diverse topics such as filter design, network analysis, heat transfer, structural analysis, circuit optimisation etc. The very limited DUECE was replaced in 1965 by a KDF 9, which enabled the scope for technical work to be enlarged considerably as well as providing a facility for commercial data processing.

While this work was in progress, engineers involved in radar data processing were examining the likely trends for the future. The semi-conductor laboratories were given the task of fabricating transistors for use in the high speed logic circuits which were necessary for real time data processing and by 1963 they were able to offer devices with the required performance.

E. Atkins and colleagues devised and constructed a processor, using an architecture formulated by W.D. Worthy, which emerged as a prototype in 1964 when it was probably the fastest machine available in Europe and possibly in the world. A decision was then taken to set up a Computer Division of the Marconi Company with Atkins as its Manager supported by a number of the engineers who had worked with him in the research laboratories. From this prototype, known as IMP, the Division developed the range of MYRIAD computers which was used in a number of radar, air traffic control, road vehicle control and message switching schemes. IMP remained in the research laboratories and was used for some 15 years or so for development of real time data processing systems and for a number of off-line tasks such as analysis of the results of flight trials.

The first transistors for these machines were fabricated in the research laboratories, but also in 1964 it became apparent that the demand for devices emerging from semi-conductor research was growing rapidly and a new Microelectronics Division was set up in a purpose built factory at

Witham. Again the Senior Research Engineer, I.G. Cressell, became Manager and in this instance took with him all his team, on the understanding that future research in silicon technology would take place in the Product Division.

Line Communication

Until the early 1960's virtually all Post Office business in line communication went to a restricted group of suppliers which did not include the Marconi Company. However, in 1963 the Post Office announced that it would be opening up the market at least for some equipment and the Communications Division of Marconi decided to make an attempt to obtain some of the business in pulse code modulation, a technique which the G.P.O. intended to use in order to increase the capacity of its existing network. At the request of the Product Division the research laboratories undertook a study of the requirements and within about a year had produced tentative designs for a 24 channel pcm equipment. Once again the team leader and a group of supporting engineers transferred to a newly formed Line Communication Division, the Manager in this instance being recruited from the existing Communications Division. This team continued development of the equipment and the Division was successful in obtaining a substantially greater proportion of the first orders from the Post Office than was obtained by any of the established suppliers.

Satellite Communication

From the launching of the first satellites by the Russians, the laboratories had been involved in a number of studies relating to the performance of satellite systems for both communication and scientific purposes and in 1965 were approached about the possibility of designing three ground stations for use by the Ministry of Defence in an experimental system being launched by the USA and known as IDCSP (Interim Defence Communications Satellite Project). The Company, via its Radar Division, was awarded the contract in competition with a US supplier and responsibility for project management was assigned to the Research Laboratories. Design of the transmitter, based on a high power travelling wave tube, was carried out by the Transmitter Development group in the Chelmsford factory and of the receiver by the development team in Communications Division. The antenna, a ??? ft. diameter dish in an inflatable radome, the latter being purchased from the USA, was designed in the research laboratories. The project, code named SCAT, was completed in 18 months from receipt of the order to first delivery to the Ministry of Defence and the commissioning team had the satisfaction of receiving signals from the satellite a short time after its launch and before it had been acquired by the US ground station.

Low Noise Amplifiers

In 1958 the MASER (Microwave Amplification by Stimulated Emission of Radiation) was announced by Hughes Aircraft in the USA. Because of its potential importance as a low noise amplifier of microwave signals, a research programme was started in the laboratories, with the system design being undertaken in the microwave physics team and that of the ferrite isolators necessary to make the device work in the magneto-physics laboratory. Although working devices were demonstrated, the problems involved in making them and in operating at liquid helium temperatures were formidable and it became apparent that more acceptable means of obtaining the low noise performance required for satellite systems or for long range radars could be devised. (A MASER, not of Marconi design, was in fact installed at the first earth satellite station in operational use by the Post Office at Goonhilly, but was later replaced by a parametric amplifier.)

Attention was next turned to parametric amplifiers and different designs for radar and communications were evolved. A design suitable for use as the input stage of a 600 MHz radar was designed for and marketted by the Radar Division. This made use of a variable capacitance (varactor) diode manufactured by Ferranti but, as will be described later, an interesting reversal of the role of the two companies took place some years later.

1965 Re-organisation

In 1965 a major re-organisation of the Marconi Company which had a considerable effect on the structure and work programme of the laboratories took place. Reference has already been made to the formation of Line Communication Division. The remainder of the former Communications Division became Radio Division and a new unit, called Space Division, was set up to develop and market satellite ground stations. At the same time it was decided that radar development which had been absorbed into the research laboratories under Eastwood's direction would be devoted again to the Radar Division, thereby placing that in the same position as other Divisions, i.e. responsible for its own development but calling upon the central laboratories for research. Technical Managers for both Space and Radar Divisions were transferred from the research laboratories, as was the whole of the development team for radar. Microelectronics Division had already been formed as described earlier and one more Division, Automation Division, was set up with P. Way (again from the research laboratories) as Manager supported by a team largely consisting of his previous colleagues.

Thus the size, composition and terms of reference of the laboratories were considerably changed, with the main emphasis thereafter being on research and on the provision of certain specialised services, notably the electrical design of antennas, as required by Product Divisions. In this re-organisation G.D. Speake became Director of Research.

Solid-State Physics

Following the transfer of the entire semi-conductor team to the Microelectronics Division, no group devoted to solid-state research was left in the laboratories. A small team composed almost entirely from newly recruited graduates was set up under the direction of D.W.G. Byatt to study materials other than silicon, responsibility for which was in the Product Division.

New facilities had to be assembled but by 1967 work was in progress on III-V semi-conductor materials, on chaleogenide glasses and on liquid crystal displays. Alpha numeric displays in liquid crystal were designed and demonstrated with sufficient commercial interest being generated to justify the setting up in 1969 of a small manufacturing unit in the Specialised Components Division of Marconi Communications Systems Limited.

Over a period of several years many displays were made in the research laboratory against specific requirements, often from the Ministry of Defence but also for Marconi Divisions and for civil customers. A particular strength was built up in high intensity light emitting diodes arranged in configurations to meet an operational need, a good example being the display of data from a runway approach radar in an airfield control tower where the ambient light level is often very high. A prototype system was installed at Gatwick Airport in 1972 and was the subject of much praise from the air traffic controllers who had had to rely previously on radar data relayed to them from a darkened room and the item went thereafter into the product range of the company's Radar Division.

Reference was made earlier to research work on parametric amplifiers. This made use of variable capacitance diodes purchased from other companies but in 1978 the laboratories were invited by the Services Electronic Research Laboratories at Baldock to take on design and manufacture of a gallium arsenide diode to work at X-band, and thereby to make themselves self-sufficient in design of parametric amplifiers for the upper regions of the microwave spectrum. The work was undertaken in the new laboratory and diodes to the required specification produced within about a year of work starting. Attention was then turned to an improved design also emanating from Baldock and the team successfully completed development against a Ministry of Defence (CVD) order. Devices to this very demanding specification are still being made in the laboratories in 1985 and sold to Ferranti for incorporation in parametric amplifiers to meet operational needs of the RAF.

Two other new units were set up follwing the re-organisation of 1965. The first was the Microcircuit Assembly Techniques Laboratory. Its initial purpose was to carry out research into interconnection techniques appropriate to the microelectronic packages which were now becoming commonplace in electronic circuitry. Amongst the techniques studied were printed circuit boards, "thin" evaporated films and "thick" printed films, soldering, welding and electro-deposition.

The second was the Central Test Equipment Research and Engineering Unit (CTEREU). This was orientated towards production and took as an initial objective the formulation of test procedures and the design of automatic test equipment, with the aim in both cases of reducing the time and cost involved in the various stages of production test. Two equipments for auto testing in the factory were designed but this activity was then terminated as equipment became available from the test gear suppliers. The unit also did an intensive study of the factors which determine the cost and time involved in testing and of the improvements which might be made by better attention to equipment design procedures. This work, partially supported by the Ministry of Defence, which had became very conscious of the costs involved in designing its own equipment, resulted in a report in several volumes which was widely sold to customers in the U.K. and from overseas. When its main purpose was fulfilled this unit became the Quality and Test Gear maintenance unit of the laboratories.

Seawolf

At about the same time as the re-organisation was taking place the Royal Navy was studying the defence of its ships against missile attack and, via the Admiralty Surface Weapons Establishment, decided to place a contract for a feasibility study for a radar system specifically tailored to this application. The contract was awarded to the Marconi Company, with the Research Laboratories leading and deriving support from the Radar Division. The solution proposed was a back-to-back L band/S band surveillance system and an X-band differential tracker, with a separate C band command link to the intercepting missile, which was being studied under a separate feasibility contract placed with British Aerospace. Stage A models for this equipment were developed in the late 1960's by the Research Laboratories while the responsibility for full development and manufacture passed to the Radar Division. In the event the system as designed was not put into production because changes in defence policy and consequent modifications in ship design demanded a reduction in overall weight. New versions of the equipment were therefore offered by the Radar Division (now become Marconi Radar Systems Limited) in the 1970's with assistance, particularly in antenna design, being provided by the Research Laboratories as requested.

Martel

In 1967 another major feasibility study was undertaken by the laboratories, but this time with Closed Circuit Television Division (later to become Electro Optical Systems Division). This was for a television system to be included in an air launched missile, again being developed by British Aerospace. Transmission of the television picture from the missile to the controlling aircraft and of control signals back to the missile were made by microwave link. As with Seawolf, project management during the feasibility phase was with the laboratories and passed to the Product Division as the contract moved into development.

Apart from these two major projects the main emphasis of the laboratories after the 1965 merger was in the study of new technologies, techniques and processes in all areas of Marconi business and in the support of the Product Divisions in specialist areas. Support from Government agencies such as Ministry of Defence, Department of Industry and Home Office or from other sponsoring bodies such as the European Space Agency was sought wherever the work involved was consistent with overall Company objectives. Thus funding for the laboratories' programme was shared between the Product Companies' research contributions, their payments for work carried out against specific requests and contracts placed by outside organisations, with the first amounting to about a quarter of the total in most years.

An interesting (although not immediately fruitful in economic terms) activity began soon after the founding of Essex University in 1965. A programme of work was initiated by the Professor of Physics (Alan Gibson, a member of the staff of the Royal Radar Establishment prior to his appointment to the Essex Chair) on the infra-red equivalents of microwave components. A research student from Baddow (P. Auton) undertook much of the work, with the practical content being carried out in the Company's laboratories, and was duly awarded his Ph.D having successfully designed circulators and other microwave equivalents.

This excursion into the infra-red region of the spectrum was one of several taking place in the laboratories in the latter half of the 1960's. Using devices made in the Microelectronics Division of the Company line-of-sight communication links were assembled and voice and data transmitted over them. Attention was also turned to the laser, which had been announced by Hughes in 1958, and prototype gas lasers were made in the laboratory until such time as they became commercially available. The initial motivation for this work was the possibility of use of lasers in very wide band communication but it soon became apparent that there were possible military and commercial uses of very high power devices, and that low power systems could find application in signal processing and in holography. This work was to become particularly important in the 1970's as expertise grew and commercial applications were devised.

In 1968 Speake left the laboratories to take up an appointment as General Manager, Telecommunications in the Marconi Company Headquarters and P.S. Brandon became the new Manager at Baddow. A more dramatic development in the same year was the merger of the General Electric and English Valve Companies, which brought the two previously competing research laboratories at Wembley and Baddow into partnership, although the latter still remained under the control of the Marconi Company. It transpired that the area of direct competition between the two laboratories was relatively small but steps were introduced to ensure that results of research work were from that time shared, unless the interests of GEC Companies sponsoring specific work programmes demanded otherwise.

Brandon, who had previously managed the Theoretical Sciences area of the laboratories, was particularly interested in the use of computers and had played a major part in the introduction of the English Electric KDF 9 computer to replace the now out dated DEUCE in 1966. By 1970 this had been supplemented by the still more powerful 4/70 and the range of tasks which could now be carried out covered virtually all areas of the laboratories' activities, as well as the Marconi Company's commercial data processing needs. The laboratories had also been equipped with a Real Time Computer Bureau, using Marconi Myriad machines, which was used for software development and proving and for a number of other tasks such as antenna development where real time processing was demanded.

New applications of the computer were regularly investigated, one of considerable topical interest at the time being the recognition of hand written characters. (The Post Office had had a programme of research for some years aimed at automatic recognition of postcodes but no technique sufficiently reliable to be put into operation had emerged.) The technique studied at Baddow involved recognition of features of individual letters (starts, stops, angles, curves) and it was hoped that the recognition process could thereby be made independent of the writer. In many cases indentification of hand written characters was achieved correctly or with success rates well over 90%, but again the process was not sufficiently reliable to be used in a commercial system and since machines for recognition of printed characters were then beginning to become available, continuation of research aimed at meeting the more limited and very difficult requirement for hand written material was not thought to be justifiable.

A more successful new use of the computer was in the placing and interconnection of components on printed circuit boards. A number of programs were written as part of the research programme and were widely used both in the laboratories and by Product Division.

Fluidics

The much wider use of electronic logic brought about by advances in semi-conductor technology encouraged thoughts on alternative forms and in particular on fluidic logic for use, for example, in mechanical systems where longer time constants than applied to electronic systems could be permitted and where explosion hazards made it desirable to avoid electrical circuits. Devices of several types were developed in a research programme carried out in the Mechanical Engineering Laboratory at Writtle and practical control systems demonstrated. Similar programmes of work were in progress in other companies over the same period but the benefits of fluidic logic relative to what could be achieved by electronic systems were not such as to encourage its application widely.

Management

In October 1970 another change took place in the management of the laboratory. Brandon left to take up a Chair of Electrical Engineering at Cambridge University and Speake, now Technical Director of the Marconi Group of Companies, returned to Baddow to act also as Director of the Laboratory.

Vehicle Location

In 1969 the laboratories took over some exploratory work which had been started in the Automation Division. (This Division was disbanded and the staff redeployed after the merger of GEC and English Electric.) The first potential application was to public service vehicles on fixed routes where it was relatively straightforward to ascertain position by revolution counting of the vehicle's wheels, since the starting point and route are known in advance. A model of the London Transport No. 11 bus route was built into the laboratories' Myriad computer and the factors causing queuing of a line of buses with long waiting gaps, a well known characteristic of that route, were clearly demonstrated. The model was also used for experimental work to establish, without having to run buses, what palliatives could be achieved by such measures as transferring passengers from one bus to another and reversing the empty one to fill gaps in the opposite direction service. A contract was received from London Transport to set up a control centre connected by radio link to a number of buses, each of which was equipped with the necessary revolution counting equipment and an encoding device to transfer its output on to the link. The Myriad computer in the control centre then calculated the positions of all the buses equipped and displayed them on a VDU. This prototype system was operated for some years while London Transport evaluated the operational benefits to be derived from a continuous picture of bus positions.

Following this work, an alternative system was devised and installed for the Bristol Bus Company. The operators were unwilling to have a system which would give false positional information if a bus had to divert temporarily from its normal route, for example, as a result of road works. This was avoided in the new system as follows; an optical beam from a gas laser mounted in the bus was caused to scan vertically by a moving mirror. At intervals on the road coded reflecting plates were mounted on roadside poles and the relevant code transmitted by radio link from the bus back to the control centre, together with the identification of the vehicle involved, whenever a laser beam passed over the code plate and was reflected back to the bus. This system also was evaluated for potential operational benefits but they were not regarded as sufficiently valuable to justify proceeding to a full scale implementation on any of Bristol's routes.

The next system evaluated was based on a patent taken out by R.D. Tyler whereby the vehicle to be located was not constrained to follow a fixed route but was assumed to operate on known roads i.e. did not make cross-country excursions from established routes. Distance travelled was measured as previously by wheel revolution counting but at each road junction the angle through which the vehicle turned was computed with the aid of a relatively simple gyroscope mounted in its boot. The co-ordinates of all junctions on the map and the angles at which exit roads emerged from them were stored in the memory of a computer built into the vehicle so that, providing the point of origin was known, the position of the vehicle could be calculated at each junction and, by wheel revolution counting, at each point in between. The position was stored in the computer and transmitted in digital code to a central computer over radio link as demanded by the computer.

Thus it was possible in principle to track many vehicles but the minimum interval between successive up-dates of position increased with the number involved. A prototype of this system, developed with partial funding from Department of Industry, and implemented by GEC Traffic Automation Ltd with assistance from the design team at Baddow, was installed for evaluation by the Metropolitan Police in London in 19??. However, it was not universally popular with the users (not all of whom wished their position to be known at all times by the Control Room!) and the benefits of full-scale installation were not regarded as sufficient to justify the costs involved. (A number of alternative systems based on position finding by radio were investigated in other parts of the world at the same time and similar conclusions on operational benefit vs. installation cost seem to have been drawn.)

In 1976 the laboratories were awarded a substantial contract from the Home Office for a system to evaluate the benefits to police forces of being able to transfer much more information from their patrol vehicles to headquaters and vice versa. In this case automatic determination of vehicle position was not attempted but earlier research work on a Touch-Map, i.e. a map from which coded information on position could be obtained by touching the appropriate point on the map was exploited. This device together with two types of keyboard for data input, an alpha numeric display and teleprinter were all installed in the vehicle. Digital messages and voice were transmitted in either direction by VHF radio link. This system was evaluated by a team drawn from three Police Forces in the Midlands but, although some of the facilities were assessed as being of considerable value, only the voice radios are as yet widely applied (1985).

Wideband Communications

In 1970 research into communication via over-moded circular waveguide which had been discontinued in the 1950's was revived as a result of considerable interest by the British Post Office in the use of such a system for trunk communication. Technological advances had made the evolution of an operational system practicable although the design of the waveguide itself, i.e. a wire helix set in dielectric was very similar to that devised over a decade earlier. The Research Laboratories were awarded a contract for the terminal equipment for use with a waveguide system initially to operate in the 30 - 50 GHz band but potentially capable of extension up to 100 GHz. This involved the design of digital modems and of a range of microwave elements to the very precise tolerances demanded of a system working at such high frequencies (i.e. wavelengths substantially less than 1 cm). By 1973 a prototype system had been installed between the Post Office Research Establishment at Martlesham Heath and Wickham Market (about 15 kms) and operated so successfully that an order was placed with Marconi Communications Systems for the first trunk link between Reading and Bristol. However, in the meantime rapid advances had been made by various laboratories, including GEC Hirst Research Centre, in the design of low loss glass fibres for optical transmission and it appeared likely (as proved to be the case) that this technology would overtake over-moded waveguide for wideband systems in the next two or three years. The Post Office decided not to proceed with any operational waveguide systems and the order for the Bristol/Reading link was withdrawn.

Fibre Optics

The stimulus for work on fibre optics had come from the announcement in 1970 by Corning of the USA of a fibre with what was at that time a very low loss factor of 20 dB/km. The potential use of such fibres in trunk communication systems, especially if further improvements in transmission characteristic could be achieved, was considerable and research programmes on development of improved fibres and on digital transmission systems making use of them were initiated at Hirst Research Centre. At Baddow, applications involving transmission of analogue signals, e.g. video from an outside broadcast television camera to a control room or to a number of users in a video conference system, could be foreseen and research work on the techniques involved was taken to the stage of prototype system demonstration both in the laboratories and, in the case of video conferencing, at the customer's (British Telecom) site. Initial work was on transmission of a single channel per fibre but by the early 1980's two forms of multiplexing were being studied: (i) electronic multiplexing on to the optical carrier and (ii) wavelength division multiplexing of the optical signals on to the fibre.

Within the Flight Automation Research Laboratory of Marconi Avionics at Rochester the use of optical fibres as a means of transmitting digital signals round an aircraft and thereby obviating the detrimental effects on equipment performance caused by pick-up of interfering signals on metallic conductors was being studied. At Baddow, miniaturised hybrid circuits were devised for use as input and output circuits for the transmission system and prototype devices were assembled in the Microcircuit Assembly Techniques Facility.

Antennas

A very strong antenna team was built up in the 1970's with a spectrum of activities ranging from the H.F. into the millimetric wavebands. At the lower end of the spectrum much of the work was concerned with development and installation of new antenna designs as called for by Marconi Communication Systems. However, some research work was carried out with the specific intention of replacing existing design methods for wire antenna, which demanded considerable skill and experience from the designer, with computer based analytical techniques which could be used by people less experienced.

At the microwave end of the spectrum much thought was given to the design of wideband systems for both radar and communication purposes. Many radar antennas developed during the 1939-45 war and in the two decades which followed it used linear arrays, i.e. waveguides with radiating slots at intervals along their length from which a beam was formed at an angle a few degrees off the normal which varied with the frequency of operation. They were therefore unsuitable for use in wideband systems where, for example, frequency of operation might be changed in a random manner in order to counter jamming, since the apparent position of targets displayed would change with the frequency. Designs were evolved for "squintless" arrays, i.e. arrays of radiating elements from which the beam emerged at the same angle (usually normal to the array) independently of the frequency of operation, and were widely used in systems sold by Marconi Radar. For some systems circular polarisation was desirable and research programmes covering the design of radiating systems producing circular polarisation but with similar beam patterns in orthogonal planes were carried out. Systems with a high factor of isolation between orthogonal polarisations were designed so that they might be used independently for satellite communication and thereby double the capacity available from a particular frequency allocation. Also satellite communication systems were designed in which there was effectively a free space path between the antenna and the receiver system (so called beam waveguides) so that the receiver could be mounted in a fixed cabin below the antenna, rather than on the movable structure, without the penalty of a connecting loss.

Throughout the 1970's the laboratories were involved in electrical design of all antennas sold by the Communications and Radar Companies and in many cases were also responsible for mechanical design and installation.

Research work enabled both electrical and mechanical design techniques to be improved. For example, with the aid of the digital computing facilities then available on site it was possible to design antenna configurations of higher efficiency and better sidelobe performance than those previously available, and to predict the effect on both these parameters of environmental changes. Improved measurement techniques on site, including the extrapolation (again with the aid of the computer) of near field measurements to far field performance, and in anechoic chambers enabled the refinements in design techniques to be evaluated.

Microwave Components

The new radar and communications systems which emerged during this decade also called for improved microwave couplers, switches, rotating joints and filters. The laboratories maintained a unit carrying out research and development on such devices, covering all regions of the microwave spectrum up to frequencies approaching 100 GHz. Most of the work was concerned with earth-based systems but in the middle 1970's the unit undertook design of a number of devices, notably microwave switches, for use in satellites and became approved as a supplier of space approved components. Most of the devices designed and manufactured were incorporated in equipment sold by Marconi Companies, although much of the development work was done under the auspices of authorities such as Ministry of Defence, British Telecom or European Space Agency and some designs were sold to other companies supplying equipment to them.

Synthetic Aperture Radar

Interest in Synthetic Aperture Radar as a means of getting high resolution from airborne systems, was not studied in the laboratories before 1970. However, between 1966 and 1970, work had been done under a contract from RSRE in digital signal processing, which was becoming practical as a result of the developments in semi-conductor based processors. The work was