophisticated control addressing and logistical signalling. GPT's experience in DASS, DPNSS, IPNS and the Q931-based protocols is invaluable in providing a suitably-integrated product offering.

The basic elements of radio propagation cannot be ignored. In order to encourage re-use of frequencies, the effective range of the radio is limited by restricting the power provided to the aerial. In the case of CT2, this is 10mw. Although this would give a distance of over 200 metres in an open space, most offices have obstacles such as walls and cabinets which absorb or reflect the signal. Planning for deployment must take these, as well as the traditional multi-path effects covered by Rayleigh fading, into account.

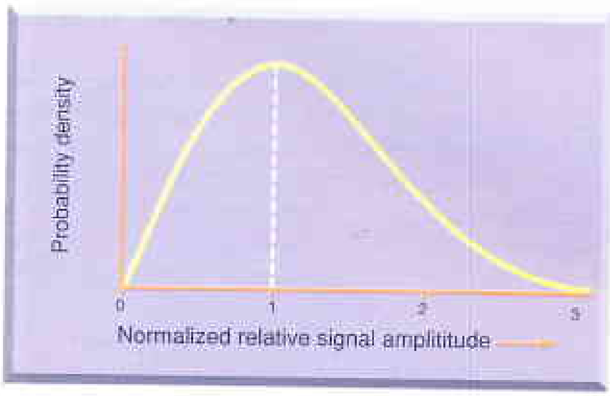
The fading at a particular location is caused by multipath interference effects. Fig. 7 shows the Rayleigh Fading (Probability Distribution Function) diagram. The vertical axis gives the probability of a particular value of the signal strength, which is shown on the horizontal axis and is normalized to be unity at the point of maximum probability. As an example we may examine the fade margin relative to unity signal strength. If we choose a fade margin of 10dB, the chances of falling within that margin are 93%. Conversely, if we wish to have a better than 99% chance of being within a particular margin, we must use a fade margin of 18.9dB.

To understand further the planning of cordless PABXs for deployment in the workplace, it is necessary to realize that the environment doesn't just change as a short-term dynamic, but can change after installation on a long-term basis. A filing cabinet, or screen, or other piece of office furniture introduced into the environment may change the pattern of propagation on a permanent basis. This sometimes causes losses nearer to 4th order, as in fig. 8.

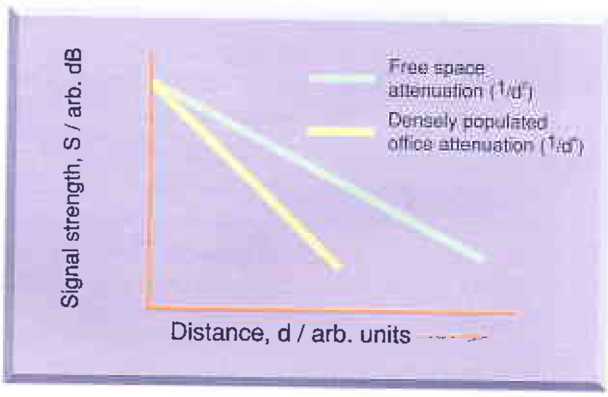
Nevertheless, it is possible to draw up a simple set of rules which satisfies most environments, although more sophisticated planning methods are needed for very complex buildings. It may be necessary to revisit installations from time-to-time, but a coverage survey can, of course, be included in the annual maintenance contract.

An experiment looking at the effect on propagation of furnishing a previously empty office building best illustrates the problems of installation performance guarantees. An initial propagation study conducted whilst the office was empty showed extremely good propagation characteristics, achieving better than free-space propagation as a result of the unobstructed tunnelling effect of the office construction. A similar propagation study carried out after the office block had been furnished showed a marked attenuation in signal as signal absorption and the interference effects of reflections increased.

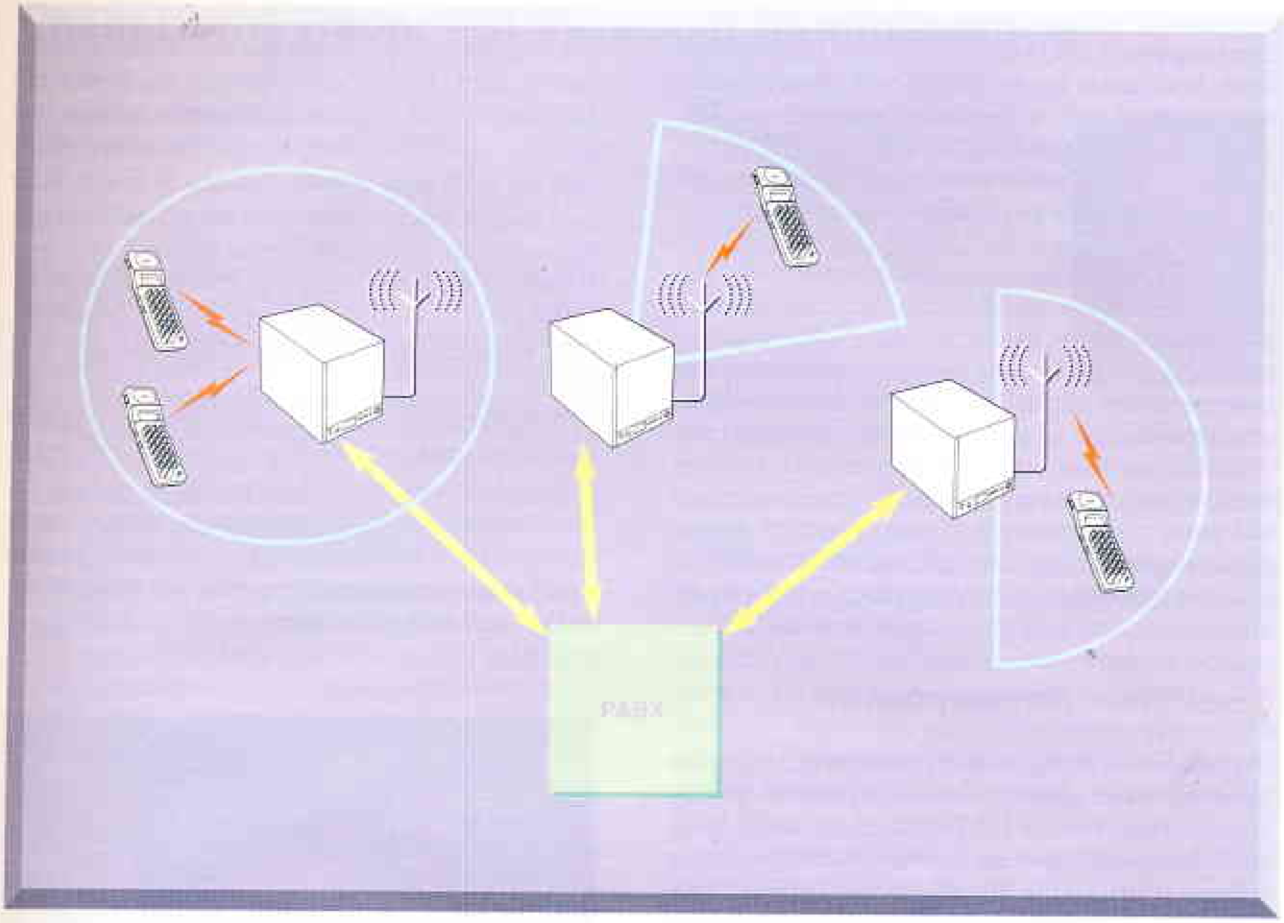
However, compensation for different environments can be made by the use of different aerial types. Illustrated diagrammatically in fig. 9 are some of the possible aerial radiation patterns. These, of course, are more shapely and three-dimensional in practice, but enable coverage to be tailored to the shape of the room and to suit the available mounting positions.



7 *Rayleigh fading probability distribution function*



8 *Radio propagation loss*



9 *Aerial radiation patterns*

Security

There are several aspects which come under this heading. First, there is the ability to make calls on a system to which the handset should not have access. This is avoided by the need for the registration process during which time a handset is authorized to use the system. This, of course, is particularly pertinent to the domestic situation. It could prove very expensive if a private telephone were to be used by anyone with a compatible handset.

Second, there is the chance of being overheard – a very common problem with CT0. This is eliminated on CT2 and DECT as channel allocation is dynamic, and therefore channels already in use will be automatically avoided. Even the use of a radio receiver tuned to the same frequency will be baffled by the encoding system.

Benefits to the Business

The benefits of cordless telephony do not necessarily all apply directly to the handset user. Customers benefit because calls reach their intended recipients at the first attempt. The company benefits because there is no need to return calls, for which it has to pay. Transactions are quicker, and the efficiency and productivity of both customer and supplier of goods and services is improved.

That awkward problem of moving people around on a large site is solved by giving them a cordless handset. Staff no longer have to be left stranded without a phone while waiting for one to be installed. Furthermore, important business visitors to a site can be provided with a handset for the duration of their stay.

Telepoint

This is best visualized as a complementary service to the cordless office and, for that matter, to the use of the handset at home. The service enables users to make calls at convenient points distributed around the country in such a way that most commonly-used areas are well covered, and those with light use, less so.

The practical range of CT2 outdoors is around 200 m, so a suitably-registered handset can make calls easily in the vicinity of banks, restaurant chains, petrol filling stations, railway and bus stations, and major stores, which will all eventually be equipped with a Telepoint base station. This means that a business or private user will eventually be able to make calls easily at convenient points on his journey to and from business appointments or the office.

In other areas, service is not as easy to obtain, but once a user establishes a knowledge of available service points, then it becomes easier to judge from where to make calls. In city centres, users can use handsets almost anywhere: selectively in small towns, and on motorways by stopping at service stations. Telepoint is not generally a two-way service, so that one cannot usually receive calls – but there are exceptions. Some operators offer a feature by which the user can register that he/she is at one location and, provided they remain there, the system can route incoming calls to them.

The Future Developments

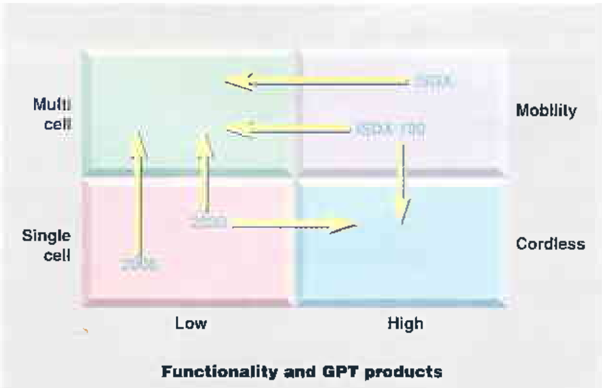
The move towards mobility at work will continue because of increasing pressure to provide quality customer service (fig. 10). Furthermore, some tasks will change on the assumption that the person doing the job is more mobile. Technology will provide ever smaller handsets (the current size may be seen in fig. 11) until only the physical limitations of keyboard size and earpiece remain. After all, until voice recognition replaces the keypad, most of us will prefer to push buttons with our fingers, and the earpiece demands a certain size to reproduce enough sound.

10 *A GPT 2000 cordless handset in use in the workplace*

The cordless handset of the future, therefore, is likely to be flat and twice the size of our average credit card. For office applications, it will still require a good display and feature buttons. But outside the office, a very limited function product will be sufficient to keep people in touch. Most probably it will be registered on a number of systems giving coverage in the office, home and street, as well as fitting into the car adapter for access to the cellular networks when on the move. GPT products for the office fit into the matrix in fig. 12.

Unfortunately, the radio spectrum is a limited resource and is only expanded by moving to higher frequencies and new coding techniques. This means that, for many years to come, different transmission techniques will continue to co-exist and the factors determining their use will continue to be availability and cost.

11 *An operative conducts the final test on a batch of GPT 2000 handsets and chargers.*

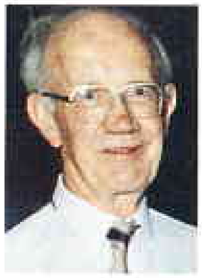


12 *Cordless GPT products for the office*

Chain Home Radar – A Personal Reminiscence

by M. J. B. SCANLAN, BSc, ARCS
Formerly at GEC-Marconi Research Centre

After graduating in Physics from Imperial College, London, M. J. B. Scanlan served four years in the RAF radar branch, working on decametric and centimetric radars in the UK and the Far East. He joined the Marconi Company in 1952, and ran the Applied Physics Group in what is now the GEC-Marconi Research Centre from 1963 to 1982 working on a great variety of systems, sub-systems and components. He began editing the Marconi Review in 1979, and became the first editor of the GEC Journal of Research in 1983 and of the GEC Review in 1985. He retired from full time employment in 1986.



This paper was written to celebrate 50 years in radar. It was begun in October 1992, fifty years after my first awed, ignorant and bewildered introduction to my first radar (an 'A' CH station at Newchurch in Kent) and finished in the spring of 1993, fifty years after my first real radar job as S.T.O. (station technical officer) at Ottercops Moss in Northumberland, an East Coast CH station. My position was immensely privileged, since after a degree in physics I was commissioned directly into the RAF VR: in even the lowest commissioned rank, I had relatively easy access to all classified documents, could mix easily with calibration and quarterly overhaul parties and learn on equal terms from the WAAF officer supervisors, who were highly skilled and experienced in CH operations.

There are good technical accounts of CH radar in the literature, but this paper attempts to give a broader picture, based on personal recollections as well as the technical accounts already noted. CH operation at Ottercops Moss in 1943 cannot have been as hectic or as important as operations at a South Coast station in 1940, yet the stations were virtually identical technically, and the *modus operandi* cannot have changed much either. Therefore it is hoped that this broad-brush account of CH radar will have some interest and value: in a relatively few years, there will be no one left to give a first-hand account.

This paper deals with only one aspect, albeit the most interesting technically and important operationally, of the complete CH (Chain Home) system. The East Coast stations described here were the first to be built and covered the south and east coasts from the Isle of Wight to the Orkneys, with the greatest concentration in S.E. England and the Thames estuary: with their massive free-standing steel towers and their gigantic, complex and horribly inefficient transmitters, they convey something of the urgency underlying their building. For the rest of the country, the same coverage was achieved by the West Coast stations, with much simpler guyed towers and a smaller, simpler and more efficient transmitter. Small gaps in the coverage were finally filled in by a few 'A' (auxiliary) CH stations such as that at Newchurch: this design was similar to that of the mobile stations, one of which, allegedly left behind in France after the Dunkirk evacuation, supposedly led the enemy to believe that he had nothing to fear from British radar.

These CH stations, all working on a wavelength of about 10 metres (30 MHz), were supplemented by CHL (Chain Home Lowflying) stations, which, working at 200 MHz and often sited on cliffs or towers, offset the one great weakness of the 10 m stations, that is, the lack of low cover. There were also GCI (Ground Control Interception) stations, rather similar technically to CHL, but sited inland and designed for the direction of night fighters.

All these ground stations were controlled administratively by Wings which were more or less coterminous with the fighter groups to which the stations reported. Each radar station was autonomous on a day-to-day basis, but Wing H.Q. provided technical services (calibration, quarterly overhauls, etc.) and administrative back-up with such things as pay and personnel services. The whole country was covered by about eight Wings, which in turn reported to the H.Q. 60 Group at Leighton Buzzard. At Ottercops Moss, we reported administratively to H.Q., 73 Wing, which was then at Malton in Yorkshire, and later at Boston Spa. Operationally, we reported to the 13 Group Filter Room at Newcastle.

The Daventry Experiment

The so-called 'Daventry experiment', on 26th February, 1935, has attained the status of folk-lore in British radar history. In the experiment, carried out at Weedon, 6 km SE of Daventry, an RAF bomber at a height of 1 800 m flew down the radio beam of the BBC transmitter at Daventry: the transmitter frequency was 50 MHz, and the wavelength therefore comparable with the size of the aircraft. At Weedon, two parallel horizontal wire aerials were erected perpendicular to the beam, and phased together so that the direct signal from the transmitter was almost cancelled out. The small residual signal was received, demodulated and

1 ***The scene is an artist's impression of radar pioneers Wilkins and Watson-Watt about to perform their historic experiment on 26th February 1935.*** ***(courtesy Marconi Radar Systems)***

applied to the Y-plates of a cathode ray tube (CRT), which was itself a rare instrument at the time. The passage of the aircraft modified the signals to the two aerials, causing the CRT spot to move.

The experiment at Weedon, which took less than 24 hours from arrival on site, is portrayed in fig. 1. A. P. Wilkins was one of the four men present, and (one suspects) the architect of the experiment, the other three being A. P. Rowe, R. Watson-Watt (both higher-ranking than Wilkins) and the driver of the grandiloquently-titled travelling laboratory in which the receiver and its display were housed. The scattered signal was detectable even when the aircraft was more than 12 km distant, a result which was taken to be very satisfactory.

This account of the Weedon (or Daventry) experiment is based on a little-publicized account by Neale[1], who in turn got it first-hand from Wilkins many years after the event. It was Wilkins who had done the calculations which showed, first, that the idea of a radio 'death-ray' (that is, a ray which would disable or destroy an aircraft) was impracticable, and, second, that the detection of aircraft by some radio-based system might be possible. The Weedon experiment was designed to verify this second set of calculations: unfortunately, there appears to be no record of the calculations themselves.

By 1935, of course, there was abundant evidence that unseen objects scattered incident radio waves sufficiently to be detected. In his initial work on radio waves in the 1880s, Hertz had shown that they were subject to reflection, refraction and interference, just as light was. In a speech in 1922, Marconi commented that:

'I have noticed the effects of reflection of these waves by metallic objects miles away',

and went on to suggest that a ship, suitably equipped, could detect the presence and bearing of other ships. Moreover, in the 1920s, the presence and height of the E and F-layers of the ionosphere had been detected and measured by radio techniques closely analogous to radar. It may be of interest to note that the height of the E-layer is 100 km, while the F-layer shows a maximum in the range 200 – 400 km. Thus the range of the E-layer corresponds roughly to the minimum radar range useful for early warning (giving 20 – 30 minutes warning of the approaching aircraft at the cruising speeds of the 1930s), while 200 – 400 km is the maximum range which might be expected, allowing for the curvature of the Earth, and depending on the height of the aircraft.

All these facts, and others leading to the same conclusion, were well known in 1935. Why then was the experiment needed? Perhaps to convince some bureaucrat who held the purse-strings? Neale suggests that the experiment was needed to verify Wilkins' calculations, which, despite the ionospheric work and the rather casual comments of Marconi, were the only quantitative estimates of what might be possible.

For whatever reason, the experiment was carried out – after all, it cannot have been costly – and the results were received euphorically – Watson-Watt is said to have remarked that Great Britain had once more become an island!

The euphoria is difficult to understand, unless the results indicated a far greater range than the

12 km actually recorded, at which range the target aircraft probably cleared the bottom of the Daventry beam. The aircraft would then have been at 18 km from Daventry, at an angle of elevation of 5 or 6 degrees: the Daventry beam was at 10° elevation, according to Neale, but Baker[2] suggests that such beams were at 15° elevation. The signal-to-noise ratio as the aircraft flew through the peak of the beam was the key result, and must have suggested that the maximum range would be well beyond 12 km. The minimum useful range for an air defence system could be set at, say, 120 km, giving 24 minutes' warning of aircraft approaching at 300 km h^{-1}. The radar equation, as such, did not appear until about 1941, but Wilkins' calculations must have shown an R^{-4} term where R is the range to the target, (the transmitter flux falls off as R^{-2}, and the scattered power from the target also falls off as R^{-2} on its way back to the receiver). If the maximum range in the experiment had been only 12 km, an insurmountable gap of 10^4 would have remained between what had been achieved (12 km range) and the minimum useful range of 120 km. It must be assumed that the experiment promised a range of, say, 50 km: this would leave a gap of about 40 times, which it would have been reasonable to expect to fill after some development.

Even supposing the maximum range problem to have been solved by the results, there remained the formidable hurdle that what had been achieved was merely detection, without any hint of how the position or height of an uncooperative aircraft might be found. (In the experiment, the position of the aircraft at any time was known only from the pilot's dead-reckoning). It is not known whether there were already ideas on how the location and height problems might be solved. What is known is that enormous sums of money were immediately granted to cover the development of 'R.D.F.', or radio direction finding, under a 'Most Secret' classification. The title was meant to conceal the fact that it also, and for the first time, covered the location of uncooperative targets.

The Roots of CH Radar

As recounted in Baker's book[2], to which this section is greatly indebted, two developments in radio (or wireless, to use the contemporary name) in the early 1920s had profound and unforeseen effects many years later. The first of these was broadcasting, which led to the growth of radio shops to maintain and repair domestic sets, and to large numbers of amateurs who could build, operate and maintain their own receivers, and even transmitters. This created a civilian pool of skilled radio operators and mechanics, besides those already in the armed services. The Marconi Company was prominent in this development, and the first broadcast station in the UK was the Marconi station 2 MT, transmitting from a wooden hut at Writtle. As Baker[2] recounts, 2 MT was allowed, by a grudging and belated licence, to transmit for half an hour per week (on Tuesdays, 8 – 8.30 p.m.) with a maximum power of 250 W.

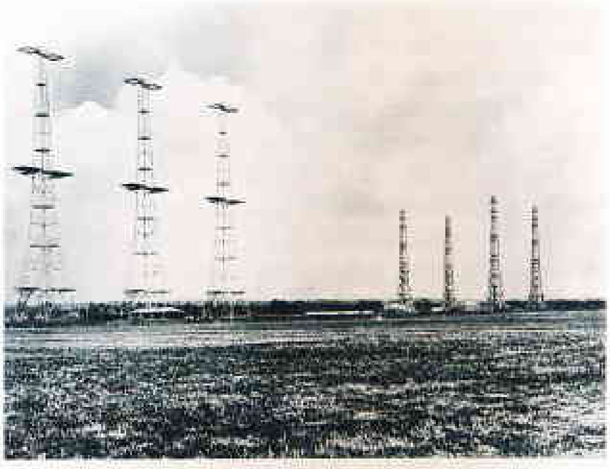
The second, more important, development was the use of short waves for long-range communication. It was believed at this time (c.1920) that the way to long range in a wireless link was to use high power and long waves. Indeed, Marconi's Wireless Telegraph Company (abbreviated to M.W.T. Co., a title which lasted until 1963 – here we shall use Marconi) had entered into contracts with the governments of Australia and South Africa to build long-wave high-power stations for communications with the UK: the UK government dithered, being unwilling for such a powerful tool to be in private hands. (As Colonial Secretary, Winston Churchill had a hand in these negotiations). As an indication of the technology at the time, the Australian station was to be of 1 MW power, and the aerial would be supported on 20 steel masts, each 240 m high.

However, in 1923, Marconi himself began a series of experiments between short-wave transmitters at Poldhu in Cornwall and his yacht 'Elettra'. The term 'short wave' here is relative: the initial tests were on a wavelength of 97 m, and further experiments were on wavelengths of 92, 60, 47 and 32 m. The conclusion of these tests was that over long distances, the shorter the wavelength, the greater the range. Accordingly, Marconi's proposed a short wave beam system to the governments involved. These proposals were accepted readily by Australia, South Africa and Canada, and somewhat grudgingly in July 1924 by the UK. The UK contract was so severe in its terms that Marconi made no profit from it: the Company was obviously run by risk-taking engineers rather than by lawyers or accountants. The work was technically, if not financially, successful and links were opened to Canada in 1926, and to Australia, South Africa and India in 1927. At the end of that year, traffic over the four routes averaged over 100 000 words per day, that is, about two and a half issues of the GEC Review.

The Daventry transmitter was, of course, a direct descendant of these short wave beam stations, and the CH system itself incorporated many features first seen there. Thus Franklin invented coaxial cable as a means of distributing power to his beam arrays: in CH, it was used to carry the receiver signals over 100 m or so from the tops of the receiver towers to the receiver itself. Another innovation was the cooled anode transmitter (CAT) valve, in which the anode of the transmitter valve was a massive water-cooled copper block. This was needed to overcome deficiencies in the glass in valves with glass envelopes: under the influence of heat, high voltages and high RF power, some glass-to-metal seals developed leaks. (An alternative solution, adopted by the British Admiralty, was to use silica envelopes, despite the difficulty of working this material).

Another 1920s innovation by Marconi which carried over directly into CH was the use of a goniometer (literally, angle measurer) for direction finding. In 1922, Marconi introduced an airborne direction finder, the Type 14 ADF, in which two large orthogonal coils, one running up and down the fuselage of an aircraft, the other across the wings, were connected via a goniometer to a receiver. By tuning in to various radio stations, bearings on them could be taken, and the position of the aircraft established. The goniometer was the key component, since it allowed the use of large coils fixed to the framework of the aircraft. Previously, direction-finding (D/F) stations on the ground used the aircraft's signals to fix its position, which was then radioed to it.

It is clear that well before 1930 many of the key parts of the CH system were in routine use. By 1935, when the query arose after the Daventry experiment 'where to go from here?', it must have seemed natural and safe to develop a system of which so many components were familiar and well-proven. The time-scale was so tight that the less the development needed, the better.



2 ***East coast type of Chain Home aerials. 360 ft (110 metre) steel towers at left for transmitting. 240 ft (73 metre) wooden receiver towers at right.***

3 ***A CH transmitter tower, formerly located on the Essex coast at Canewdon, now at the GEC-Marconi Research Centre, Great Baddow.***

Technical Outline of CH Stations

Neale's paper[3], published in 1985 under the editorship of the present author to celebrate the fiftieth anniversary of the birth of British radar (that is, the Daventry experiment), is by far the best overall technical account of a CH station, and should certainly be read, if possible, by those interested. Here only a much shorter account is given; if this leads readers to Neale's account (which may not be easily accessible to some), so much the better. Technical accounts of the transmitter[4] and receiver[5] have been given in post-war papers by the developers of these components.

The most striking features of an East Coast CH station were the towers: three steel towers, each 110 m high and with three cantilevered platforms on each side (fig. 2) carried the transmitter arrays†, while four 73 m wooden towers carried the receiving arrays. The two sets of towers were

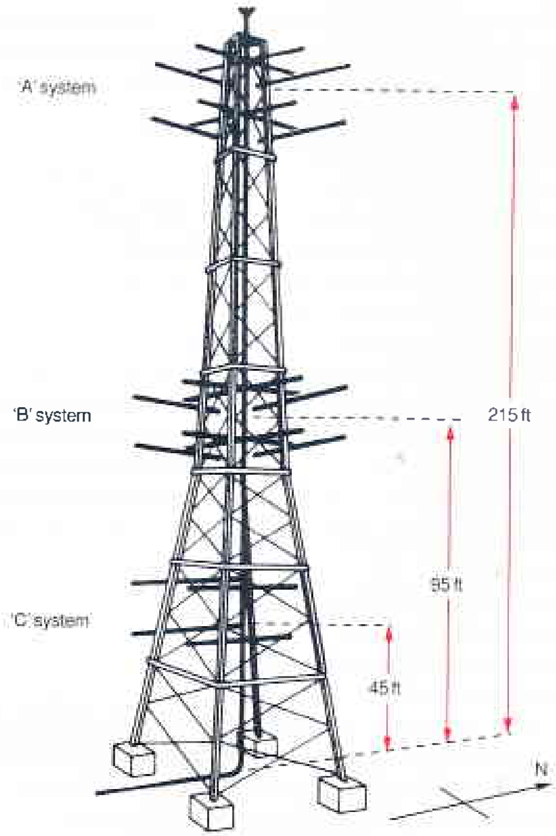
† One of these transmitter towers, perhaps the last to survive, can be seen at the MRC site at Great Baddow and is shown in fig. 3. It was originally installed at Canewdon in Essex, one of the earliest CH stations, and was transferred to its present site in 1959 when the Canewdon station was demolished. The tower is therefore about 55 years old.

perhaps 300m apart, and each group had a low building, surrounded by an earth-banked anti-blast wall, near the foot of the towers and housing the two transmitters, in the one case, and the two receivers and the operations room in the other. By comparison with the towers, the buildings were inconspicuous and bomb-proof, except for a direct hit. Even the towers, with their lattice construction, were difficult to damage by bombing or gun-fire from the air.

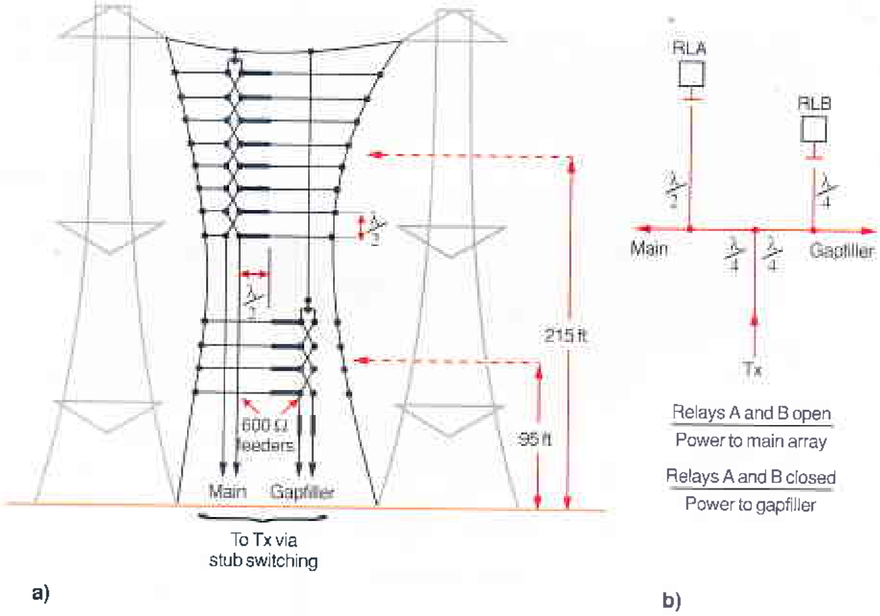
The two transmitter arrays comprised a main array (eight horizontal dipoles stacked vertically at $\lambda/2$ intervals to give a mean height of 65.5m) and a gap-filling array of four dipoles at a mean height of 29m: each dipole was backed by a reflector. The power from either transmitter could be switched to either array, and between the main arrays and the gap-filler in either case. The complete transmitter array system is shown in fig. 4, based on Neale's fig. 3.

The receiving aerial systems were three in number, denoted 'A', 'B' & 'C' (fig. 5, based on Neale's fig. 8). The 'A' system, at a mean height of 66m, consisted of two pairs of crossed dipoles, with two pairs of 'sense' dipoles: the 'B' system, at a mean height of 31m, was similar, but the 'C' system, at a mean height of 13.7m, had only a pair of stacked dipoles with fixed reflectors.

In the horizontal plane, the transmitter beam was 100° wide, centred on the so-called 'line of shoot'. In the vertical plane the coverage was determined by the ground reflection pattern. As the lowliest CH operator soon learnt, an array of dipoles at a mean height of h feet gives a ground reflection pattern, with a first lobe at $47\lambda/h°$, λ being the wavelength in metres, a gap at $95\lambda/h°$, a second lobe at $141\lambda/h°$ and so on. These formulae, and their proof, were a standard part of a CH operator's trade test, by which she (operators were usually



5 *Dipole arrays on a receiver tower*



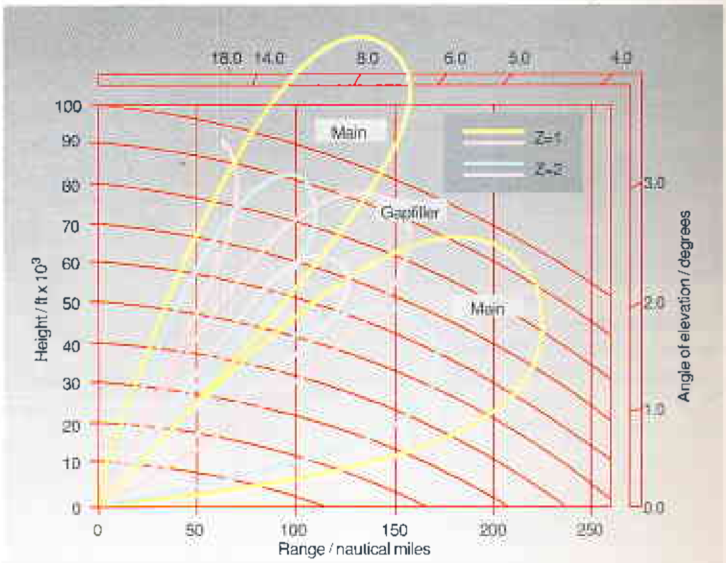
4 *a) CH transmitter array, and b) stub switching*

WAAFs) might progress in pay and prospects. The phenomenon involved is exactly analogous to Lloyd's mirror in optics. In purely metric terms (h and λ in metres), the first lobe is at $14.3\lambda/h^\circ$, the first gap at $28.6\lambda/h^\circ$, and the second lobe at $42.9\lambda/h^\circ$. As applied to CH, λ taken to be 10 m, the formulae give lobes at 2.2° and 6.6° with a gap at 4.4°, for the main transmitter array and the 'A' receiving system. For the gapfiller array and the 'B' receiving system, there are lobes at 4.9° and 14.7°, and a gap at 9.8°. This pattern of lobes and gaps forms the vertical polar diagram (V.P.D.) as shown in fig. 6, which is reproduced from Neale's fig. 6. Of course, this is a theoretical diagram, and assumes that the reflecting ground in front of the arrays is flat, smooth and highly conducting. If these conditions are not met (as they never are completely), then calibration will be needed, and was in fact always carried out, however good the site might appear to be. Further discussion of the V.P.D. will be deferred until the operating procedure of the station is described. Incidentally, Neale's assertion that the pre-war siting instructions laid down that chosen sites must not 'gravely interfere with grouse-shooting' is, I think, apocryphal: at least two thirds of the 22 East Coast stations, and all the most important stations operationally, were well away from traditional grouse-shooting areas.

The East Coast CH transmitter, type T.3026, has been fully described by its designers[4], and more briefly by Neale[3]. The transmitter hall contained two transmitters, each consisting of two large cabinets and a control console fig. 7. The transmitters, although based on a design for a short-wave beam transmitter, needed extensive modification for radar purposes: in particular, in order to generate a well-shaped pulse, the transmitter must be turned on and off quickly at the required times, and the power radiated between pulses must be low when compared with the receiver sensitivity. These were formidable and unfamiliar problems at the time.

Several features of these transmitters are worthy of special note. The RF power was generated in a master oscillator at half the operating frequency, then amplified and doubled in frequency in a driver stage, then amplified to full power by a pair of tetrodes in push-pull. The driver and the two output valves were water-cooled and demountable, continuously evacuated by oil-vapour vacuum pumps, backed by mechanical rotary pumps. These three valves were CATs (cooled anode transmitter), the anodes being so heavy as to

7 ***East coast CH transmitter room***



6 ***Typical theoretical CH performance represented by a vertical polar diagram (V.P.D.)***

require a chain and pulley for lifting. The purpose of this elaborate cooling, pumping and lifting system was to allow the valve filament to be replaced. The filament began life as a thick (5 mm?) hair-pin of thoriated tungsten, 30 cm long, and ended its life when it became so thin as to fracture under the inevitable vibration. The power consumed by these filaments was enormous: 2.6 kW for the driver, 5.5 kW for each output valve. Since even the standby transmitter ran with its filaments hot, the total filament power for the six main valves alone was over 27 kW, as compared with the mean RF power output of about 200 W (25 pulses per second, 16 µs pulse width and a peak RF power of 500 kW). When all the other power supplies are added in, together with power for vacuum pumps, water pumps and blowers, it will be appreciated that the overall efficiency (that is, the ratio of mean RF output to mains input power) was only about 0.5%.

Replacing a filament was a lengthy and error-fraught procedure, which I went through only once: fortunately, my C.O. at the time was an experienced CH engineer, who had done this job before. The valve was allowed to cool, the pumps switched off and the anode lifted against its weight and the atmospheric pressure acting on it. With the anode removed, the screen and control grids could also be removed and the new filament bolted in place: finally, the grids and anode were replaced and the vacuum pumps restarted. Absolute cleanliness was essential, since the grease from a single finger mark would delay final evacuation for hours, besides leading to the suspicion of a leak: the preferred cleaning agent was ether. The final vacuum seal was between machined metal surfaces, and the anode must be lowered exactly in place and square to its mating surface: needless to say, any grit or lint between these surfaces was fatal to any hopes of an adequate vacuum. Then a ring of 'Apiezon' (the name conceals a neat Greek pun) was added around the anode base seal, the filament and grids 'conditioned' by heating to high temperatures, and the valve was once more ready to run. Considering the novelty and complexity of the vacuum systems (most vacuum pumps up to and including the 1930s used mercury vapour), the successful replacement of a filament was something of a triumph: fortunately, it was not something to be carried out every week or month.

The CH receiver was comparatively orthodox, apart from its bandwidth: however, the receiver cabinet, perhaps 2 m high by 2 m wide by a metre deep, also contained all the timing and time-base circuits, the CRO and its power supplies, and the goniometer and range switches. It progressed through various stages of increasing complexity: in 1943, the current versions were the R.F. 6, 6A, 7 and 8 (R.F. stood for 'receiver fixed', as distinct from airborne). The circuitry (all thermionic, of course) was arranged on shallow trays, valves above and other components below; the trays were attached to front panels, which might carry switches, meters and controls, and which were attached by their vertical edges to the uprights of the receiver frame. Viewed from the front, these panels formed an unbroken surface. The display, a 33 cm oscilloscope tube, protruded at the left, with its face perhaps a metre from the floor, and sloping at 30° to the horizontal. Thus, the seated observer viewed the tube squarely, with the gonio knob to her left hand and the range knob to her right. Various controls, for example, for switching the transmitter from main beam to gap-filler, or for switching the gonio from direction-finding to height-finding, were operated by push-buttons within easy reach. Also within reach were the bandwidth switch (three bandwidths were available, 500 kHz, 200 kHz and 50 kHz, to conform to the pulse-width in use) and the receiver tuning controls (all three of the RF stages were tunable and the tuning was checked frequently). Since the display CRT was electrostatic, it was relatively easy (at least by comparison with a magnetically-deflected display) to have a very linear and easily-expandable time-base. This was important, especially with manual plotting, when the time-base was aligned as well as possible with a linear scale, from which the operator read off the range of the target.

The time-base was calibrated with range markers generated from a 9.3 kHz crystal oscillator, which gave marker pips at 10 mile (16 km) intervals. Range accuracy was of considerable importance in the CH system, since despite the undoubted skills of the operators, bearing accuracy was unreliable on very small echoes at extreme range. However, if the same target was picked up by two or more stations, the filter room could often take a 'range cut' on the various plots and so establish the position of the target with some accuracy. In any case, of course, early warning was more important than extreme accuracy: the accuracy of position-finding, even from a single station, would improve as the target grew closer and the signal strength increased.

The signals received on the dipole arrays at the top of the tower were fed, via at least 100 m of coaxial cable, to the stators of the goniometer, picked up by the rotor and transferred via slip-rings to the receiver input: inevitably there were severe losses along this path, losses which might seem at first sight to invalidate the whole system. However, the loss in signal-to-noise ratio would be much lower, because of the very high level of galactic noise present at 30 MHz. Assuming a galactic level of, say, 3 000 K at 30 MHz and a receiver noise factor of 3 dB (= 300 K), then a signal-to-noise ratio of ten, say, at the dipoles will be maintained through the cable and the gonio, but the levels of both signal and noise will have been reduced by the losses of, say, 10 dB. The total noise at the receiver will be 600 K, and the signal will be one tenth of its level at the dipoles: the signal-to-noise ratio through the receiver is now five, that is, a loss of 10 dB has only reduced the signal-to-noise ratio by 3 dB (from ten to five).

The very rapid increase in galactic noise with increasing wavelength, especially as the wavelength exceeds one metre, favours the lower frequencies, when there are severe losses between aerial and receiver, and may have been one reason for choosing 30 MHz, as compared, say, with 60 MHz, the frequency of the Daventry experiment. In any microwave radar system, a loss of 10 dB between the antenna terminals and the receiver input would be catastrophic, and every effort would be made to avoid losses of even a fraction of a dB.

The receiver room of a CH station was also the operations room, where the raw data measured by the CRT operator were converted into the position and height of the target. The raw data consisted of the range, and two gonio readings, one for bearing, the second for height. These were converted into position and height either manually or by an electro-mechanical calculator, the so-called 'fruit machine', which was based on banks of uni-selector switches, as found in Strowger telephone exchanges. These machines were cared for by ex-GPO personnel, usually sergeants in the RAF; these gentlemen were a law unto themselves who looked down on the ordinary RAF mechanic and were in turn treated with great deference by station technical officers, nominally their superiors. Of course, both the manual plotting table and the wiring of the Strowger switches were modified to allow for calibration results.

Besides its main complement of towers, transmitters and receivers, as already described, a full East Coast CH station had its so-called 'buried reserve'. This consisted of a pair of small auxiliary towers, and an auxiliary transmitter and receiver, each buried in a deep pit. The buried reserve transmitter was an MB2, much smaller and more orthodox than the main transmitters (for example, all the valves were sealed off in glass envelopes, and the transmitter was air-cooled); its power output was much the same as that of the main transmitters. The receiver was one of the RF series, often one step behind the main receivers in the operations room. The aerials were also smaller and simpler, without the elaborate switching arrangements of the main arrays. The buried reserve system was intended as a last-ditch stopgap, in case the transmitter hall or the operations room of the main system was knocked out by bombing. The reserve system was periodically run up and checked as a system, but was rarely used operationally because of the duplication in the main system, and because, as it turned out, the main system towers and buildings were difficult to damage from the air.

The Operation of a CH Station

Every CH station worked at least 23 hours a day, day in, day out: an hour a day was normally allowed for maintenance, but this could only be taken by agreement with the filter room, and would be cancelled if an adjacent station were off the air for any reason, or if heavy air activity were expected. A table (in effect, a black list) was published every month, giving every station's unscheduled time off the air, and good reasons were demanded if this exceeded a few minutes.

If a station was fully up to strength, it would have four watches of operators, each of six WAAFs and led by an NCO, and four watches of mechanics, each of three men, two in the transmitter hall, one in the operations room. Ideally, a WAAF officer, a highly experienced and skilled ex-operator, was present on each watch as a supervisor, and a station technical officer and the senior NCO mechanic would be present all day, and on call throughout the 24 hours. Very often, of course, the station was not at full strength, and would be reduced to a three watch system, in which everyone worked a full 24 hours every three days: such a regime could not be sustained for more than a few weeks. Mechanics were in even shorter supply than operators, and a watch would often be reduced to a single mechanic, who would haunt the transmitter hall, accompanied by an operator for safety. Under such circumstances, the daily maintenance routine became something of a scramble.

As an aid to an understanding of CH operations, consider a station whose 'line of shoot' was due east, that is, on a bearing of 90°. The transmitting arrays faced E, of course, and the receiving dipoles of the 'A' and 'B' systems ran N–S and E–W: the 'C' system dipoles, used only for height-finding, lay N–S. The sensing dipoles lay N–S, to determine whether a target was in front of, or behind, the station, and E–W, to sense whether the target was north or south of the station. The coverage of the station was determined solely by the width of the transmitted beam, about 110°: in our example, this would be from 35° to 145°. The receiving arrays, of course, received signals equally from any direction.

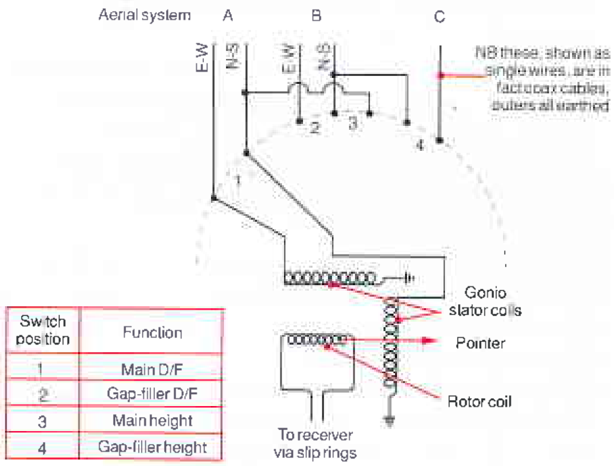
Now envisage the receiving dipoles connected to the goniometer coils as in fig. 8, where the stator coils also run N–S and E–W: in practice, of course, the coils could lie in any direction, with suitable adjustments of the gonio pointer and scale.

A target due east of the station would give a signal only in the N–S dipoles, and this would be transferred to the N–S coils of the goniometer. The goniometer would pick up a maximum signal when its search coil also lay in the N-S direction, and a minimum, (ideally, zero) signal when the search coil lay E–W. Hence, if the gonio pointer is aligned with its search coil, it will point to the east, that is, to the bearing of the target, when the gonio is set for minimum signal. An ambiguity could arise here, since the goniometer would also give a minimum for a target bearing due west, or even when its search coil was 180° from the true bearing. In practice, the ambiguity was resolved by the use of the sensing dipole before any attempt was made to take a bearing.

In the height-finding mode, of course, the gonio measured, not so much an angle, as the ratio between the signals on dipole arrays at different heights: this ratio gives the angle of elevation of the target, and this, combined with the range, gives the height a via simple formula.

The most important operator, by far, was the girl 'on the tube' (fig. 9). It was her duty to update plots on existing tracks at regular intervals, while at the same time watching for new echoes: to this end, the gonio was swung continuously. Since the bearing of a target was determined by swinging the gonio for a minimum (zero) echo, the station was blind on that bearing, or indeed on any bearing on which the gonio rested: hence, the first rule for operators was that the gonio must always be swinging over the full 100° or so of the station coverage. The girl on the tube, together with the others of the team, were paralleled together on the telephone to the plotter in the filter room, who would accept the plots, allocate track numbers (H- for hostile, F- for friendly, X- for unknown), allot priorities ('another plot on X-, please', 'can you get a height on H- ?') and probe for information 'Staxton has a plot about 120 miles from you: can you see anything?' (Staxton being the neighbouring station).

The routine of establishing a new track was quite complex. If the operator noticed a new echo, which would first show as a tiny break in the noise, she would at once 'sense' it to determine that it was in fact in front of the station before announcing 'I have a new echo at such and such a range'. She would then sense again, to determine whether the target was north or south of the 'line of shoot'. She would then attempt, by swinging the gonio for a minimum, to take a bearing, and then a height. On a very small echo, as first picked up, the bearing would probably not be very accurate, and it might



Switch position	Function
1	Main D/F
2	Gap-filler D/F
3	Main height
4	Gap-filler height

8 *Schematic diagram of signal path from aerials to receiver. (Line of shoot is assumed to be due east, orientated as shown in fig. 5, and the gonio is shown for minimum on a target also due east.)*

9 *The 'girl on the tube' responsible for updating plots and watching for new echoes. Her left hand should be operating the goniometer, whose wooden handle is clearly visible. (courtesy the RAF Museum, Hendon)*

be impossible to take a height, since the signal on the lower of the height-finding dipoles would be much smaller than that on the upper, which was itself only just detectable. However, even the range information was valuable as early warning and because it might enable a range cut with an adjacent station: also, knowing the station V.P.D. and the range of pick-up, a skilled operator (or her supervisor) could estimate a height with surprising accuracy. As the target grew closer in range, the signal strength on both upper and lower dipoles would improve, and height measurements and more accurate bearings would become available.

Calibration

The theory of CH direction- and height-finding is simple enough, but depends heavily on the site being ideal. Many sites were obviously far from ideal, and even for those which promised well, it was difficult to be sure about surface slopes and conductivities in the critical areas in which ground reflection occurred. For this reason, CH stations were always calibrated.

Calibration began with a careful check over the receiving system, from dipoles to gonio: in particular, it was important that the feeder runs between pairs of dipoles were of the same electrical length. By injecting signals into the dipoles and adding short lengths of flexible cable in a 'phasing box', equality of electrical length was achieved. The goniometer was also carefully checked for sensitivity and a high cross-talk ratio between the pairs of coils.

Finally, calibration flights were carried out, using either an autogyro (a predecessor of the helicopter) which would hover over local landmarks such as churches, or a small aircraft, which would fly a succession of radial flights at various heights. The position of the target aircraft was often checked with a theodolite. The radar transmitter was not involved in this process, since the aircraft carried a 'squegging' oscillator, which gave an unmistakeable and relatively large signal, which could be 'D/F d out' relatively easily and accurately by the gonio.

Needless to say, calibration was carried out, not by station personnel, but by a peripatetic band of specialists. While calibration, or re-calibration, was in progress, normal operations were in abeyance, and the station routine disrupted.

Technical Maintenance

At the heart of the RAF system of maintenance for all radar stations (not only CH) was Form 1497, a large pre-printed sheet of paper which on one side carried notes and comments on any repairs or modifications carried out, and on the other side a list, on a day-by-day basis, of the routine maintenance operation which had been carried out. A separate Form 1497 was made out each month for every major piece of equipment (receiver, transmitter etc): the form was clipped like a loose leaf in a book, the covers of which were two pieces of plywood, hinged along one edge and painted black on the outside faces. One side bore a large 'S' (serviceable), the other a large 'U/S' (unserviceable); when the boards were hung in some prominent position on the equipment to which they referred, the serviceability state was immediately obvious to all. Details of the fault (for example, 'no time base') could be looked up on the Form 1497 inside.

Every item of equipment also had a schedule of 'Daily Routine Maintenance' operations. Thus, on Mondays, operations 1, 4, 7, 11 and 15 might be called for on a receiver: for detailed instructions on these, recourse must be had to the handbook, which was of course a secret document. The mechanic would therefore sign out the handbook, carry out the prescribed operations, enter them as completed on F.1497 and return the handbook. In this way and over a period of time, every operation would be carried out, entered on the form and signed for as complete and satisfactory. Over a longer period, the senior N.C.O. mechanic and the station technical officer would also work their way through the routine, either independently or by supervising the mechanic: these tests would also be entered and signed for.

Often, a maintenance operation such as 'clean and inspect the time base panel' would be called for, which seemed to hark back to the maintenance of an aircraft engine. In that case, cleaning might have some point, and inspection might reveal an incipient fault. With a tray holding perhaps a dozen valves with their associated components, inspection was not likely to reveal much; it might detect a loose top cap or a 'soft' valve, but was unlikely to show that a valve was near its end of life, or that there was an incipient dry joint in the panel. While inspection did little harm, if not much good, cleaning did little good, and could do much harm: for instance, a displaced valve might lose contact to one of its pins, causing a difficult and quite unnecessary fault.

Test gear was provided, of course, but the bare minimum to carry out the prescribed tests. Essentially, it consisted of a signal generator and a multimeter: there was no oscilloscope, so that for any out-of-the ordinary fault, for example, in the time-base circuits, recourse must be had to Wing headquarters, perhaps (and very desirably!) a hundred miles away: there there was an oscilloscope, unless it were already out on a panic call from elsewhere.

Fortunately or not, the perennial shortage of mechanics often meant that only a minimum of tests could be carried out: efforts were then concentrated on those tests and checks which had immediate bearing on the technical health of the station. This was no bad thing, it turned out: a panel thick with dust would carry on quite happily, while attempts to achieve the surgical cleanliness demanded by visiting senior officers did not improve serviceability. Hence the desirability of being far away from Wing H.Q.!

At intervals, nominally every three months, a Quarterly Overhaul party would descend on a station and carry out a complete check of major items: these were teams of two or three engineers, relatively well equipped with test gear, and specializing in receiver or transmitters. These people would carry out a fairly thorough overhaul, extending, for instance, to checking the receiver bandwidths and realigning as required. The transmitter team would check every aspect of the transmitter, including, for instance, the conductivity of the cooling water, which was held in a vast and rather inaccessible tank under the transmitter itself.

Anti-Jamming Provisions

It was clear from the design of a CH station that considerable thought had gone into protecting the system from jamming. Some of these provisions may now be mentioned.

The cathode ray tube itself was specially built to reject transient signals, in favour of target echoes, which would be longer-lasting. This was achieved by using two phosphors in the tube: a blue phosphor excited immediately by the electron beam, and an orange phosphor, excited more slowly by the glow of the blue phosphor. If the tube was observed through an orange filter, transient signals which excited only the blue phosphor were not seen, while the long-lasting echoes were easily visible.

The IFRU (intermediate frequency rejection unit) consisted of a pair of very narrow band rejection filters, which could be tuned separately across the intermediate frequency bandwidth. They were present to reject any accidental or deliberate CW interfering signal.

The AJBO (anti-jamming blackout) circuit was designed to counteract swept frequency jamming. In this very damaging form of jamming, an oscillator is swept in frequency across the pass-band of a receiver, to give a bell-shaped response on the CRT, and completely obliterating any echoes. The AJBO circuit, which worked at video frequency, was designed to discriminate against the slow rise time of the bell-shaped response and blackout the tube: some of the signal time-base would be blacked out and lost, but some would remain, unless the sweep frequency of the jammer was locked to the station PRF (pulse recurrence frequency).

The IJAJ (international jitter, anti-jamming) circuit was designed to introduce a slight random jitter to the PRF of the station, so that jamming pulses triggered by reception of one's own transmitter pulse would not be synchronized with the time-base. Since true echoes would be steady, they could be distinguished from the false pulses from the jammer, which would vary in time from pulse to pulse because of the jitter.

CH stations were also equipped with frequency agility, in that, at least in principle, both the receiver and transmitter could change to any one of four pre-set frequencies in a few seconds under push-button control. In practice, since a need for this facility never became apparent, it was never seriously tested.

Security and Safety

As has been noted above, the Daventry experiment heralded a very large effort towards the implementation of RDF (radio direction finding). The deliberately misleading name was the first of the security measures intended to cover all the developments and their outcome in a cloak of secrecy. Britain was thought to be alone in this field, or, at very least, well ahead of the field. Of course, this was a misapprehension, since as soon as the technology became available, the forecasts (for example, by Marconi himself) of radar were implemented in different ways by almost every advanced industrial nation.

Security, in the sense of preserving secrecy, took various forms. All the documents concerning the system were classified as 'Secret', and elaborate procedures for their destruction in emergency were laid down: for instance, some documents were printed on rice paper, and were to be destroyed in a bucket of acid. Training sessions for operators, and mechanics could be held, but no notes could be taken. A muster of secret documents by an officer from Wing H.Q. was carried out every quarter: this was supposed, impossibly, to account for every page of every document.

Security also extended to control of entry onto the technical site (the living quarters were usually some miles away, and relatively easy of access). The technical site, half a kilometre or more in diameter, was surrounded by a so-called 'unscalable' steel fence, 2 metres high, in which the only gap was the gate and guard room. Every authenticated visitor, including the watch personnel as they arrived for duty, was given the watchword for the day, without which the doors of the transmitter hall or operations room should not be opened. Of course, this system was a challenge to some senior visitors, who were wont to try to bluff their way in by announcing themselves by their (very senior) rank, or as 'G.P.O.'. A particular offender in this respect was the Senior Technical Officer, one Wing Commander Scott-Taggart, who had achieved considerable fame in the 1920s by designing DIY domestic receivers under titles such as the JS–T1 (a one valve receiver), JS–T2 etc. If he succeeded in bluffing his way in, the door-opener (usually the most junior of the watch) was invariably put on a charge. He felt justified in these tactics, no doubt, by the need to emphasize security, but it did not take long for the news to get around and for the doors to remain firmly shut unless the password was given.

Inside the 'unscalable' fence, each building was protected by a barbed wire apron about 3 m high and thick, complete except for a narrow access gap. Early in 1943, after the Brüneval raid on a German 'Würzburg' radar station, concern was felt about a possible reprisal raid on a British station. Accordingly, some men (including the author) were sent on courses of weapon training etc., by which it was hoped that a station could hold out for an hour or two, until help could arrive. This was a ridiculous hope, as was proved in a night exercise when a half dozen of us, opposed by the alerted military might of the station, penetrated to the door of the operations room without detection. A dozen paratroopers, operating without warning, would certainly have done much more.

By far the most serious risk to the safety of personnel was that of electrical shock. To guard against this, all dangerous areas were closed off by doors, the keys of which must be withdrawn and used to enable the equipment in question to be switched on. Needless to say, this precaution proved too onerous in practice: after all, the equipment must be accessible and switched on if faults were to be found. Therefore, dummy keys were always available, presumably, since the keys were of an unusual pattern, with the connivance of the authorities. The transmitter was of course the main danger, and in particular, the main EHT smoothing condenser; at 2 μF, and charged to its working voltage of 35 kV, this demanded the utmost respect, and was provided with its own 'earthing stick', that is, a metal chain, earthed at one end. The other end, held on a long insulating wand, could be held to touch danger points, so connecting them to earth.

The only other serious danger was in climbing the towers, especially the transmitter towers. This had to be done from time to time as part of routine maintenance; although it could be an unpleasant task, accomplished without a safety belt, no serious accidents were ever reported to my knowledge. In the gales and mists of Ottercops Moss (the site was 300 m above sea level), one climbed slowly and held on very tightly!

Training for Radar

Formal training for technical officers destined for service in ground radar took place at a 14-week course at one or other of the RAF's wireless schools. The course covered all ground radar (CHL and GCI, as well as CH) and was very intensive – eight hours a day, six days a week. There were formal lectures on the theory of the system, and on the operation of each unusual circuit, for example, the time-base. These were supplemented by practical sessions of familiarization with the layout of the equipment, and of fault finding: here the instructor would simulate a fault and the trainees be expected to diagnose it. Here also we learnt the distilled wisdom of the experienced serviceman: 'always keep one hand in your pocket', 'resistors go open-circuit, capacitors go short-circuit', and so on.

It could not be expected that everything would be covered, and the main CH transmitter (the T.3026) was left out, although the much less complex mobile transmitter was included. Such omissions were no doubt necessary and carefully calculated, but it was disconcerting to arrive at Ottercops Moss never having seen the transmitters. Fortunately, I was privileged in having access to the handbooks, and in being able to haunt the quarterly overhaul party.

Radar mechanics were poorly served on the whole: if they arrived at a station with unfamiliar equipment, there was much less time or opportunity for them to learn. Since they were so few and their work more technical than that of the operators, there was no formal training on the station as there was for operators. The unfortunate mechanic must pick up what he could from the maintenance manual, and from watching those with more experience.

Operators, on the other hand, were well cared for: if on a four-watch system, there was some 'free' time, and this was used for training by a WAAF supervisor or senior NCO, or on occasion by the technical officer. The theory was of course much simpler than for a mechanic, and could be taught without classified documents: nevertheless, no notes could be taken. Regular trade tests were held, so that it was possible to progress by two or three stages relatively quickly. Alas, no such easy progression was available to mechanics.

Conclusions

At first sight, the CH radar would not promise to be a very effective system. The PRF was very low at 25 p.p.s, giving a non-ambiguous range of about 6000 km: under 'anaprop' (anomalous propagation) conditions, even this PRF proved too high, and returns from one pulse appeared on the next time-base. This phenomenon, aided by modern data processing, is the basis of over-the-horizon radars: in CH, the nuisance was overcome by halving the PRF to 12.5 p.p.s. As a result of the low PRF, the mean power was also low (200 W at 25 p.p.s., only 100 W at 12.5 p.p.s). At 30 MHz, the galactic noise level is very high, but as explained above, this was not as serious as it might appear, given the high losses between dipoles and receiver. The aerial gains were also low: 8 or 9 dB for the main transmitter array, perhaps 3 or 4 dB for the receiving arrays. However, the saving grace of the system was that it was a floodlit system, which meant that 25 pulses were received from every target within the coverage in every second, save for the brief intervals when the gonio passed the bearing of a target: the mean strike rate was therefore at least 10^3 per minute. A rotating beam radar, on the other hand, would put ten to twenty pulses on the target in every revolution, which would take 10 – 15 seconds: the mean strike rate was at most about 100 per minute, moreover, returns from successive revolutions would be completely uncorrelated. One concludes that CH was designed not so much by theory as by a series of careful step-by-step experiments.

Whether by awe-inspiring foresight, or merely by serendipity, the CH radar system, for all its shortcomings, proved a most valuable factor in the air war over southern England in 1940. The battle was fought as dictated by the enemy, an assault by massed aircraft flying at considerable height in daylight. These were ideal conditions for a defence guided by CH, which gave early warning of high flying aircraft, together with a sufficiently accurate indication of position and height for the defence to be deployed in good time and in commensurate strength. Another great strength of the system was the fact that all the stations in a given sector reported to one filter room, which therefore had an overview of the complete picture: it did not matter too much if a single station was out of action for any reason. If the enemy, having monitored the radar transmissions and measured the heights of the towers (the towers at Dover were plainly visible from across the channel) had appreciated the lack of low cover and attacked much nearer sea level, or had expended more effort on jamming the stations instead of trying to destroy them by bombing, the outcome might have been very different.

It is perhaps worth recalling that the commanders on both sides were veterans of the air battles of 1914 – 18, where superior height was generally decisive. The British were therefore content with the cover given by CH; the enemy, for his part, even if he appreciated that CH could not give low cover, evidently decided that superior height was too valuable an asset to be sacrificed, even if this meant early detection. They probably underestimated, not so much an individual CH station, but the integrated and centralized defence system in which detection, plotting and height-finding by CH was only the first, if vitally important, step.

Acknowledgements

This account relies heavily and gratefully on Bruce Neale's 1985 paper on CH and on Bill Baker's 'History of the Marconi Company': I count it a privilege to have known and worked with both these authors. The CH people I knew in 1943 also contributed greatly, by a process almost of osmosis, to my knowledge: alas, they are too numerous to mention, and I have completely lost touch with them.

If it is true, as has been alleged, that all old radar people suffer from nostalgia, it is above all true about CH people. Just as a steam train enthusiast despises diesels, so CH people tend to look down on later radars, however efficient or effective. If this paper helps to foster and preserve that nostalgia, it will have served its purpose.

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In Brief

GEC-Marconi Materials Technology and GEC-Marconi Avionics

GEC and DRA, Malvern Jointly Win Prince-of-Wales Technological Innovation Award

GEC-Marconi Materials Technology Ltd., GEC-Marconi Avionics and DRA, Malvern are the joint recipients of this year's Prince-of-Wales Award for Technological Innovation for their work on uncooled pyroelectric imaging technology. Two years ago, GMMT Caswell and the Defence Research Agency at Malvern jointly were selected as one of six finalists in the competition. Over the last two years, the exploitation of the respective technologies has been reviewed by a panel of experts. A prototype thermal imager was developed into two products by GEC-Marconi Avionics at Basildon; namely a hand-held camera for industrial/security use and a helmet-mounted imager to enable firemen to see through smoke. This was judged by the panel to be the best of the finalists. GEC-Marconi has received a large order (more than £10 million) for the fireman's camera from the USA.

GPT

FOCUS 500: New Videoconferencing Unit from GPT Video Systems

GPT Video Systems has launched a new standards-based 'mobile studio' videoconferencing unit: the FOCUS 500. The unit is a complete communications centre, incorporating flexibility, mobility and global connectivity. FOCUS 500 allows meetings to take place between participants in different locations, even on different continents, without any of them leaving their offices.

Major Chinese Videoconferencing Network Order

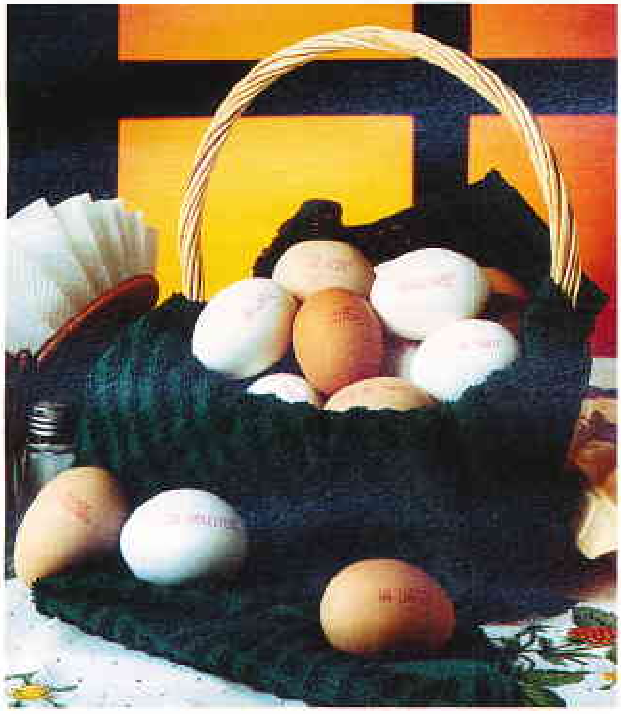
The first videoconferencing network in the Peoples' Republic of China is to be supplied by GPT Video Systems. The Hunan Post and Telecommunications Administration, responsible for telecommunications within the Chinese province of Hunan, will link 14 cities across the region. The announcement comes less than a year after GPT Video Systems secured other major contracts in Malaysia, Indonesia, Korea and Hong Kong. Central to the agreement is the supply of the FOCUS range of videoconferencing equipment, with its plug-in-and-switch-on design philosophy.

Submarine Cable World First for GPT

The world's longest high-fibre submarine cable – manufactured by GPT Submarine Communications, the underwater cables division of GPT Telephone Cables Limited – is expected to go into service later this year. The contract, worth in excess of £2 million, has been awarded by main contractors BT (Marine). The cable, containing 24 fibres, will be installed in the Irish Sea from Girvan in Scotland to Larne in Northern Ireland – and is to be specially armoured to withstand trawling by fishing vessels, treacherous rocks and fierce currents for which this region is well known.

Videojet

Videojet Eggshell Ink Now Available as Government Accepts Proposals to Code Eggs Individually



The UK Government has accepted the recommendations of the Advisory Committee on The Microbiological Safety of Food (ACMSF) concerning salmonella in eggs, with important implications for the packaging industry. In particular, the Committee proposed that eggs should be consumed within three weeks of lay and that use-by dates should be provided on egg packs themselves. Videojet Systems International Ltd. manufactures a Red Eggshell Ink which has been approved by the United States Department of Agriculture (ESDA) for printing onto eggs. The new 16–9301 ink is an alcohol-based, food grade ink specifically formulated for application to processed eggs before packaging. The Videojet Eggshell Ink can be used to display a range of useful information, including the use-by date, or date of laying.

Emmy Award for Videojet Systems International

The National Academy of Television Arts and Sciences has awarded to Videojet Systems International, Inc. the 1992 Engineering Award for Outstanding Achievement in Technological Development. The prestigious award was primarily to honour Videojet for 'Electronic Character Generation for Television'. The technology behind the award was first developed in the mid-1960s and the most famous example of its use was when it enabled a world-wide audience to read the voice transmissions of Neil Armstrong, Eugene Aldrin and Michael Collins from the first manned landing on the moon in 1969. The winning product, the Videograph Display Control Unit, and its technology permits digitally coded messages to be converted into a picture or video form suitable for mixing with a standard television signal. The result is a television display with the digital input message displayed as an overprint of the normal TV picture.

NNC

European Industrial Grouping Awarded Design Contract For Fusion Demonstration Device

The European Fusion Engineering and Technology Grouping (EFET), of which NNC Ltd. is a member, has been awarded by the European Commission a Framework Contract covering EEC industrial contributions to the overall design of the International Thermonuclear Experimental Reactor (ITER). This is the first example of a major worldwide collaboration (USA, Russia, Japan and the European Community) in the field of applied research. The goal of the ITER projects is the demonstration of the scientific and technical feasibility of a fusion power reactor.

GEC-Marconi Avionics

GEC-Marconi Oil & Gas Awarded Hudson Order

GEC-Marconi's Oil & Gas Group have been selected by Amerada Hess Limited, on behalf of the Hudson field partners, to supply a subsea production control system for the second phase of the two-phase Hudson field development in the North Sea. Hudson is a development in 160m of water with Phase 2 incorporating a subsea manifold with eight cluster wells linked to the Shell Tern platform 11.5km away. GEC-Marconi Oil & Gas is to supply a multiplexed electro-hydraulic control system that will control production of hydrocarbons at the subsea manifold. The equipment will include nine subsea control modules and associated tree and manifold instrumentation together with platform-based hydraulic power units and master control station computers.

Marconi Speech & Information Systems

New Facilities for Speech Recognition on Flexicall

Marconi Speech & Information Systems, Portsmouth, has made an exciting addition to its world-leading Flexicall system by introducing a multi-language third generation speech recognition system. The result of extensive research and investment into speech recognition technology over many years, this package is one of the most powerful of its type available. The recognition system is based on Marconi's own continuous word recognition technology and can allow the speaker-independent entry of either isolated, or continuously-spoken words or phrases. It has now been expanded to cover major European languages.

EASAMS

Ground Segment for UK Satellite and ADS Trials

EASAMS has won a contract from the UK Civil Aviation Authority (CAA) to supply a complete enhanced Air Traffic Control Ground Segment (ATC GS) for the continuing CAA National Air Traffic Services (NATS) Automatic Dependent Surveillance (ADS) trials. The NATS ADS trials are in support of the International Civil Aviation Organization (ICAO) global Communications, Navigation and Surveillance/Air Traffic Management system to meet the needs of aviation into the twenty-first century. EASAMS' system design will comprise two major segments: the Ground Communication Terminal, and the ADS Data Processor.

Marconi Radar and Control Systems

Marconi Simulation to Supply Power Plant Simulator for China

GEC ALSTHOM has ordered a Full Scope Power Plant Training Simulator from Marconi Simulation for the Shajiao 'C' Power Station Project. The Marconi simulator will use accurate, physics-based models and detailed operations interfaces, as well as large arrays of parallel processors. The powerful Marconi 'Graduate' processing system coupled with the SOUL programming language is being used in the system. A set of high fidelity models of plant systems and processes enables a complete range of exercises to be developed, from normal operating procedures to complex fault and emergency situations.

GEC-Marconi Communications

Sri Lankan Broadcasting Station for The Voice of America

A contract for $35 million has been awarded to Marconi Communications Inc. of Reston, Virginia, USA by the United States Information Agency on behalf of The Voice of America (VOA) for a complete turnkey broadcasting station in Sri Lanka. This is the first turnkey station ordered by VOA as part of its ongoing modernization programme and includes all civil work – buildings, feeders, matrices, antennas, audio and control systems. The Contract includes the installation of 3 transmitters already supplied to the VOA through Marconi Communications Inc/Cincinnati Electronics Joint Venture. Marconi Communications Inc. is already installing short-wave and medium-wave broadcast transmitters and antennas for VOA in Morocco, Thailand, Greece and Botswana.

Marconi Instruments

Microwave Test Set Wins Design Award

Marconi Instruments has won a British Design Award for its 6200 Microwave Test Set (MTS). The award recognizes Marconi Instruments achievement in integrating many separate instruments into one compact and portable unit. The MTS is an integrated test equipment package which revolutionizes field maintenance measurements of microwave communications and radar systems – replacing the many instruments traditionally required to make tests and determine faults.

GEC ALSTHOM

GEC ALSTHOM Wins Gas Turbine Orders Worth Over £50 Million

GEC ALSTHOM's European Gas Turbines UK subsidiary, EGT Ltd., has won orders world-wide worth over £50 million to supply 15 industrial and aeroderivative gas turbines to a total of six countries. Two Modular 25 MW RLM 5000 aeroderivative gas turbine generating sets have been ordered for an offshore platform in the Arabian Gulf. This is the most powerful gas turbine in the world for offshore application. The orders include a number for EGT's 13 MW RLM 1600 aeroderivative gas turbine. Four of these are for cogeneration installations in Spain and the other for gas compression in the South China Sea. These bring to 28 the total sales of the RLM. EGT has also been awarded a number of orders for its 4.5 MW Typhoon and 6.2 MW Tornado industrial gas turbines for the UK, Spain, Australia, Japan and France.

Rolling Stock for Line 5 of Santiago Metro

GEC ALSTHOM has been selected by Chile's inter-ministerial committee to supply the rolling stock for the new Line 5 of the Santiago metro. Valued at 67 million ECU (£87 million), GEC ALSTHOM's proposal covers the supply of 58 tyre-mounted coaches. These will include the latest technological advances, including aluminium body shells, asynchronous traction and on-board computers to provide a high level of safety, easier maintenance and improved passenger information services.

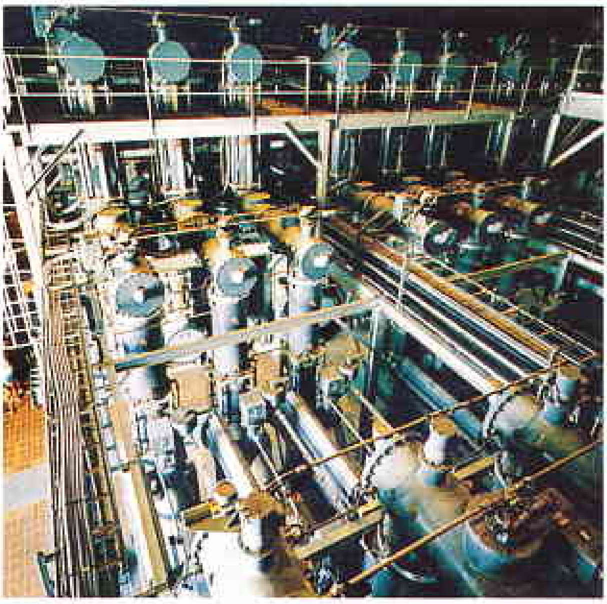
Opening of Paris – Lille Line with GEC ALSTHOM-Built TGV Nord-Europe High-Speed Trains

The opening in May by the French Railways (SNCF) of the TGV Nord high-speed line marks for GEC ALSTHOM an important stage in building up the European high-speed train network. The first of the 90 'TGV Reseau' high-speed trainsets was delivered by GEC ALSTHOM in June 1992. The TGV Reseau is considerably different from the TGV Atlantique with a more powerful and responsive traction system and greater passenger comfort. Some TGV Reseau trainsets have a triple voltage traction system and an adapted signalling system allowing them to run in Belgium and the Netherlands, a first step towards the TGV–PBKA train service scheduled to link Paris, Brussels, Cologne and Amsterdam in 1997, whilst the Eurostar cross-channel TGV will link Paris, London and Brussels. The TGV will be the only high-speed train able to run on the networks of these European Community countries.

Chantiers de l'Atlantique Wins Order for 1800-Passenger Cruise Ships

GEC ALSTHOM's Chantiers de l'Atlantique subsidiary has won an order to build up to three cruise ships for Royal Caribbean Cruises Ltd (RCCL). The ships will be powered by diesel-electric propulsion to ensure maximum operating flexibility of 24 knots and will have accommodation for around 1800 passengers. This order will bring to seven the total number of cruise ships built by Chantiers de l'Atlantique for RCCL since 1985. These include 'Sovereign of the Seas' and her two sister ships which are the largest cruise liners in operation in the world.

420kV Substation Project in Hong Kong



GEC ALSTHOM T&D Substation Projects Ltd. has been awarded a US$9.3 million contract by the Castle Peak Power Company Ltd. (CAPCO) of Hong Kong to extend the existing 420kV substation at Castle Peak Power Station. The contract includes the supply of 420kV gas-insulated switchgear manufactured by GEC ALSTHOM. When complete, these new circuits will provide the interconnection between Castle Peak and the new Black Point gas-fired combined-cycle power station scheduled to commence operation in late 1995. A separate contract for the supply of the power generation equipment at Black Point was awarded by CAPCO to a consortium of GEC ALSTHOM Combined Cycles International Ltd. and General Electric Company (USA) in March 1993.

TECHBRIEFS – News-sheets from the GEC Research Centres

Hirst Research Centre (Wembley)

H/218/1 Image and video processing – expertise available in the development of algorithms, system design and construction of image processing hardware.

H/219/1 Image and video compression – facilities available for the development of algorithms for compression, system design, and construction of video codecs.

H/220/1 Speech recognition – whole-word and sub-word algorithms developed for automatic speech recognition.

H/221/1 Virtual reality: advanced human-computer interfaces – a state-of-the-art virtual experimental platform is being established.

H/222/1 Biometrics: techniques for user authentication – work is being carried out in areas of biometrics such as speaker, signature, and keyboard verification for information security applications.

H/319/1 Integrated display drivers – the use of GEC's polysilicon active matrix display technology to integrate the drive circuits and display matrix transistors onto one glass substrate.

H/909/3 Quality inspection of the physical aspects of integrated circuits – a service for assessing the quality and reliability of integrated circuits.

H/1418/1 Local area networks – expertise in assisting GEC product units in applying LAN techniques to diverse product developments.

H/1419/1 Field-programmable gate-array to semi-custom IC conversion – a conversion process which allows the advantages of FPGAs to be exploited without incurring re-design errors and higher costs.

H/1421/1 Digital ASIC design using VHDL and logic synthesis – a design system using the 'top down' approach of VHDL; it enables more time to be spent refining the system architecture which is then transferred rapidly into logic gates using logic synthesis.

GEC-Marconi Research Centre (Great Baddow)

M075 Calibration and environmental testing service – includes advisory service provided in strict confidence.

M162 Liquid level measurement – a range of rugged sensor probes suitable for use with all types of liquid in hazardous and severe environments.

M223 Propagation planning bureau – advanced software for predicting mobile radio coverage. DOS version for PCs.

M301 Integrated design: from logic to light – a design resource for electronic and optoelectronic multichip modules and advanced optical devices.

M521/2 Near-field antenna test facility – a large indoor test chamber available to any organization for rapid, accurate measurement of antenna performance.

M593 Microwave dielectric resonators – high Q, with excellent temperature stability and ease of microwave coupling, suitable for wide application in low-loss filters and low-noise oscillators.

M777 Design assurance service – assessment of factors such as reliability, structural integrity and safety in overall design of quality in products.

MS90 VLSI system design at MRC – brief outline of facilities and expertise available.

MS98 A scenario modelling tool – software tool for detailed analysis of equipment performance in land, sea and air scenarios.

MS100 Programmable optical RF delay line module – wide bandwidth, variable delay module for signal processing, phased array antennas, EW systems etc.

GEC ALSTHOM Engineering Research Centre (Stafford)

S974/2 Electromagnetic engineering software – electromagnetic finite element software, developed for UNIX environment using PHIGS and X Window system, used for the solution of general purpose and complex design problems.

S981/3 Environmental services – a consultancy and monitoring service provides advice on the control of substances in the light of changes in environmental law.

S982/3 Filament wound, high performance composites – for achievement of void-freedom, by a process unique to ERC which confers superior mechanical, environmental and electrical properties to composites.

S986/2 Advanced microwave substrates – a range of cordierite glass-ceramic substrates has been developed with low dielectric constant, low loss, excellent surface finish and whose thermal expansion can be chosen to match a range of applications extending up to millimetre wave frequencies.

S986/4 Controlled expansion materials – a range of glass-ceramics with tailored thermal expansion coefficients from zero expansion up to that of aluminium has been developed.

S991/2 Component testing – economic testing of large components under simulated service loadings to determine strength, durability and fitness for purpose.

S994/2 Joining ceramics to metals – active metal vacuum brazing is being successfully used to join engineering ceramics such as Si_3N_4 and SiC to metals including nickel-based superalloys, stainless steel and cast iron.

S994/3 Furnace brazing metals – techniques have been developed for using Ni-Cr braze alloys to join steels, and Ni-based alloys etc. Applications include brazing ferritic steel cores to stainless steel shafts, ferritic/austenitic transition joints, and the brazing-on of wear-resistant claddings.

S998/2 Active noise cancellation – application of noise (and vibration) cancellation techniques to structures and equipment to reduce nuisance and/ or improve comfort level without significant increase in weight or cost.

S998/3 Condition monitoring by expert systems – application of expert systems to condition monitoring instrumentation can identify, at an early stage, reductions in performance and efficiency, and diagnose faults before they lead to expensive failures.

Engineering Research Centre, GEC ALSTHOM (Whetstone)

W/921/021 Investigative instrumentation for confined and difficult areas of gas turbines and other machinery. Covering pressure, temperature, strain, and proximity sensors.

W/924/004 Design review in accordance with BS5750 and BS7000 including assessment of design specification, calculations, history record, and performance characteristics.

W/924/010 Hydraulics: computer simulation of hydraulic systems and components. Design, development, prototype build and test.

W/924/011 Solenoid valve design using latest software tools where operating conditions include high temperature, minimal power consumption, fast response, vibration and shock

W/932/001 Transonic flow: calculation methods originated and developed for the design and analysis of flow through turbomachinery.

W/933/005B Environmental chamber facility for developing and testing customers' products. Humidity from 10% to 99%; temperature from −15°C to +50°C.

W/934/003 Electronic cooling design, using the latest available techniques in heat transfer technology, design expertise and experimental facilities.

W/942/001A Engineering design service, for applications including test rigs, process equipment, domestic appliances and prototype products.

W/950/001 Software products: overview of engineering analysis programs, including thermal and structural analysis packages.

W/950/002 Software services: overview of software services provided, including software development, consultancy and re-engineering.

W/950/003 Software re-engineering service to bring old and difficult-to-maintain software in line with modern software practices and quality standards without major redevelopment.

W/950/004 ESARAD: graphical geometric modeller program to calculate view factors, radiative exchange factors, and external heat fluxes

W/950/005 Graphical user interface (GUI) technology for new and existing technical software to internationally recognized standards including both design and implementation.

W/956/001A ESATAN: general purpose thermal analysis program using lumped parameter method, with particular application in the space industry.

W/956/002 FHTS: extension to the ESATAN thermal analysis program to allow modelling of piped fluid networks.

NNC Engineering Development Centre (Risley)

TN18 X-ray diffusion facility – facilities include automatic specimen changer, multi-colour output, and automatic diffraction pattern acquisition.

TN19 Mathematical modelling and analysis – key areas include state-of-the-art 3-D flow codes, modelling of complex flow physics and validation against customized experiments.

TN20 Transport of aerosols – computer codes assess material release, predicting aerosol size and concentration for complex flow paths.

TN21 Leak detection – recently developed special techniques using portable gas analysers.

TN22 High load testing – mechanical testing of materials and components. 250 tonne hydraulic test facility for application of tensile, compressive and fatigue loads.

TN23 Microbiological corrosion – a facility for the detection, diagnosis, evaluation and monitoring of microbiological corrosion.

TN24 Single, multiphase and multicomponent flow – NNC offers mathematical modelling of fluid flow, as well as heat and mass transfer.

TN25 Software and safety critical C & I – failure and hazard analysis where a safety critical function is involved.

TN26 Operational plant support – covering the development and implementation of total repair schemes and equipment for solving operation plant problems or providing plant life extension.

TN27 Materials technology – materials and NDT advice for design and construction including: welding; heat treatment; practical and theoretical back-up; and materials assessment.

For further information please **write** to the Editor.

60 YEARS AGO

GECoPHONE All-Mains Radio Receiver and Loud Speaker and MAGNET Electric Fire.

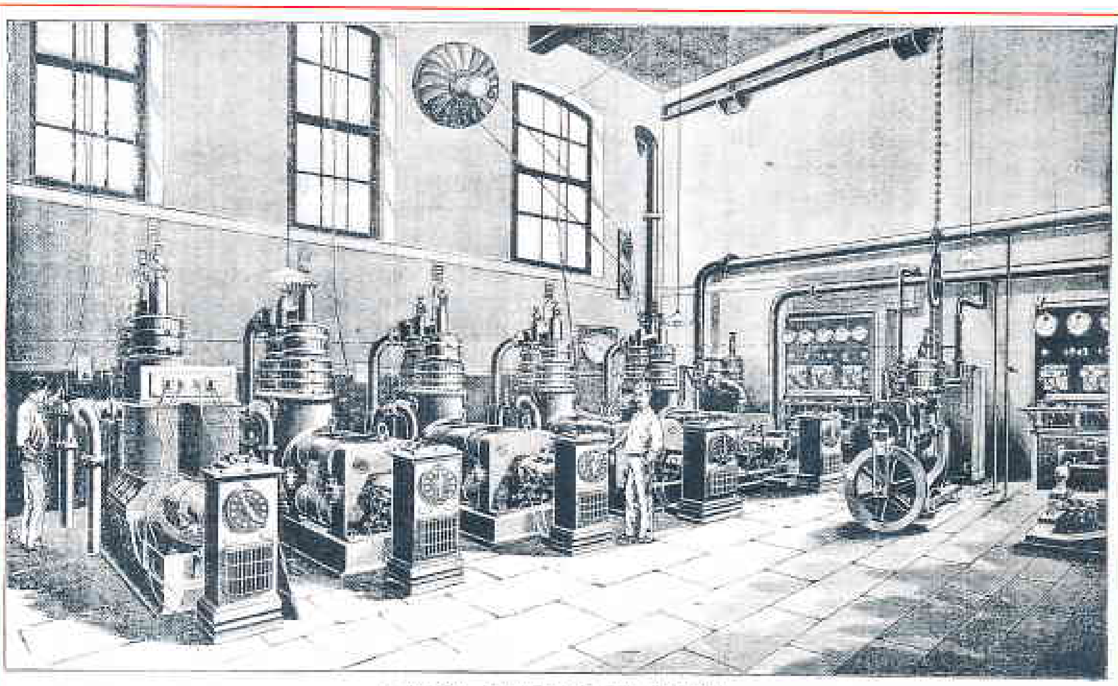
A wireless receiving set indeed is practically indispensable to the farmer to-day, apart from its value as a means of entertainment. Weather reports, latest market prices and special talks dealing with agricultural problems are broadcast especially for his benefit.

With electric light and electric heating, cooking and labour saving devices, the loneliest farmhouse becomes as bright and comfortable as the most up-to-date house in a modern city, while with a wireless set the same news service and the same variety of entertainment can be enjoyed as in London itself.

Surely it is no exaggeration to say that electricity is bringing in a new era for those living on the land; an era of increased efficiency in working on the farm and one of less drudgery and more joy in the home.

(From 'GEC – Electricity in Agriculture and Horticulture', p. 36, published by The General Electric Co. Ltd., June 1933)

100 YEARS AGO



A TYPICAL ENGLISH CENTRAL STATION.

(From 'The General Electric Catalogue, section 'A' – Electric Plant and Machinery', 6th edition, published by The General Electric Co. Ltd., 1893)

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