MARCONI RESEARCH CENTRE

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A HISTORICAL SURVEY OF THE MARCONI RESEARCH CENTRE

by

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ABSTRACT

A short summary of the principal technical activities of the Marconi Research Laboratories from the construction of the first building on the Great Baddow site in 1938 to the formation of GEC Research Limited in 1985.

KEYWORDS

History, Marconi Research, Great Baddow Laboratories.

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1. INTRODUCTION

The seed from which the Marconi Research Laboratories (now the Marconi Research Centre, a unit of GEC Research Limited) were to grow came from the grounds of the Villa Griffone, near Bologna, where the young Marconi carried out his first experiments on the generation and transmission of wireless waves. Their existence had been predicted by Maxwell and demonstrated by pioneers such as Hertz, Lodge and Branly, but their potential for use first in communication and later in radio and television broadcasting was only established by many years of disciplined research by Marconi and others of his generation.

Marconi formed his company in London in 1897 with the name the Wireless Telegraph and Signal Company, changed some three years later to Marconi's Wireless Telegraph Company. For some years the research work was carried out by Marconi himself with a number of colleagues amongst whom were C.S. Franklin, Captain H.J. Round and Dr J.A. Fleming (later Sir Ambrose Fleming), who was Scientific Adviser to the Company from 1900 until his retirement in 1931. All three were prolific inventors and many patents were registered in their names. (Some appreciation of their contribution to the development of the Company in its early years may be obtained from W.J. Baker's "A History of the Marconi Company" - published by Methuen.)

In 1912 a Research Department was formally constituted under Franklin in a small building near to the Company's Hall Street works in Chelmsford, but with the outbreak of the First World War it came under the direction of the Admiralty, to whom all the Company's activities were largely devoted until 1919. In 1921 the Research Department was reconstituted, this time under the direction of Captain Round, but the decision was taken to form a separate Research Department under Franklin, perhaps an indication that great minds do not always think alike!

In 1916 Marconi had carried out some early experiments on the generation and propagation of short waves and the topic was regarded as of such importance that Franklin and his small team were asked to devote most of their attention to it. In 1919 T.L. Eckersley, who was to become one of the world's foremost experts in the theory of propagation of electromagnetic waves joined the Company and the results obtained by his researchers encouraged Marconi to believe that a worldwide communication system based on the use of short waves was practicable. Practical research work carried out by Franklin and others confirmed (and often anticipated!) the theoretical predictions. A link using a wavelength of 15 metres was established between Hendon and Birmingham in the early 1920's and in 1923 signals radiated from Poldham in Cornwall were received on Marconi's yacht Elettra in the South Atlantic, on a wavelength of 97 metres and less. That this was possible, in spite of the fact that (as we now know) the experimenters were not using the optimum frequencies to achieve minimum path attenuation, was due to the systematic research work which they had carried out on r.f. power generation and on antenna configurations. In 1924 the company received a contract from the Post Office and successfully put a worldwide system (the Empire system) into operation.

In 1930 a Television Research group was formed and in 1931 research was formally separated from development, with the appointment of H.M. Dowsett as Research Manager. Dowsett was succeeded by J.G. Robb in 1935 and the following year the decision was taken to draw together the various research teams, located in and around Chelmsford, into a single laboratory and a site was purchased at Great Baddow, sufficiently far from possible sources of electrical interference to permit research work to be carried out on the detection and amplification of very small signals.

Building work began in 1937 and as it progressed through 1938 research staff were brought from other sites in and around Chelmsford, some into temporary hutted accommodation and others into the new building as areas were made available for occupation. (The hut occupied by Eckersley and his propagation team in 1938 is still in use by the current generation of propagation specialists in 1985!)

Completion of the buildings permitted the integration, on one site and under the direction of Robb, of a number of previously scattered units engaged on a variety of research activities. These included a telephone laboratory, primarily concerned with audio research, and led by Murphy who was later lost at sea when his ship was sunk by enemy action. Other teams were involved in propagation, low noise receivers, radio direction finding, television and specialist component studies, the latter including quartz crystal development and gas discharge devices. Most of these were of potential importance in wartime and it was not surprising therefore that very soon after the commencement of hostilities in 1939 the laboratories disappeared under camouflage netting and came again under the control of the fighting services.

2. THE WARTIME PERIOD (1939-45)

In April 1940 the Air Ministry took over part of the unit, including T.L. Eckersley and his team, which had been joined in the 1930's by G. Millington, also to become an internationally respected authority on electro-magnetic wave propagation. In 1941 the rest of the laboratories came under the control of the Admiralty and for the remainder of the war cooperated with the Admiralty Signals Establishment in fulfilling the urgent needs of the Services. (The Chief Scientist of ASE during this period was G.M. Wright, who had led a team working on frequency stabilisation by tuning fork and on radio facsimile transmission in the Marconi Research Department in the 1930's. He returned to the Company as Engineer in Chief in 1946.)

2.1 Propagation

In 1941 the Interservices Ionospheric Bureau was formed, under the auspices of the Admiralty and the RAF, to take advantage of the knowledge and expertise of the propagation team. It was reinforced by officers and other ranks from the RAF Royal Navy and US Army Signal Corps. Amongst the last were John Kojan who joined the Marconi Company's permanent staff after the war and Dana Bailey, who had come from the US Bureau of Standards and who returned there to pioneer the application of Ionospheric Scatter in the 1950's. The team devised techniques of ionospheric sounding and developed measuring equipment the results from which were used to predict the performance of h.f. radio channels. Typical of the equipment built and put into service was a pulse transmitter feeding a wide-band rhombic aerial for vertical incidence ionospheric sounding. The equipment was installed at Stock (about six miles from the laboratories) on a site with the inappropriate name of Smallgains Lane! It was controlled by telephone line from the laboratories and the delayed echoes received from the ionosphere were monitored round the clock by the RAF operators. Data assembled from measurement of this sort was circulated to all three services to guide system operators in selection of optimum frequencies for h.f. communication. (Similar information is still compiled by the Propagation Group in the Marconi Research Centre and circulated to a wide range of h.f. users via H.M. Stationery Office Publications.)

While the measurement and prediction of h.f. radio performance was the predominant activity of the propagation team in the war years, attention was also devoted to tropospheric influences on direction finding and radar systems and to many other topics referred to the specialists by service users. Dr R.V. Jones in his book 'Most Secret War' describes how his attention was drawn to a report by Eckersley which showed that it was possible for German bombers flying over the UK to receive guidance signals from a transmitter on a sufficiently high site in Germany. It appears that Eckersley changed his mind at a conference at the Air Ministry but his report was nevertheless the spur which led Jones to initiate the measurements which demonstrated that the bombers were indeed being directed by a beam system originating in Germany and resulted in the introduction of effective countermeasures. Jones described Eckersley as "The country's leading expert in radio propagation" and it is apparent from references in the book that his work and that of his team at Baddow were vital to the war effort.

2.2 Direction Finding

Another activity of considerable wartime interest and well established in the laboratories from their inception was radio direction finding, work on which was being prosecuted in several different groups. At the outset considerable assistance in the design of the receivers used in d.f. was given by Dr E.E. Zepler who had been head of receiver development in Telefunken, Berlin and with his colleague Dr Bohm, Head of Research, had been obliged to leave Germany in the mid-1930's. However Zepler as a German subject, was interned in 1940 and after gaining his freedom about a year later became a lecturer at Cambridge and subsequently the first Professor of Electronics at Southampton. Other engineers continued the work on direction finding notably in teams led by S.B. Smith and by R.J. Kemp, whose activities had been switched from television in the interest of the war effort. Work on receivers was led by R.B. Armstrong, whose team included Dr G.L Grisdale and Mervyn Morgan both of whom were to reach very senior posts in the Marconi Company after the war. Apart from its use in propagation research direction finding was used in aircraft, ships and land-mobile equipment, in the monitoring of transmissions from the enemy and even in spy-catching. At one stage about 100 members of the Womens Royal Naval Service were using DF Sites for monitoring enemy transmissions and RAF personnel, led by D. Gill (who in post war years became manager of the Marconi Specialised Components Division), were building DF equipment for use in that service.

2.3 Radar

The Company had not been closely involved with the development of radar prior to the war although Marconi in a speech to the American Institute of Engineers in 1922 commented that he had observed reflections of electromagnetic waves by metallic objects miles away and suggested that this might be used for detection and determination of bearing of ships. When, following the work of Watson-Watt and others, the decision was taken in 1935 to install CH radar stations around the UK the responsibility for supply and installation of the transmitter 'curtain' arrays was given to the Company, and this work continued well into the war years. By 1942 parts for use in a naval centimetric radar were being shipped out of the Chelmsford factory. A radar calibration (EP7) designed by Norman Lea, whose team had developed considerable expertise in frequency control and timing techniques, was also used by the Navy and in 1943 a contract was awarded to the Company for development of the 960, a naval radar operating at a frequency of about 90 MHz. The transmitter was developed by the Transmitter Development Group in the main factory and the aerial, receiver and display units in the Research Laboratories. C.D. Colchester was principally responsible for the aerial and C.S. Cockerell (later Sir Christopher Cockerell, inventor of the hovercraft) for the display. First trials of the equipment were made in October 1944 and the first operational set was installed in HMS King George V in August 1945. Notwithstanding the relatively early date of design and the short development cycle the equipment embodied both sophisticated anti-jamming techniques and a built-in noise jammer.

2.4 Spark Therapy

One activity carried out in the laboratories during wartime was in a very different field from that normally associated with Marconi. The Company had, during the period of depression in the early 1930's, begun to look for new outlets and had undertaken studies on the use of electro-magnetic energy in medical diagnostics and therapy. Under the leadership of A.W. Lay a small team had developed a spark generator operating at about 1 MHz for electro surgery and diathermy. Work continued during the war and equipment was supplied to the Army for surgical use in the field. The instrument known as the Marconi Ekco Therator was used both for cutting tissue, by applying intense but controlled current in the appropriate area, and for control of blood flow, by applying local heat to a blood vessel and thereby encouraging coagulation. Since operations were virtually bloodless and instantly cauterized the instrument was popular with army surgeons and the commander of the New Zealand forces wrote to Lay to tell him that his machines had saved the lives of over 1,000 New Zealand troops.

The machine, as a spark generator, inevitably radiated energy over a wide part of the e.m. spectrum and was used in one variant as a jammer against the German beam system referred to previously.

2.5 Components

During the war period much research was devoted to components partly because many devices were special to the equipment and partly because new component developments offered the prospect of equipment superiority relative to that of the enemy. In the second category the most important example was almost certainly the emergence of the cavity magnetron from the work of Randall and Boot at Birmingham University in 1939. The Marconi Company had in 1919 pooled its resources with those of GEC to form the Marconi-Osram Valve Company (still part of the GEC Company as M-O Valve Company) but maintained a small vacuum physics research team in the Baddow Laboratories, led by Dr Brett. At the outset of the war this was making small quantities of the Stabilovolt, a gas discharge voltage stabiliser with taps at 70 volt intervals up to 280 volts, based on a German design. The requirement for stabilised power supplies in most military equipment led to a vastly increased load, compounded by an involvement in magnetron development, on the Baddow team. Brett, who had been seconded temporarily to the Admiralty for similar work with Dr Sutton, returned to Baddow and was joined by A.J. Young, who had worked with Aisenstein in running valve manufacturing facilities for the Marconi Company in Russia and Poland. Young led the work on magnetrons, which closely paralled that at GEC's Hirst Research Centre and the M-0 Valve factory, and produced devices for centimetric transmitters being delivered to the Admiralty from the Chelmsford factory. By May 1942 demand had grown to a level well beyond the resources of the laboratories and a production unit was set up at Waterhouse Lane, Chelmsford (at peak production in 1945 nearly 2,500 magnetrons per month were leaving the factory). When the Cable and Wireless UK facilities were nationalised in 1946 and transferred to the Post Office, the Marconi Company (as the manufacturing organisation) was sold to the English Electric Company, and the valve unit became the English Electric Valve Company. In 1985 it still includes magnetrons amongst its major products.

Amongst the passive components used during the war and subsequently was the quartz crystal on which most communication and navigation systems depended. A team led by Norman Lea was carrying out research on methods of frequency stabilisation, including methods of reducing the effects of long term drift in crystals which was a troublesome problem in equipments of that generation. In parallel

T.D. Parkin and colleagues were engaged in the growth of crystal quartz and the cutting of crystals for use in the stable sources. The majority of the sources were embodied in equipment being manufactured in the Chelmsford factory and the demand grew to such an extent that production units specific to the purpose had to be set up. Over 9000 were made in 1943 with half of the Baddow Site, as well as a Chelmsford unit, being devoted to the activity. The Baddow manufacturing unit was led by D. Fairweather who in the post war years became manager of a crystal manufacturing unit at Hackbridge.

Publication of many of the activities carried out during the war years has never been made because of their relevance to national security but they can best be summarised as a sequence of reactions to national needs as they were foreseen at the time and as they developed as the war proceeded.

2.6 The Engineer as Wartime Citizen

This policy was not confined to the technical work. The Laboratories had its own Home Guard platoon, led by the unit's cashier, Norman Knight, and fire brigade led by R.F. O'Neill, a senior engineer involved in aerial design. In addition to their technical activities, engineers did night duties on the site as fire watchers, first aiders and telephone switchboard operators. During the day some acted as spotters of enemy aircraft and sounded Klaxons to give warning to their colleagues still at work. All were ready to respond to physical challenge as they did to technical problems when the occasion demanded it.

Research had to be devoted to short-term aims and the results embodied in practical equipment in the shortest possible time. Longer term projects such as television had to be put on one side and individuals had to adapt themselves to new roles and new challenges. However, many of the techniques and devices which emerged from the wartime work were to find application in peacetime roles later and those members of the research teams who had not moved permanently into development, manufacturing or commercial activities had developed the expertise and motivation to take on the new tasks which the end of hostilities presented to them.

3. THE RETURN TO PEACE

After the war ended the Service Units withdrew from the site, staff who had been seconded to work elsewhere e.g. at the Admiralty Signals Establishment or at TRE Malvern returned, and the Laboratories turned their attention to peacetime needs. The nature of the research did not however undergo a fundamental change.

3.1 Frequency Control

For example there was still a need for precise control of frequency of communication channels and work to overcome the long term drift of quartz crystals was continued. The problem was eventually overcome by packing the crystals in glass sealed units (a procedure which had begun in wartime) and later in T05 cases, similar to those used for transistors. The frequency range over which crystals could be supplied was also extended from 1 kHz to 100 MHz, using flexural modes at the lower end and overtones at the upper, and frequency stability was improved by enclosing the crystals in ovens at precisely controlled temperatures. In Lea's frequency control team these developments were incorporated into frequency standards with drifts as low as a few parts in 10^{10} per month which could not be surpassed until the arrival of atomic standards. An example of an equipment resulting from this work was the TME2 Frequency Measuring Equipment (a successor to the wartime TME 1) used by the BBC at its Tatsfield monitoring station and by broadcasting administrations throughout the world.

In addition to the work on oscillators of the highest stability, demanding multiple ovens with temperature control of the crystal to a few millidegrees, research into temperature control of a lower order was aimed at the achievement of frequency stability of about 1 part in a million for communication requirements. In an oven designed by D.J. Fewings, working in a team controlled by Dr. G.L. Grisdale, he used the expansion of naphthalene at its melting temperature to activate a control switch to the heater.

Many thousands of these ovens were sold by the Specialised Components Division to customers, the majority of whom where outside the Marconi group. Another successful series of crystal oscillators used transistors as rapid-heating elements, and crystals in transistor cases, with the whole assembly being contained in an evacuated miniature valve envelope to provide mass-free thermal insulation.

3.2 Television Resumed

The initiative on television research and development had been lost to the United States during the war years but work was restarted in 1946 in a team strengthened by the recruitment as Chief Television Engineer of L.H. Bedford, who had been one of the leaders in radar development at Cossor's. An agreement with RCA enabled the team to obtain up to date information from which to advance their own work and by 1949 Bedford was able to demonstrate, to an audience at the Royal Society of Arts, pictures from an image orthicon camera which lost very little in either contrast or definition when the source of illumination was changed from a spotlight to a single candle. In the same year the Varsity Boat Race was for the first time televised from start to finish using a similar camera and the research team was able to turn its thoughts to the problems involved in system improvements including the introduction of colour to the pictures.

The Marconi Company had not been involved in the manufacture of domestic radio receivers since 1929 when it sold its Marconiphone Company and the use of the copyright signature "G. Marconi" to RCA in an agreement which precluded its trading in domestic receivers for a period of 20 years. However in the late 1940's the Baddow Laboratories were given the task of designing a television receiver. This went into production at an English Electric factory at Liverpool and was marketed as the Model 1550. Some members of the team involved in its development were then transferred to radar display work and others to the problems of stable channelised aircraft transmitters and receivers.

In the meantime the studio research team was studying the problems involved in introducing higher resolution black and white systems (625 lines instead of 405) and colour. Under the direction of L.C. Jesty they made an experimental 2-tube colour camera which was used for demonstration purposes well before the decision was taken to standardise on the PAL system in the U.K., and assembled the necessary background technology to enable a development activity to be launched immediately the decision on the preferred system was known. In 1956 it was decided that system principles were sufficiently well established for the television activity to move out of the research domain and the team transferred to development activities at Chelmsford, dividing their interests between two divisions - Broadcasting and Closed Circuit Television.

3.3 Microwaves and Millimetric Waves

When the Laboratories were first formed a small team led by N.M. Rust was given the specific responsibility for exploring new ideas which could be used as the basis of patents, the Marconi Company from its inception having had a strong tradition for initiation and exploitation of patents. This team like others was engaged on activities specific to the war effort but as it ended began to study again how some of the ideas formulated could be used in peacetime. In the period 1946-47 J.F. Ramsay published in the Marconi Review a series of articles on Fourier Transforms in Aerial Theory which was widely used by antenna engineers throughout the world for many years, until the advent of digital computers made it possible to improve on the analytical design techniques which he employed.

Within Rust's team work also began on the possible uses of the upper end of the microwave frequency spectrum, one of the participants being P.S. Brandon - a future Chief of Research for the Marconi Company and later Professor of Electrical Engineering at Cambridge University. A magnetron to operate at about 40 GHz had been designed in the Services Electronics Research Laboratory at Baldock and was being further developed at Elliott Bros Ltd Borehamwood. Other components were designed at Baddow and used as a basis for system experiments. Very few of the components for the frequency band were readily available at this time and the Laboratories had to design and manufacture their own. In doing so they developed a number of relatively new techniques such as electroforming, and precision casting and machining and although the 40 GHz work was temporarily suspended in the early 1950's these were applied successfully in other frequency bands and were resuscitated in the 1960's when work began on low loss waveguide transmission for potential use in trunk communications. At 40 GHz many of the techniques were quasi-optical and amongst the antenna components studied were lenses in an "egg-box" construction i.e. a 3-dimensional array of rectangular waveguides bonded together and dimensioned so that the phase change of an electro-magnetic wave passing through the structure varied over the cross-section in a way precisely analogous to that in a dielectric lens.

3.4 CW Radar

Brandon and others were at this time carrying out research on FM radar and designed an S-Band system which was used to carry out experiments on a site at Benacre, near to Lowestoft. This excited interest from the Admiralty (for submarine Schnorkel detection) the army (for sentry use) and some non-military users, including the Marconi International Marine Company but did not develop into a practical system, primarily because the technology was too far ahead of the market need.

4. THE ERIC EASTWOOD PERIOD

Other work such as that on direction finding, precise frequency control and measurement, and electromagnetic wave propagation continued throughout the 1940's but the Marconi Company, which had been owned by Cable and Wireless (Holdings) since 1929, became part of the English Electric Company in 1946 and this was to introduce a new personality of considerable influence, Dr. Eric Eastwood, and a new area of activity to the Research Laboratories. (F.N. Sutherland an English Electric engineer of considerable experience had become General Manager of Marconi at the beginning of 1948 and at about the same time R.J. Kemp succeeded Robb as Chief of Research.)

4.1 Type 11 - The Introduction to 600 MHz Radar

It was decided to transfer the task of up-dating a little-used wartime radar the Type 11, operating in the 600 MHz frequency band, from the Nelson Research Laboratories at Stafford to Great Baddow. (The up-dating involved conversion of the relatively crude coho-stalo system of moving target indication to a fully coherent system). Although the two events were not directly connected Dr. Eastwood, who had worked on radar in No 60 Group, RAF throughout the war, for much of it with the rank of Squadron Leader, also transferred from Stafford to Baddow at about the same time in order to take up an appointment as Deputy Chief of Research. Thereafter, Kemp tended to concentrate on the longer established activities of the Laboratories and Eastwood on the development of new ones, with a particular emphasis on peacetime applications of radar.

4.2 Marine Radar

Work had already begun by 1946 on the development of marine radar for use by merchant shipping. The prototype of an X-Band radar, given the name Radiolocator I, was built in the Research Laboratories by a team which included R.P. Shipway, recently returned from wartime service at TRE, and B.J. Witt. It was installed on the Duke of Lancaster, operating between Heysham and Belfast. A second prototype, Radiolocator II, followed (one model only was built) and with its successor, Radiolocator III, further development and manufacture passed to the main factory in Chelmsford. Radiolocator III was marketed in quantity by the Marconi International Marine Company.

4.3 UK Air Defence

Eastwood's first major task, in which he was assisted by C.D. Colchester and Shipway amongst others, was a major study of the UK ground radar defence system carried out on behalf of the RAF and culminating in a set of recommendations for up-dating (known was Project Rotor). Subsequently this was extended to cover mobile radars also (Project VAST). The Air Ministry accepted most of the recommendations in the report in 1949 and much of the redesign and manufacturing was entrusted to a newly formed Division of Marconi's (then called Services Equipment Division and later Radar Division).

4.4 Fixed Coil Display

The ROTOR plan was concerned with the re-establishment of three radar systems, CHEL (Chain Home Extra Low), CEW (Centimetric Early Warning) and

GCI (Ground Controlled Interception). In wartime all had used plan position displays with moving coil deflection systems, i.e. coils rotating round the neck of the cathode ray tube in order to produce a rotating time base synchronised with the rotation of the radar antenna. In the new plan for CHEL and CEW for ROTOR and in all the VAST vehicles this technique was again employed but Eastwood advanced a convincing argument, based on a forecast requirement for data handling in radar displays, that the large GCI stations should be equipped with fixed coil displays. Deflection to the time base in the required direction was achieved by applying suitably phased voltage waveforms to two orthogonal pairs of coils. Thus it was possible to insert extra information, such as alpha-numeric data on target height, at any required position in the interval between successive time bases.

More importantly, it allowed data relevant to the position of targets to be extracted (by overlaying markers) for processing or display elsewhere. Eastwood set up a team under the direction of R.P. Shipway to examine the possibilities on specially developed equipment.

The Royal Radar Establishment of Malvern had already made preliminary studies of fixed coil displays and in work sponsored by them the Baddow team undertook a project to develop a system for use on operational RAF sites. In order to ensure the linearity and directional accuracy of the time bases the currents in the deflection coils had to be controlled very precisely and much original thought went into the analogue display circuitry. Shipway also adopted the concept of "fully toleranced circuit design" whereby from the outset of the design process, manufacturing tolerances of circuit components were taken into account, thereby minimising the problems likely to be encountered in manufacture and test, and contributing greatly to reliability of the equipment in service. Full manufacturing drawings were produced and over 1000 display units subsequently made in Marconi and Plessey Company factories.

By the end of 1953 the first displays, with the associated radar office equipment, were in operation at RAF Bawdsey.

4.5 Radar Research in L. Band

Another activity begun in 1950 in association with RRE was a practical study of a frequency band which had not previously been used for ground radar in the UK. The early CH radars had operated in the h.f. band. (about 25 MHz) and the later generation, following the development of the cavity magnetron, in the centimetric bands (about 3 GHz). An intermediate band, around 200 MHz had been used for GCI (Ground Controlled Interception). The new work was centred on 1.3 GHz and it was hoped to get some of the advantages of all the other three, e.g. relative freedom from the dense clutter experienced on centimetric radars when operating in rain, considerably better detection of low flying targets than was achievable in the HF band and height finding with a single radar antenna, as in the GCI's but without the necessity of using the very flat sites which had characterised them. Again there was little test equipment and few components available for this frequency band and much of the early period was devoted to developing both. The research was successful in that it demonstrated the feasibility of developing a long range radar with excellent anti-clutter characteristics in this waveband but the objective of carrying out bearing measurement and height finding from one antenna system was not achieved. The idea which was attributed to C.D. Colchester who also led the team was to use three waveguide arrays, each with a radiating flare, mounted above one another. Signals from the upper and lower were combined and compared with that from the centre. Since the combined beam was only half the width of the centre one the ratio of signals varied with angle of elevation but, as they originated from antennas at the same mean height, it was hoped that the effect of earth reflection would be the same for both and that the derived elevation angle would not appear to vary due to site effects as the antenna rotated. The experimental work showed that the variation was in fact sufficient to make the derived angle of elevation, and therefore target height, much less accurate than could be obtained from a dedicated narrow beam heightfinder and the idea was not pursued. Surveillance radars for this band were however developed and marketed by the Company for both military surveillance and civil air traffic control.

4.6 Moving Target Indication

An interesting aspect of this work was that of clutter suppression. The Type 11 referred to earlier had employed a technique of moving target indication (MTI) which involved comparison of the phase of signals received from successive radar pulses, with phase in each case being referred to that of the transmitted pulse by use of either coho-stalo or a coherent drive system. The comparison was made by delaying the earlier received pulse in a water delay line - a temperature-controlled vertically mounted column of water with input and output transducers at the upper end to convert the radio frequency signal to acoustic and vice versa. The pulse recurrence frequency demanded by the system was such that the path through the water, from surface to base and back again had to be about 3 metres (i.e., the tube about 1i metres high) which made the system cumbersome and impractical for anything other than a static installation. The MTI team led by W.S. Mortley devised an alternative system whereby the delay medium was mercury, in a shallow flat cell, with the acoustic wave transversing it horizontally by a tortuous multi-reflection path. The cell while still very heavy required considerably less space but became obsolete very rapidly when it was appreciated that the same effect could be achieved by passing the acoustic wave through an irregularly shaped multi-facetted slab of quartz, designed so that the signal crossed the slab many times from its launch by the input transducer to its emergence at the output. Quartz being a material with low expansion coefficient the delay cell was not only much lighter and smaller than the mercury equivalent but it also needed no temperature control and was not subject to spillage. In addition to their work on cell materials Mortley and his team developed the amplifiers necessary to drive the input transducers and to amplify the output signals, and this work led subsequently to the use of quartz and other materials in pulse compression for radar.

4.7 Air Surveillance at Jersey Airport

Although much of the work in the radar field was stimulated by the requirements of UK and Overseas Defence Authorities attention was also being given to potential civil uses of radar. In 1948 the Marconi Air Radio Division was awarded a contract for an air surveillance radar to be used for aircraft control at Jersey airport. It was intended that this should be based on the marine Radiolocator II but the requirements for appropriate cover in the vertical plane demanded a new antenna design with switchable beams, one having a $Cosec^2$ shape for longer range targets, and the other having a fan shaped high cover pattern for use when targets were close in. Removeable circular polarisers were fitted to the antenna to reduce the effect of rain attenuation, which could be relatively severe because of the high operating frequency (10 GHz). In order to achieve the necessary increase in range required for this application a higher power transmitter was also required. It used the English Electric Valve 4J50, delivering a peak power of 200 kW (0.5 µsec, 1000 pulses/second), which was high for that time. Further enhancements in performance were achieved by using both logarithmic and linear receivers, with swept gain and short time constant facilities. The final design has therefore little in common with Radiolocator other than the operating frequency band.

This prototype, designed entirely in and installed by the Research Laboratories and employing a number of new techniques was in operational use in Jersey until 1959 when it was replaced by a new design operating at approximately 600 MHz.

By the mid 1950's a total capability for pulsed radar research was established in the laboratories, G.N. Coop who had worked on television transmitters and on the 1.3 GHz transmitter within the Chelmsford works, having transferred to the laboratories to lead a high power team; O.E. Keall and others working on receivers and R.P. Shipway and colleagues on display and data handling systems, all in conjunction with the antenna and signal processing work already mentioned. The CW and FM work on the other hand had tended to decline, with insufficient market drive to push it forward. However one of the most significant advances of the century, the widescale application of semi-conductor technology was still to come.

4.8 Antennas - A New Measurement Facility

One of Franklin's outstanding contributions to the short-wave beam system in 1924 was the flat broadside array of linear radiators supported in front of a wire reflector on tall T-towers. The narrow beams produced by these structures were probably the most effective land-based long-range communication antennae until the Multi Unit Steerable Array some fifteen years later, and they were only replaced in the 1950's by the cheaper rhombic design because of its wider frequency coverage and lower maintenance cost.

In 1953 the Research Laboratories started a program to investigate the performance of wire communication antennae, and for this purpose a wire-mesh covered platform was constructed in the field to serve as an earth plane on which scale models of wire antennae could be mounted. The models worked at 300 to 600 MHz and were rotated to plot the horizontal polar patterns, whilst a 40 foot insulated boom carried a battery fed test oscillator over the earth plane for vertical polar diagrams. Over thirty years this equipment has been used to measure ship, land vehicle, aircraft, television and other antennae, and similar installations were set up at Service establishments. A full size range for testing antennae on vehicles up to 100 tons in weight was installed at SRDE Christchurch using a railway type turntable produced by the Mechancial Engineering Laboratory.

Among the continuing h.f. communication projects was an investigation into the effectiveness of polarisation diversity for receiving long-distance transmissions. It was conclusively shown that antennae at the same site with orthogonal polarisations gave equal performance for diversity reception as pairs spaced several hundred yards apart, and several h.f. receiving stations have been equipped with long-periodic arrays of this type; these are mainly defence installations, the civil h.f. links having been displaced by high capacity satellite and cable methods.

5. PHYSICS-BASED RESEARCH

5.1 Semi-Conductors

In 1948 the advent of the transistor had been announced from the Bell Laboratories in the USA and the whole of the electronics world began to look in that direction. By 1951 Eastwood had set up a semi-conductor research laboratory under the direction of I.G. Cressell and he with a number of colleagues began to grow germanium crystals and study doping techniques. Although the laboratories had some background in crystal growth from Parkin's work on quartz during and after the war, the techniques involved for semi-conductors were very different and like other UK workers the team had to build their experience virtually from scratch. New techniques for refinement and analysis were developed and small quantities of prototype devices made for evaluation by other units within the laboratories and by product divisions of the Marconi Company. All the early work was, as in the rest of the world, devoted to germanium but by the late 1950's the semi-conductor laboratory had extended its skills to the uses of silicon and, to a lesser degree, gallium arsenide. A manufacturing facility had also been set up within the English Electric Valve Company and was producing, inter alia, large area high current rectifiers to designs evolved by the Baddow Laboratories.

By the end of the 1950's much of the work of the semi-conductor laboratory was devoted to the support of a new factory set up as a collaborative venture between English Electric, Mullard and Ericsson. However this proved to be a relatively short term arrangement as by 1962 the collaboration was terminated following the acquisition of the Ericsson interest by the Plessey Company.

5.2 Vacuum Physics

In 1954 R.J. Kemp moved from the laboratories to Chelmsford to become Deputy Engineer in Chief of the Marconi Company and Eastwood took over as Chief of Research. In that year he set up another new activity, the Vacuum Physics Section, under the direction of G.D. Speake. Work on valves had ceased in Baddow at the end of the war, with most of the personnel having moved to Waterhouse Lane, Chelmsford to a manufacturing unit which, following the purchase of the Marconi Company by English Electric, became English Electric Valve Company (EEV). Eastwood believed that there was a need for continued research work in vacuum physics, particularly to fulfil the need for small quantity specialised devices in radar. The team with support from the Royal Radar Establishment worked on devices for radar receiver protection (TR cells) and on noise tubes to be used as standards in receiver noise measurement. The first application of their devices was in radars for the 1,300 MHz band, developed by the Radar Division of Marconi and sold to a number of customers in the military surveillance and civil air traffic control fields. Devices for the 3,000 MHz band followed and, although discussions took place from time to time regarding possible transfer of manufacture to EEV the quantity demand remained small and customers' needs are still being met in 1985 from the pilot facility. Design and manufacture for new requirements was however passed to EEV and from the end of the 1950's only such research work on vacuum and low pressure gas discharge devices as was necessary to support systems research work by other units in Baddow was carried out in the laboratories.

5.3 Magneto-Physics

A third physics-based activity, also started in the early 1950's and led by Dr R.J. Benzie, was concerned with the study of magnetic materials for use at microwave frequencies. Benzie, a wartime RAF colleague of Eastwood, had carried out research on magnetic phenomena for his D. Phil at Oxford and had taken up a teaching post at Exeter University. There he was sponsored by the Marconi Laboratories to study nuclear magnetic resonance which it was thought might, because of the narrow line width involved, offer a means of separating moving targets from the often much larger signals returned from fixed objects such as hills or buildings in radar systems. In 1952 Benzie left the University to join the laboratories on similar work. His experiments on nuclear magnetic resonance did not result in a practical system for a number of reasons, not the least of which was the necessity for the resonance material to be at liquid helium temperature, a considerable disadvantage in an operational radar. He turned his attention therefore to a range of new materials, commonly known as ferrites, which were being studied because of their potential use in microwave devices with non-reciprocal properties - i.e., devices in which phase change and/or attenuation of electromagnetic waves passing through them was dependent on the direction of propagation. Demand for isolators and circulators based on the use of ferrite materials grew rapidly with the development of microwave communication links and of new generations of radar, the latter requiring components capable of handling high peak and mean powers. A range of materials in a variety of sizes was necessary in order to cover the different frequency bands, operating power levels and attention/phase characteristics required and this was achieved by study of the precise constituents of the ferrite mixture, and of processing parameters such as pressure and sintering temperature. Early requirements for isolators and circulators within the Marconi operating divisions were met from the research facility but by the early 1960's the demand had grown to the extent that it was decided to set up a development and manufacturing facility within the Specialised Components Division and the bulk of the staff from the research group on ferrites was transferred to new premises in Billericay to undertake this task. (Benzie had by this time transferred to English Electric, Stafford as Director of the Nelson Research Laboratories.)

All these physics-orientated activities were aimed at fulfilment of system needs of the Marconi Companies and much of the research in other parts of the laboratories was devoted to the study of system parameters, including the assembly and testing of prototypes, usually in association with one of the operating divisions.

6. THE LATER 1950's

6.1 Fur Hat and Linesman

In 1957 the Marconi Radar Division was approached by the Royal Swedish Air Force with a requirement for a study of the Swedish Defence and Air Traffic Control System. A contract was awarded to the Company and Eastwood and other colleagues who had been involved in the studies for the RAF were instrumental in carrying it out. On completion of the study, proposals were invited for design and installation of a Control and Reporting Centre and a fixed price contract was won by Marconi, with a large proportion of the design and commissioning work being allocated to the Research Laboratories. It drew substantially on the expertise acquired by Shipway's team on earlier projects, amongst which were a number of specialised displays.

For example, a large diameter (21") PPI display mounted horizontally so that four users could group around it had been developed under the ROTOR contract. In the same project, techniques had been developed for automatic positioning of a nodding height finder by overlaying a strobe marker on a selected target on a PPI. Circuits for displaying alpha numeric data on displays in positions controlled from a joystick or rolling ball had been designed during technique studies carried out on behalf of RSRE in the middle 1950's. Also for RSRE raid analysis techniques, whereby areas of interest in an operational scene could be examined in detail on a 'B' scope (bearing/time display) or a Magic Carpet, were studied on specially designed equipment. (The Magic Carpet was a display on which horizontal deflection was a combination of range and bearing, and vertical deflection of time and signal strength, the overall effect being a picture in which the signal pulses appeared in three dimensions from the background).

All these techniques were used in fulfilling the requirements for the Royal Swedish Air Force Board in a project known as Fur Hat.

By the time that the contract was received, developments in transistor technology were beginning to make the use of digital techniques in circuitry practical particularly in the processing of raw data received from the radar heads. The Fur Hat system incorporated a purpose built programmable digital computer light-heartedly christened TAC (an acronym for transistorised automatic computer which also happened to mean "Thank You" in Swedish), for fighter interception computing. Its main data processor was a hard-wired logic device in which data storage was carried out in a parallel array of acoustic delay lines. The first station was completed successfully by 1963 with the result that a further contract for a second station was placed and was fulfilled approximately 2 years later.

While the Swedish Air Force was modernizing its control and reporting system the Royal Air Force was carrying out a similar, albeit more extensive, exercise to culminate in an up-to-date control centre at West Drayton. In this also the expertise of the laboratories was utilised in the design of fully transistorised marked raw radar displays with much higher transition and character writing speeds than had been achieved previously. Interface units were also designed to couple the displays to the digital data processing system for which Plessey was the contractor. Regrettably the periods involved in the specification, design, manufacture and commissioning of the UK system (known as Linesman) were so prolonged that it came into operation several years later than the Swedish counterpart, and was less advanced in terms of the technologies employed.

In carrying out its major tasks on behalf of the defence and air traffic control authorities the digital data processing team was looking for opportunities for exploiting its expertise in civil applications. One was the control system of a nuclear power station (WYLFA) in North Wales, for which two TAC processors were required.

Another was a status monitoring system for an electricity generating station, which made use of the X2000, an ultra—high resolution CRT display with strobe—written characters. Both of these products were sold via the English Electric Industrial Products Unit at Kidsgrove. (It is interesting to note that although the X2000 was never manufactured in quantity it gave very satisfactory service as part of a system for flight trials analysis and software proving at Baddow for nearly two decades from the early 1960's onwards.)

Bright Radar Displays

The display systems designed for Fur Hat and Linesman were to be used in control rooms where subdued lighting was the norm. There was, however, a requirement for a display which could be used in aircraft control towers and other daylight applications. For such purposes English Electric Valve Company developed the E702 five inch diameter direct-view storage tube which was capable of giving a display many hundred times brighter than the standard cathode ray tube. A unit based on this tube was developed by D.W.G. Byatt and colleagues and was installed in 1962 at Gatwick Airport where it displayed signals received by the S232 radar. After evaluation at Gatwick and subsequently at Heathrow Airport, the system was put into development by the Marconi Radar Division and many were sold for use in airfield control towers, where they gave the controller the facility to determine the exact range of an approaching aircraft and the ability to follow its movements until it could be seen through the tower window.

An alternative method of obtaining a bright display was to use a scan conversion tube, made by CSF in France, in which the radar PPI data, produced by a rotating time base synchronised with the antenna rotation in the normal way, was written on a target and subsequently read off by a raster scan process in a manner very similar to that used in a television camera. Displays on this principle were in operation in the laboratories in the early 1960's.

6.2 AJ Studies

Although the Linesman programme was unduly prolonged and to some extent out-dated there was one facet of the newly emerging UK ground defence system in which it was well up with the latest technology and in which the concept had not been previously employed. This involved the detection of individual aircraft carrying jammers in the presence of many others. The effect of such a raid on a normal radar would be to block out at least the whole of the sector in which the aircraft were concentrated, and probably much of the remainder of the display also.

The laboratories in association with the Royal Aircraft Establishment undertook during the period 1955-1958 a study of a system (WINKLE) whereby signals from the jammers were collected by two antennas - the normal radar antenna and a second 'high speed' antenna, perhaps 100 kms distant, which produced a narrow beam scanning the whole sector of interest in the period during which any single target would be in the main radar beam. Signals from the high speed antenna were passed over a radio link to the main radar site where they went through a series of delay lines before being combined in correlators. Correlation was only achieved when the delay in the line corresponded to the difference in paths traversed by the noise signals in reaching the correlation point. Thus from the known delay a target could be placed on a particular hyperbola and its precise position determined as the intersection point between the radar beam direction at the moment of correlation and the relevant hyperbola. This system also used a programmable digital processor (a re-engineered version of TAC). The delay lines were quartz into which an acoustic wave was launched via a quartz crystal transducer, with a similar transducer being used to collect the output. The necessary high speed of scan which enabled a sector of about 70 degrees to be covered in the interval during which the normal radar scanned over a single target was achieved by using a torus reflector with a series of feeds in the half-radius plane, individual feeds being connected to the output receiver sequentially through a rotating pick-up which scanned a circle of secondary collectors, each of which was coupled to one of the main feeds. Thus for each rotation of the pick-up the antenna beam scanned a sector of space determined by the total angle subtended by the torus at its centre.

Initial trials of the system in the North Sea were satisfactory and the equipment was then put into development and manufacture for use by the RAF.

6.3 Doppler Radars

While not commanding the attention given to pulse radar during the 1950's work on various forms of CW radar continued, one of the earlier activities being a study of FM CW radar for use at sea. This was followed in 1950 by a further study, led by Mervyn Morgan, of a pulsed doppler navigation radar for the Royal Air Force. The equipment, then code named Green Satin, determined the direction and speed of an aircraft relative to the ground, using the ground reflection of slanted microwave beams radiated from the aircraft. From observations of the Doppler frequencies in the returned signals, and alignment of the antenna array relative to a compass bearing, the position of the aircraft relative to its starting point could be determined without any reference to ground based equipment. The system was ready for aircraft trials by September 1951 and became standard for RAF planes until the 1970's. Later versions were sold by Marconi Aeronautical Division for use in civil aircraft across the world.

In the latter half of the decade Morgan and his team undertook a study of a pulse doppler radar (Green Sparkler) using a 1 KW 10 GHz klystron manufactured in the USA by Varian. The initial work was devoted to a study of noise performance and other relevant parameters but it led to four practical applications for a radar based on a low power CW klystron. They were:

1) Measurement of the velocity of approach of aircraft landing on a naval carrier.

2) Determination of the precise velocity of a shell after emergence from the muzzle of a gun,

3) Measurement of velocity of vehicles on the public roads, and

4) A speed meter for a hovercraft, requiring no contact with the water and therefore no drag.

Equipment with the acronym EVA (Electronic Velocity Analyser) for shell velocity measurement was delivered to the British Army and worked satisfactory under the arduous conditions experienced in the field, and PETA (Police Electronic Traffic Analyser) was used by the Police Force in many countries for detection and proving of speeding offences on the public highway.

6.4 Microwave Communication

The advances in radar techniques during this decade were accompanied by similar developments in communication. In 1947 Rudy Kompfner, who worked for the Admiralty during the war and moved to the Bell Laboratories in the USA thereafter, had conceived the idea of a travelling wave tube for use as an amplifier or oscillator. Rapid advances in the development of different structures for use at both ends of the power spectrum, i.e., for high power transmitting tubes and low noise microwave amplifiers, took place, led from the USA but with considerable effort also in the UK and France. The English Electric Valve Company undertook development and manufacture and the Baddow Laboratories studied potential applications. As microwave amplifiers and power generators the tubes were particularly useful in broad band radio link systems, such as those required from transmission of television or radar signals, but the commercial importance of such links for carrying many telephone channels over inaccessible paths was also very quickly realised. The early work was carried out in a group led by Rupert Collins. (His team also designed the first i.f. amplifiers, using "lighthouse tubes", for the 1.3 GHz radar mentioned in 4.5, although they were replaced very early in the programme by wired-in miniature valves.) Collins left the company in 1954 and thereafter the work was shared between two teams. One, led by W.L. Wright, concentrated on transmission of radar and television signals. Experimental links were installed between the Company's own radar sites (at Bushy Hill and Rivenhall) and the Baddow Laboratories, and between Baddow and RRE, Malvern. The team was also responsible for design and installation work on the links for the WINKLE system described in 6.2 and for operational links used for transmitting information from RAF stations to control centres. The second team, led by S. Fedida, carried out the initial research work on telephony application and, when the decision was taken to embark on manufacture and marketing, Fedida transferred to the Communications Division of the Company and led the development team based at Writtle. (Some years later Fedida left the Company to join the Research Laboratories of the British Post Office at Martlesham, Suffolk and led the research team which conceived the Prestel system).

The work in Wright's team on radar links continued throughout the 1950's and 1960's, although Wright himself transferred to a newly formed Space Division in 1965. Amongst these achievements were demonstration links in the UK (between RAF Bawdsey and RAE Farnborough) in 1956 and in North Norway in 1958/59. Following this work they undertook, on behalf of Marconi Radar Division, development of a private venture link (SX 120) and assisted in its installation in Norway and Cyprus in 1963/64, and in the UK Air Traffic Control system in 1967. Parallel work on link channelling for the Linesman System began with a Ministry sponsored study in 1962, followed by development and installation over the period 1963-68. Consultancy work in this field continued until 1973.

6.5 VHF, UHF and Tropospheric Scatter Propagation

The regular ionospheric predictions which had been made by the propagation experts for the users of h.f. services in time of war continued throughout the peacetime years from 1945 onwards. The Propagation Group also gave support to communication and radar engineers in wave propagation matters at all frequencies from 10 kHz to 50 GHz, including the performance of site surveys and experimental measurements. It had become the recognised UK source of information on propagation effects in all the radio communication bands, including the effects of obstacles such as building and hills on the reliability of transmission of a signal - much of the theoretical work on the subject, being carried out by Millington. It was not therefore surprising that when the independent television was launched in the UK in 1955, advice on site selection and on the coverage likely to be obtained from individual stations was sought from this group. A contract was placed on the laboratories by the Independent Television Authority to cover both prediction of performance, using detailed information regarding the topography of the area concerned and density of population, and measurement of field strength achieved in practice. The correlation between the predicted and measured performances was so close that for the later stations measurement was not usually regarded as necessary.

In the same period interest grew in communication beyond the horizon at frequencies above 30 MHz by various forms of scatter mode propagation, a phenomenon for which Marconi and the early radar users had found evidence. G.A. Isted made measurements of signals caused by scattering in the E-layer of the ionosphere 85 to 100 km above the earth, the ionisation for the background signal being due to solar radiation, and strong bursts of signal being scattered from meteor trails. A test circuit was set up between Gibraltar and East Hanningfield, and as a result of this work an operational two-way link using a high power 40 MHz transmitter with curtain broadside antenna arrays was installed for MOD between Ventnor and Malta by the Communications Division of the Company.

A more prolific source of business was the investigation of scattering from the troposphere, up to about 5 km height, at higher frequencies. This began as propagation experiments in the mid 1950's on a test link between Bromley, Essex and Grantham. A further experiment in 1955 utilised the high power 1300 MHz radar transmitter at Chelmsford to measure signals at every 160 km range from Grantham to Aberdeen. The results of the propagation measurements led in 1957 to setting up a demonstration link between Start Point in Devon and the old racecourse at Galleywood, using a
10 kW CW transmitter produced by the Communication Division and 10 m parabolic

antenna made at Newcastle. The link on 858 MHz was run daily by D.A. Paynter for more than a year, carrying 24 high quality telephone channels, as well as telegraphy, and finally some rather sub-standard television pictures. As a result of these demonstrations tropospheric scatter systems became an established product line, providing commercial telephone links of several hundred kilometres over sea and desert, for island chains, oil rigs and defence networks.

6.6 Radio Guidance for Blue Streak

In 1956 Eastwood was approached by the Ministry of Defence about a radio guidance system for the Blue Streak inter-continental missile, which was at that time one of the elements in the U.K.'s defence strategy. He assembled a team of senior engineers and was awarded a contract for design and development. Trials of the system were to be carried out in Essex and a 360 ft. mast from the wartime CH Station at Canewdon was transferred to Baddow to form a platform for missile control experiments. The team of about 100 engineers was well advanced in the system design, including microwave components to be mounted in the missile for reception of guidance signals, when the Ministry decided to abandon radio guidance in favour of inertial guidance, the technology of which had advanced rapidly in the period concerned. The Canewdon mast was not therefore put into use for its intended purpose but has been applied for many other projects since. It was for some time the receiving end of a microwave link bringing live radar signals from the Bushy Hill Site to the Laboratories and has on a number of occasions served as one end of an antenna polar diagram measurement site.

6.7 Integration of Broomfield Radar Team into Baddow

The major expansion in activities which had taken place in the 1950's caused considerable pressure for space within the 1939 building and the various hutments around it. In 1958 a new 2-storey building, approximately doubling the floor space of the original one was completed and the opportunity was taken to transfer a group of engineers from Broomfield (Chelmsford) to Baddow. This team had been involved in development of a range of radar equipments, a number of which had been sold to NATO countries, and its members were integrated with those at Baddow who were engaged on similar tasks for the Ministry of Defence and the Swedish Air Board and on private venture research and development work. This meant that Eastwood had at his disposal a considerable technical force, probably unrivalled in the UK in terms of its breadth of experience and capability. This, added to his own personal reputation, ensured that the laboratories were often approached when new national projects, demanding outstanding technical capabilities, were being considered. However, the sudden loss of the Blue Streak commitment left a substantial number of engineers available for other work, most of which had in the short term to be company-sponsored.

6.8 A New Generation of 600 MHz Radar

The opportunity was taken to reexamine the requirements of the traffic market for radar. The Company's S232 radar, developed in the early 1950's and operating in the 600 MHz frequency band, had proved be very successful for civil air traffic control, primarily because its freedom from weather clutter and its good MTI performance (resolution of moving from fixed targets). Developments in high power travelling wave tube amplifiers gave promise of even better MTI performance and in association with English Electric Valve Company, who designed a t.w.t. for the purpose, studies of a new system at 600 MHz were undertaken. A new antenna with a linear slotted waveguide feed and single curvature rodded reflector was also designed and feasibility of the total system rapidly demonstrated. Further development was undertaken within the same teams and the equipment was sold successfully as the S264 radar to many civil traffic authorities across the world. By the advent of this particular equipment research on delay lines for MTI purposes had moved from the liquid to the solid state as previously described. The research carried out into the launching of ultrasonic energy into such lines was also destined to be used subsequently in other applications of quartz, such as surface wave filters and frequency dispersive delay lines for pulse compression radar systems.

Digital Techniques

Some of the engineers released from the Blue Streak programme were also made available to work on the Fur Hat programme where they developed display and data handling processes extensively based on digital techniques. (It was the proposal to use digital techniques which had contributed to the award of the Fur Hat contract to the Marconi Company rather than to Decca, who had offered equipment based on more conventional analogue techniques.)

6.9 Radar Ornithology

While this practical systems work was in progress Eastwood and a number of dedicated colleagues were making a systematic study of the causes underlying the clutter effects which had characterised radar from its earliest usage. Some of these such as the reflections from large stationary objects e.g., hills or building were easily identified, but the origin of the phenomenon known as "angels", whereby a display could be substantially covered by very large numbers of apparently stationary or slow moving targets, was less clear. In one formation known as "ring angels" the targets would emanate from a particular point on the display and move radially outwards from it to form a ring, with further rings being generated from the same centre at intervals of about 15 minutes. It was not uncommon to observe several of these rings arranged concentrically, with each expanding outwards at the same velocity, but the effect was usually confined to a few fixed sites in the area covered by the radar and a period of an hour or so after dawn. The origin of the expanding rings could be determined precisely from the radar display and by visiting the relevant spot at the appropriate time the research team was able to correlate the formation of the rings precisely with the departure of flocks of starlings from their roosting site at dawn. The relatively slow movement of dense echoes on the display were also correlated with the known migration routes of birds and a line of echoes generated from objects a mile or two off the coast line at night was attributed to swifts feeding on airborne insects. It became clear that the majority of "angels" seen on radar displays were indeed birds flying singly or in small groups, and the results of the very effective programme of research were collated by Eastwood in his book "Radar Ornithology".

One other prominent effect observed during this research activity was the appearance of a band of noise on the radar display in the direction of the sun, as the latter crossed the horizon at dawn and dusk. This was by no means the first time that noise emanating from the sun had been seen on a radar display but it did lead to a realisation that radio noise from stellar sources could be used to determine, or at least to verify, the polar diagram attributable to the radar antenna. The technique is not likely to be used for checking horizontal polar diagrams because it is relatively easy to measure the signal received from a ground based source by the antenna as it rotates, but it was used in a number of instances for checking vertical polar diagrams where the only other way of making on-site checks would have been to install a radiating source in an aircraft or balloon.

6.10 Antenna Research - Early Work on Electrical Beam Scanning

Such on-site checks were often the culmination of a research and development exercise on an entirely new form of antenna. The laboratories had been gradually building up expertise in antenna design from the late 1940's when J.F. Ramsay published the series of articles on Fourier Transforms mentioned earlier. Apart from the general objective of producing cheaper and more effective designs for communication and radar systems there were two central themes for the antenna work over the period. The first was to produce systems with as wide a bandwidth as possible in order to provide users with the facility of changing channels as required in order to get better performance or, less constructively, to enable jammers to interfere with a wider range of users!. The second was to provide means whereby a radiating beam could be moved in space without the necessity for moving the whole antenna structure i.e. scanned electronically. Much of the work in these areas was carried out in association with Ministry of Defence research establishments; RAE for airborne and ASWE for shipborne applications.

Amongst the most important of the broadband antenna studies was that originally led by M.F. Radford on log-periodic arrays i.e. a planar structure of dipoles, or similar radiators, of length and separation increasing logarithmically from one end to the other. Many versions of the antenna, at frequencies ranging from the h.f. band into the microwave region of the spectrum were designed and used by Marconi Companies and by other companies under licences granted in connection with one of Radford's patents.

Two techniques for electronically scanning a radar beam were investigated, the antenna in each case consisting of a number of discrete elements. The combined beam from the elements radiated in a direction determined by the phase separation between them. Thus if the phase separation was a multiple of 2π the separate elements would add constructively in a direction perpendicular to the array, giving a beam in that direction. For any other phase separation, the beam would emerge at a different angle. In one technique the phase between the elements was changed by inserting ferrite elements to which a controlled magnetic field could be applied. In the other, a relatively long waveguide path was introduced between the elements either as a zigzag in normal rectangular waveguides, or as a helically wound guide with radiating elements tapped off at each turn. The effect of changing the radio frequency in such a system is to cause the phase at the successive elements to change (by an amount depending on the length of path between them). Thus the output beam moves in space as the frequency of the system changes. (It is interesting to note that in the 1940's C.D. Colchester and C.S. Cockerell had filed a patent describing a system in which the frequency of a radar signal was varied during the pulse duration, achieving thereby a within-pulse beam scan.)

Work on both types of antenna (phase scanning and frequency scanning) was supported by the Admiralty Surface Weapons Establishment, with the Marconi Laboratories concentrating on frequency scanning, but having a peripheral interest in phase scanning because of its work on ferrite materials. However, neither system was developed for operational use at that stage; phase scanning proved to be too expensive because of the need for many ferrite elements, each of which had to be reproducible in magnetic performance and was therefore costly to manufacture; frequency scanning arrays were also expensive to make and had the disadvantage that, since frequency change was the means of moving the beam, it could not also be used as a way of avoiding jamming. Thus although the work at that time demonstrated successfully the principles of beam scanning by electrical means, it was some years before the technology of component manufacture had advanced sufficiently to make it possible to design systems which could be manufactured at an acceptable cost.

Also in the late 1950's interest grew in the possibility of designing a single antenna which could receive beams from different directions simultaneously. One application could be a height finding antenna by which the angle of elevation of a target could be determined from the particular beam in which it was detected, or more precisely, by comparing the amplitudes of signals received from the same target in two overlapping beams. Another which was receiving much attention from designers on both sides of the Atlantic was the isolation and possible tracking of individual targets in a multiple attack, such as might come from inter-continental missiles with fragmenting warheads. To achieve the required resolution of targets, large antennas were necessary and studies were carried out on techniques for producing spherically symmetrical structures of diameter up to 80 ft. from materials in which the dielectric constant could be adjusted in order to give lens like properties. Multiple feeds distributed on one side of such structures (Luneberg lenses) would produce the desired multiple beams on the other. The required lens characteristic had been achieved in the USA on relatively small structures by making a sphere as a series of concentric shells, each being of a material of a different dielectric constant from the others. In an ingenious variant studied by E.F. Goodenough the variation of dielectric constant was achieved by disposing table tennis balls at an appropriate density in a dielectric foam. Had this system been put into operational use it would have had a major affect on the turnover of the "ping-pong ball industry!

As part of the same investigation the Ministry of Defence entrusted the Laboratories with the task of developing a modulator for a very high power radar transmitter which might be used in such a system.

6.11 High Power Radar Transmitters

The transmitter was intended to produce an output pulse with a peak power of 100 megawatts, nearly 2 orders of magnitude greater than that generated by most high power radar transmitters of the period. In order to achieve the equivalent of an even higher peak power it was planned that pulse compression techniques would be used to reduce the effective pulse length in the ratio 1 to 20. Thus the system would have an effective peak power of 2000 megawatts! The output valve, a klystron operating in the 400 MHz frequency band, was being specially developed by the Services Electronics Research Laboratory, Baldock. Extremely high voltages (about 500 kilovolts) had to be applied to the valve during the pulse period and there was consequently a high X-ray flux in the system. The modulator was therefore enclosed in a lead-lined pit with all the controls outside the danger area. The very formidable problems involved in this unique activity were well on the way to being overcome, i.e. the modulator was operational and the klystron oscillating at about two thirds of the peak power of 100 kilowatts, when the decision not to proceed further with the system was taken by the customer. While it had not resulted in an operational requirement, the work had demonstrated that the Laboratories had an unrivalled team in high power modulator and antenna work. The decision not to exploit it fully was one of defence strategy, not a consequence of technical shortcomings.

6.12 Satellites

One of the most important advances of the 1950's not previously mentioned was the launch of artificial satellites, beginning in 1958 with the first Sputnik. Because of its potential importance for long range communication, interest in this work in the Marconi Laboratories was considerable and very early measurements were made on Doppler shifts associated with satellite movement, using techniques developed by Lea and his colleagues for frequency control and measurement. By 1959 studies on potential uses of satellites were in progress in several parts of the laboratories, one of the earliest being carried out in association with the Royal Aircraft Establishment and the Royal Society on a scientific satellite, to be equipped with a large telescope and aligned by television. Other system studies followed, covering communications equipment and antennae for defence links, navigation, satellite to ship and satellite to aircraft communication. In order to make best use of the limited power available from the satellite, both analogue and digital methods were studied, much of the work being carried out under study contracts placed by the European Space Agency.

Apart from specialised component work the Marconi Company did not operate in the space sector of satellite communication and research work was therefore confined to system studies and simulation activities. Moreover from 1965, when a large group of engineers transferred to the newly formed Space Division, hardware development for the ground sector passed from Baddow into the domain of the product unit, with the research team acting as sub-contractors for specialised items of equipment and for the electrical design of the antennas.

6.13 Mechanical Engineering

There are few activities in electronics research which do not have a significant mechanical content and although its design may in some cases be within the capability of a practical electronics designer there are others, such as the development of large antennas, where a high degree of mechanical competence is required. Under both Kemp and Eastwood R.A. Nightingale led a mechanical design team, supported by Drawing Office facilities provided centrally from the Marconi Company headquarters, which provided the necessary expertise to other research workers and undertook the design of structures such as antennas and rotating mounts for those projects where the laboratories developed prototypes. This team operated within the Great Baddow Laboratories until 1961 when it was decided that it should move to Writtle and come under the control of a newly appointed Mechanical Engineering Director (G.W.F. Adler). Its terms of reference (and its strength in people) were expanded to include the provision of expert services in stress analysis, heat transfer, servo-mechanisms, fluidics and any other activity where the reliability of a product was influenced by mechanical considerations.

In most of the projects previously described, and in those which were to develop later, this team provided supporting services including, as necessary, the design of small mechanisms which were primarily mechanical in nature, such as "tracker balls" for controlling the movement of a strobe on a radar display and precision encoders where angular movement was translated into a digital code via an optically encoded disc.

In 1958 Adler took up a new appointment as Manager of the Mechanical Products Division at Felling which designed and made antennas and other mechanical components for the Radar and Communications Divisions of the Marconi Company, and the mechanical engineering team at Writtle again became part of the Research Laboratories.

7. THE EARLY 1960's

7.1 Waveguide Communication

In 1960 research work began on transmission of electromagnetic waves in over-moded waveguides, i.e. in a waveguide much larger than was necessary in order to support the fundamental mode.

An H_{01} mode in a circular waveguide is transmitted with very low attenuation providing that conversion to other more lossy modes can be avoided. This was achieved by making the waveguide from a closely wound helix in a dielectric supporting medium, thereby inhibiting the longitudinal current flow in the walls associated with higher order modes, and by avoiding bends as far as was practicable. The waveguide was obtained from another company (British Telecommunications Research - subsequently part of the Plessey Company) and the research programme carried out in collaboration with them.

Such a system using a waveguide about 6 cms in diameter and carrying an electromagnetic wave in a frequency band about 30 GHz is capable of carrying very wide band information, e.g. many television channels, and the systems research work was therefore accompanied by studies of potential millimetric wave sources and detectors. Oscillators centred on approximately 40 and 80 GHz were constructed in a microwave laboratory led by M.J.B. Scanlan and components from external sources were procured for evaluation. However, the first systems use was in an experimental X-Band radar at ASWE, Funtington in which the antenna was at the top of a mast, an over-moded waveguide about 6" in diameter being used for transferring the signals from the antenna to the base of the mast and vice versa. The components and measurement techniques developed at this stage of the work were to prove very valuable when in the early 1970's the Post Office and other telecommunications authorities in USA, Japan and Europe began to develop an interest in waveguide trunk transmission using digital modulation techniques.

7.2 Management Change

In 1962 Eastwood left the Research Laboratories to take up a position in the Engineering Directorate of the Marconi Company and subsequently to become Director of Research for the English Electric Company. He was succeeded as Chief of Research by G.D. Speake under whose direction many of the projects initiated in Eastwood's tenure of office were continued. One of these was a study of the accuracy of blind landing systems and of the effect of extraneous factors such as anomalous propagation and reflection of signals from buildings and aircraft. This work was carried out on an interference-free site at a disused airfield at Saling by a small team led by SAW Jolliffe, who had had previous experience in navigational aids in the late 1940's and early 1950's when he and others had worked on a VOR system. This new work was supported by the Royal Aircraft Establishment and was particularly relevant to the introduction of blind landing aids on Trident aircraft in 1959. The studies were pursued for some years and included, inter alia, investigations of the increase in accuracy expected to accrue from movement of the operating frequency of Instrument Landing Systems from the metric to the microwave band.

Towards the end of the 1960's interest in Microwave Landing Systems had increased to the extent that a study under the auspices of NIAG (NATO Industrial Advising Group) was commissioned by NATO, and carried out by an international team with Jolliffe as Chairman. Regrettably, although real advantages could be seen for the introduction of microwave systems they have not by the middle 1980's been adopted on any significant scale.

The last major radar activity initiated under Eastwood's direction was design and development for a system for the Army, subsequently sold overseas, and known as Green Ginger. It was an air-transportable equipment mounted in trailers, with back-to-back S and L band surveillance systems on a single antenna mount and a separate nodding height finder operating in C band.

7.3 Computing

The development of the transistor had made possible the use of digital computers in systems such as Fur Hat from the late 1950's. Their use as practical aids to engineers carrying out research and development work began with the installation of an English Electric DEUCE computer in January 1959. At the outset this was used almost wholly by specialist theoretical teams led by P.S. Brandon. Programs were written to enable tasks previously only capable of being performed by mathematical specialists to be undertaken directly by the engineers involved in research programs, and covered many 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.

A.B. Starksfield, E. Atkins and colleagues devised and constructed a processor, using an architecture formulated by B. Partridge and D. Jefferies, which emerged as an experimental model in 1964 when it was probably the fastest machine available in Europe and possibly in the world. It was affectionately called IMP by its designers (not because of any idiosyncrasies in its behaviour!) and was soon in use in the laboratories for development of real-time data processing systems and for a number of off-line tasks such as analysis of flight trials of new radar systems. It continued to fulfill that function for some 15 years after its completion.

Following the emergence of IMP a decision was 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.

They had two major tasks. One was to develop, on behalf of English Electric Computers (Kidsgrove), the 4/30 computer, one of the new System 4 series which that company was intending to launch in the next two or three years. The other was to develop from IMP a range of computers, known as the MYRIAD series, which were subsequently sold for use in radar, air traffic control, road vehicle control and message switching systems.

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.

7.4 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.

7.5 Satellite Earth Terminals

From 1959 the laboratories had been involved in a number of studies relating to the performance of satellite systems for both communication and scientific purposes. These included defence links, navigation, satellite to ship and satellite to aircraft communication. Analogue and digital methods were investigated as means of making the best use of the limited power available from the satellite. The step to design of practical hardware was taken in 1964 when the Company was approached about a requirement for 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 Marconi 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 40 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. (This first station, installed at SRDE Christchurch, was transferred to Deffard (Worcs.) when that unit became part of RSRE and with some up-dating was still in use in the mid 1980's.)

With the formation of the Line Division of the Company in 1965 W.L. Wright Chief of the Communications Group transferred from the research laboratories to become its Technical Manager and other members of the research team joined him and contributed to the design of the Ascension Island terminal for the Apollo mission and of many ground stations, including those at Goonhilly and Madeley, with antennas up to 30 metres in diameter.

7.6 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. The formidable problems involved in fabricating the maser and the liquid helium cryostat in which it was required to operate were overcome and working devices demonstrated. However, the period over which it was to find application in operational systems was relatively short because similar low noise performance was achieved from other, less cumbersome systems. (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 (para 8.2), an interesting reversal of the role of the two companies took place some years later.

7.7 Velocity Measurement by Opto-electronics

In 1964 the laboratories were asked by a potential customer to investigate methods of measuring the linear velocity of hot strip emerging from a steel rolling mill. W. Agar, then a member of Morgan's CW radar team, suggested that an optical technique showed more promise in this application than radar, and filed a patent on a new system. Light reflected from the strip was transmitted through a grating to a detector, which converted it into an electric signal, the frequency of which depended on the spacing of the grating elements and the linear velocity of the strip. Frequency measurements could then be carried out by well established electronic processes. The validity of the technique was established in the laboratory and some trials were initiated in a working steel mill in 1966, the later experiments being carried out in association with English Electric, Stafford. Similar equipment was assembled, under a contract from the Ministry of Defence, for measurement of the muzzle velocity of shells emerging from guns and the launch velocity of rockets. Trials of this equipment were made by the Army, in the UK and in Germany, in the early 1970's.

Also in the early 1970's the UK Police Forces were seeking a replacement for the PETA speed meter (see para. 6.3) and a contract was placed by the Home Office for examination of the optical technique. A device with the required accuracy, known as OSCAR, was demonstrated to Police Forces but was not adopted by them, partly because they were reluctant to spend the time and effort involved in convincing magistrates and juries of the validity of a new technique, and partly because a very cheap form of electronic stop watch which could be used (albeit with less accuracy) by police officers in a vehicle became available at the same time.

A further application, developed in the period 1976-1980, was in the measurement of the stopping distance (or angle) of moving machinery in the event of an emergency, such as hazard to the operator. A number of these equipments, known as TINA, were sold direct from the laboratories to the Health and Safety Executive.

8. THE LATER 1960'S

8.1 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 devolved 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.

The largest laboratories in the new structure were the Radar Research Laboratory (led by Dr. G.N. Coop), the Communications Research Laboratory (Dr. G.L. Grisdale), the Autonomics Laboratory (A.B. Starksfield), the Theoretical Sciences Laboratory (P.S. Brandon) and the Mechanical Engineering Laboratory (R.A. Nightingale). The last mentioned of these was located at Guy's Farm, Writtle. An Antenna Laboratory (F.A. Dutton) continued to do development, particularly for the Radar, and Radio and Space Communication Divisions of the Company, making use of centralised measurement facilities on sites at Baddow and Rivenhall. Physics-based research was carried out in a microwave group led by Scanlan and in the ferrite group of the Marconi Specialised Components Division, with the latter being under the administration control of the Divisional Manager but responsible to the Director of Research for its research programme.

8.2 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 chalcogenide 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 but, in view of the success of the direct view storage tube (described in 6.1) in a similar role, the Radar Division decided not to undertake quantity manufacture.

Reference was made in 7.6 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 following the re-organisation of 1965.

8.3 The MAT Laboratory

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.

Using the expertise developed as a result of the research programme it was also able to offer a service to the Marconi Systems Companies on the diagnosis of causes of failure in semi-conductor components.

Owen Joseph, who had been a member of the semi-conductor research team in the early 1960's and became a product manager in the Microelectronics Division when it was formed at Witham, returned to Baddow in 1970 and under his guidance the MAT Laboratory expanded rapidly to meet a demand from the Systems Companies. The prototype devices, made initally to study a process, were embodied in new designs and the unit facilities and staff were increased to meet the specialised needs of the product divisions. By the middle of the 1970's the MAT Laboratory had established itself as a composite research, development and manufacturing facility, with the quality standards required for military or civil equipment, and was supplying a wide range of complex devices to product companies in the GEC Marconi group on competitive terms. At the same time the results of research were fed to the companies for use in their own manufacturing units, and general advice and assistance was given to those in the process of setting up new ones.

8.4 CTEREU

The second new unit 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 initial purpose was fulfilled this unit became the Quality and Test Gear maintenance unit of the laboratories.

8.5 Seawolf

At 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 modifications in ship design demanded a reduction in overall weight. New versions of the equipment were therefore offered and sold 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.

8.6 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.

8.7 Early Contacts with Essex University

An interesting collaborative 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.

8.8 Project Mallard

In 1967 the Marconi Company was one of four in the UK (the others being GEC, Plessey and STC) which took part in a major study of a battlefield communications system, which was to be largely digital in its implementation and would offer network facilities to commanders in the field on a basis not previously achievable. The United States, Canada and Australia also participated with the objective of making the systems used by the Armed Forces of those nations wholly compatible.

W.L. Wright moved from the Space Division to Fort Monmouth in the USA to become one of the senior members of the co-ordinating team. The Research Laboratories at Baddow, primarily in the group led by P.N. Sargeaunt, played a major part in the studies under the direction of a "UK Board" set up for the purpose. (The Board had representatives of the four companies and a Managing Director from Plessey.)

Project Mallard was very advanced in technology but even more so as a concept in international collaboration. In 1969 the four nation agreement broke down and the UK proceeded on a more limited system (Ptarmigan) in which Plessey was destined to play the major role.

8.9 The GEC - English Electric Merger

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 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 activity and were widely used both in the laboratories and by Product Divisions.

8.10 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.

9. THE 1970's

9.1 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.

9.2 Vehicle Location

In 1969 the laboratories took over some exploratory work on road vehicle location 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 by the Autonomics Laboratory, management of which had been taken over by R.P. Shipway, who had returned to Baddow after a period at the Chelmsford headquarters as Technical Director of the Electronics Group of Marconi Companies. 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 the laser beam passed over the code plate. Over 2000 coded plates were installed on nine routes in Bristol City Centre and the system was assessed over a period of several months for potential operational benefits. During the evaluation exercise the General Manager of the bus company left and the incumbent decided that further investment would be devoted to improvement of the serviceability of the buses rather than to their control en route. (Our experience during the trials with bus availability tended to confirm his view!)

The next system evaluated, known as LANDFALL, was based on a patent taken out by R.D. Tyler and L. De Tullio. The vehicle to be located was no longer 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. 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 1978. 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. The Plessey Company announced a system with features very similar to LANDFALL in 1986.)

9.3 The MADE Project

In 1973, following a private venture study begun in 1971, 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 headquarters and vice versa. This was known as MADE (an acronym for Mobile Automatic Data Equipment). 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 (1986).

9.4 Wideband Communications

From its earliest days the Marconi Company has developed new business as a direct consequence of successful research and resourceful exploitation of it. Inevitably not all projects were immediately successful, but often work abandoned due to technical problems has been re-started because new techniques enabling the problems to be solved have become available. This was the case when in 1970 work on over-moded circular waveguide, discontinued in the 1950's, was revived in order to meet a potential demand by the British Post Office for new, very high bandwidth trunk systems. Technological advances in digital modulation systems using solid-state devices 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 in 1977 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 the attenuation through such fibres could be so reduced that this technology would overtake over-moded waveguide for wideband systems in trunk routes 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.

9.5 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 attenuation of about 4 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.

9.6 Antennas

In the early years of the laboratory, aerial research was carried out by the communications and radar teams and closely allied to systems studies in which they were involved. However, when the new (B Block) building was opened in 1958 the opportunity was taken to group the experts, together with people with microwave background from the vacuum physics section, into a microwave physics group. In 1962 the aerial work had expanded to the stage where it was decided to constitute a specialist aerial research group, under the direction of F.A. Dutton, other activities remaining with the microwave physics group led by M.J.B. Scanlan.

In 1969 a team based on the Baddow site, and led by S. Nolan, which was involved in the design of R.F. communications antennas on behalf of the Communications Division of Marconi, joined the aerial research group which was then renamed the Antenna Department in recognition of its dual role in research and development. Thereafter, in addition to carrying out centrally funded research work it did virtually the whole of the electrical design of antenna systems on behalf of the Marconi Product companies until the early 1980's when some degree of decentralisation was re-introduced.

In this period the Department engaged in a spectrum of activities ranging from H.F. into the millimetric bands. 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 antennas, 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.

9.7 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.

9.8 Satellite Sub-Systems

As was mentioned earlier the Marconi Company decided in the 1960's not to operate as a prime contractor for supply of satellite-borne equipment. However, as a supplier of ground stations it was concerned with overall system performance and with the analogue and digital methods being employed. Research at Baddow was concentrated on those topics and continued to grow throughout the late 1960's and 1970's, with much of the work being supported by contracts placed by the European Space Agency. By 1969 the English Electric/GEC merger had brought into the Marconi group of companies the GEC unit based at Stanmore (re-named Marconi Space and Defence Systems) within which was a satellite design and manufacturing division. This increased the importance of the systems research activities. Three of them justify special mention.

One was a new technique for analysis of system performance, using specially developed software, prominent in which was a program called MODSIM, established in the early 1970's by J.K. Skwirzynski and colleagues, and further developed by them under a contract from ESA. It was extensively used within Marconi units and was also sold under licence to other satellite system designers working on behalf of the Agency.

The second was a hardware-based system for evaluation of performance of a projected satellite system by experiments carried out on earth. The European Space Agency set up an experimental system using two mountain sites between which there was an uninterrupted line-of-sight path, and a contract was placed with the communications group at Baddow to design and supply the 180 Mbit/sec digital equipment used in assessment of system performance. This was installed in 1975 and on-site support was provided for about 2 years thereafter.

The third was the setting-up on the Company's Rivenhall site, a facility for measurement of the polar diagrams and sidelobe performance of a satellite antenna, to an accuracy not hitherto achievable. This was done in close association with the Satellite Division of Marconi Space and Defence Systems which, with partners from Europe, was involved in the design and manufacture of the MAROTS experimental satellite for ESA. (It is interesting to note that not only was the team entrusted by ESA to set up this unique facility, but the engineers concerned were regarded so highly that some of them were recruited by the Agency, in mid-programme, to join its own staff!) The contract for this work was placed in 1975 and the site completed to ESA's full specification in 1977, although practical measurements on antennas had been made before the completion date.

Work for the Post Office (later British Telecom.) included a 60 Mbit/sec modem for use in trials of the Intelsat System (1973-1978) and 120 Mbit/sec equipment for the "OTS/MAROTS" system at Goonhilly (1976-79). The same team developed an 60 Mbit/sec modem for the Independent Broadcasting Authority in 1979.

9.9 Synthetic Aperture Radar

Synthetic Aperture Radar as a means of getting high resolution from airborne systems, was not studied seriously 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 completed successfully and led to a further contract in 1970 to build a processor specifically designed for synthetic aperture radar studies at the Government research establishment. This was the first equipment of its type and showed that the technique of digital processing had now advanced sufficiently to become the basis of practical SAR systems.

By the mid 1970's it had became apparent that similar techniques might be used in satellites for studies of earth resources, the behaviour of the sea surface and weather patterns. In addition to continuing work on airborne radar, research was therefore devoted to processing of satellite derived data, some financial support being provided by the Department of Industry and the European Space Agency, with both RSRE and the Royal Aircraft Establishment having an interest in the outcome. By the end of the decade the laboratories had established a leading position in this field and were working closely with the Satellite Division of Marconi Space and Defence Systems (which became Marconi Space Systems Limited in 1984) in proposals to the European Space Agency for work on operational satellites.

9.10 Special Materials

After the merger of GEC and English Electric in 1968 the Marconi Companies had access to the work on semi-conductor physics in GEC's Hirst Research Centre and the need for a solid-state physics unit in Baddow was correspondingly reduced. Some work on gallium arsenide and other III-V compounds was continued in order to enable devices such as light emitting diodes and varactor diodes to be made as necessary to meet system needs, and support was obtained from Ministry of Defence for research work on components for specialised military applications. (A small manufacturing unit within the laboratories was accepted by MOD as an approved source for these components.)

In the early 1970's it was decided that the unit should devote attention to other materials which might be of strategic importance to the Product Companies, one of which was polyvinylidene fluoride, a plastic material made in sheet form which could be made both pyrolectric and piezoelectric by applying an electric field at an elevated temperature. The properties were retained permanently on cooling to normal room temperature. With minimal effort and using film imported from Japan but processed in the laboratory, prototype heat sensors, microphones and loudspeakers were assembled. (Some of these were demonstrated on a BBC Tomorrow's World programme in 1974). However, although the material could be used as an alternative to those already in use for such purposes it became clear that its main advantage lay in specialised applications, particularly those in which the sensor had to be configured into an unusual shape. One such device was supplied to the National Physical Laboratory for measurement of energy distribution across a laser beam but the principal use of the material proved to be in acoustic transducers for use underwater. Some devices for this purpose were supplied to the Admiralty Underwater Establishment and others were exploited through the Naval Unit of Marconi Space and Defence Systems. By the early 1980's demand had grown to a scale such that it again justified a small manufacturing unit within the laboratories.

9.11 Video Recording

Plastic films also seemed to be a promising alternative to magnetic tape for video recording providing that a practical means of writing on the tape could be devised. The research laboratories were therefore encouraged by the Broadcasting Division of Marconi Communication Systems to undertake research on writing techniques. Two alternative methods were studied; they were (a) producing a charge pattern on the film by electron beam and then fixing it by raising the temperature of the film and allowing it to deform under the electric field so induced and (b) deforming the film directly by a laser beam modulated by the video signal. In both cases the video signal was assumed to be digitised initially, as the trend in the television authorities was to move towards digitisation of signals wherever practicable. Also in both cases the tape reader had to be capable of detecting indentation patterns on the tape, although this was not regarded as a major difficulty.

Work on the first method was discontinued early in the programme, primarily because writing by electron beam demanded a vacuum system, which was not likely to be acceptable if an alternative technique at atmospheric pressure could be devised. The second method was pursued to the stage of demonstration of a working system but was then discontinued on the advice of Broadcasting Division who decided that advances in magnetic recording had removed the need for an alternative in their area of the market.

9.12 Process Instrumentation

In 1975 a number of companies in the process instrumentation field became part of GEC Marconi Electronics Limited under the direction of Sir Robert Telford and GEC Marconi Process Control was formed to co-ordinate their activities. T.W. Straker as Managing Director of that Company asked the laboratories to set up a small team to carry out research specifically related to that field and work began on a range of sensors for flow, temperature, pressure level and load measurement. Direct support for the work was provided by the Product Company until 1980 when the Process Control activities passed to the Fisher Company (USA) with GEC receiving a share in the equity of that Company in exchange. Thereafter the unit continued to carry out some research under specific contracts from Fisher, but most of its activities were devoted to the interests of other GEC Companies.

Amongst the many topics studied was the use of vibrational sensors, the prime charateristic being that the frequency of oscillation was dependent on the magnitude of the variable (pressure, flow, depth) being measured. As frequency variations are easily translated into digital signals, such devices were wholly compatible with the digital control techniques being applied in both military and civil systems. Another speciality of the laboratory was encoding of rotational movement by means of precision discs on which were inscribed digital codes and from which data was taken by interception of an optical beam. This work which started in the Mechanical Laboratory in the 1960's continued throughout the 1970's with gradual but consistent improvement in the accuracy available.

A number of the sensors, including the optical encoders, were embodied in products sold by Marconi Companies, either as they emerged from the research laboratories or after further development in the company concerned.

9.13 Theoretical Work

Almost all of the work described in previous sections had a strong theoretical content, sometimes the direct responsibility of the laboratory concerned and sometimes carried out in a central theoretical facility. However, for some research topics the initial stimulus came from the theoretical areas. Propagation studies featured continuously in the programme, with major contributions being made to the work of international bodies such as CCIR as well as general support to the Marconi Companies in prediction of system performance. In 1976 S. Rotheram from the Propagation Team was awarded a GEC Fellowship which enabled him to study for a Ph.D at Cambridge University.

Following his work there he carried out further theoretical studies at Baddow which resulted in a much better understanding of how electromagnetic waves propagate over the surface of the sea. Prediction of the performance of radar or communication systems propagating close to the sea surface became thereby a much more precise science.

Amongst the more prosaic duties still being carried out into the 1980's was the provision of long range forecasts of H.F. system performance to be used by operators who wished to know the optimum frequencies for use at specific times. This service, financed by the Ministry of Defence, was available to both military and civil users via publications available from HM Stationery Office.

Propagation loss is an important parameter in prediction of system performance but there are other variables involved in the design of the electronic equipment itself, such as the noise factor of the receiver and the degradation of components and sub-systems in operation. The theoretical teams in the laboratory produced very sophisticated computer programs for simulation of system performance, and for estimate of operational parameters such as mean time between failures and whole life cost assessment.

Other important theoretical studies in the 1970's included prediction of the likely damage to equipment caused by the electro-magnetic pulse induced by a nuclear explosion and of the reliability of an equipment over its lifetime. The effect on an antenna's polar diagram of the platform, such as an aircraft, on which it is mounted was also assessed by means of theoretical models and recommendations made on methods of achieving an optimised configuration.

9.14 Ground Radar

The impetus for most research in ground radar during the 1970's came from the needs of the military or of combined military/civil systems. Much of the work in Baddow came from the Ministry of Defence via one of its Research Establishments.

The prime emphasis throughout was to improve the operational performance of a radar system in the presence of natural -clutter" and of man-made jamming. Work on transmitters covered the use of solid-state devices in new forms of modulator and in inverters, and on the phase and amplitude characteristics of high power amplifiers. One substantial project known as FRME (Frequency Response Measuring Equipment), completed in 1972 under contract from the Royal Radar Establishment, involved measurement of amplitude to ±¼ dB and phase to ±1° in a high power tube under operational conditions. Measurements could be made at microwave frequencies ranging from 2.7 to 10 GHz on a pulse-to-pulse basis and over a wide range of pulse recurrence frequencies. They were also valid in amplifiers, such as those used for pulse compression systems, in which the radio frequency was varied during the pulse duration. The FRME equipment was probably the most sophisticated system of its type existing in the early 1970's.

The use of wideband antenna arrays and frequency changing as a means of avoiding jamming have been mentioned earlier. The ability to scan a beam electronically in three dimensions by computer control is also potentially important as it permits energy to be switched at high speed into areas where targets are most likely to be located.

Some theoretical and experimental work on techniques for scanning of the beam had been made in the 1960's and during the following decade this was extended with the specific objective of devising systems which could be manufactured at an acceptable cost. The problem was a formidable one, in that scanning systems involve large numbers of separately addressed radiating or receiving elements, of which both phase and amplitude components must be capable of variations in a controlled manner and in which the requisite amplitude/phase variations are maintained with time, i.e. do not vary as a result of uncontrolled variations in the performance of receivers, amplifiers or other system elements.

A prototype system in which receiving beams were scanned in one plane over a sector of approximately 70° by phase variations at the individual elements, and where built-in monitoring and feedback arrangements ensured maintenance of this correct amplitude/phase relationship, was assembled and its performance measured. In a parallel programme networks were constructed in which energy from a number of receiving elements was channelled to a number of different outputs to produce the equivalent of beams originating from different directions in space (beam-forming networks).

By the end of the 1970's knowledge gained from this research was being used by Marconi Radar Systems in design of their new Martello radar which offered a surveillance and height finding capability from the same antenna but did not yet offer the facility of fully computer controlled scanning. Scanning in the horizontal plane was by antenna rotation but in the vertical plane separation of targets, or of jamming signals, was achieved by means of a beam former. The first models of beam formers were analogue and used resistive networks operating at i.f. and using discrete components. Using techniques developed in the Microcircuit Assembly Techniques Facility these were superseded by thick film networks, i.e. networks in which the required resistors and interconnections were printed on a single substrate using inks with the requisite electrical properties.

By the early 1980's analogue techniques were being largely replaced by digital processors. The incoming signals were digitised and clutter suppression (MTI), sidelobe cancellation for reduction of the effect of jamming and beam forming were all being carried out digitally. The demand for increased processing speed and data storage capability was insatiable and research teams were highly dependent on advances made in the computing industry in many countries. A good illustration of the scale of the requirement was in "over-the-horizon" radar.

In the late 1970's the Research Laboratories were invited by the Royal Radar and Signals Establishment to undertake a study into the use of H.F. radar for the detection and tracking of targets beyond the optical horizon as an alternative or complementary approach to the use of airborne surveillance radar. Assistance was sought from Marconi Communications Limited who contributed expertise in the transmitter field, arising from their work on H.F. communications, and from Marconi

Radar Systems, particularly in signal and data processing. The theoretical studies were backed by practical experiments carried out in Essex and on board a Royal Navy ship and the practicability of an operational system demonstrated in 1981. In such a system the bandwidth available is severly restricted by the need to avoid interference with communication channels in the same band. Antenna beams are wide because of the long wavelength and limited horizontal aperture. Resolution in both range and azimuth is therefore relatively low. Sea clutter, including that from the regular "Bragg waves" which are characteristic of the ocean surface is considerable but its effect can be reduced by Doppler processing, i.e. target discrimination by velocity measurement. All these factors lead to a requirement for a high speed parallel processor in order that targets can be identified in the short time available for interception to be initiated. Much of the research was therefore concerned with the software techniques necessary for effective employment of the processors then becoming available.

A further topic of research in the same period was the application of bi-static radar techniques, i.e. the use of transmitters and receivers on widely separated sites. Such systems would be less vulnerable than those with common transmitter/receiver facilities but involved new problems, particularly in signal processing and plot extraction, which were the subject of research in the first half of the 1980's decade.

9.15 Avionic Applications of Holography

Reference was made earlier to the work on infra-red techniques at Essex University and to that on lasers in the Baddow Laboratories. In 1968 the team was joined by Dr. K. Firth who had been working at the BTH Laboratories at Rugby on lasers and a programme was initiated on potential uses of holography in Marconi Companies. Initial work was devoted to the production of 3-dimensional pictures and many demonstration samples were produced but did not lead directly to new products. However, following the absorption by English Electric in 1968 of Marconi Elliott Avionics the opportunity for application of holographic techniques in the avionics field arose.

The Marconi team at Rochester had been successful in selling to the U.S. Air Force "Head-up" displays i.e. displays in which data from the cockpit instrument panel was presented to the aircraft pilot via an optical system which superposed it on his view of the external scene. In order to meet increasing competition from US suppliers the Avionics team were seeking to improve the system by increasing the pilot's angle of view and reducing the loss of intensity of light from the instrument panel during its transmission through optical system. An engineer from Rochester (S. Ellis) devised a new optical system with the required characteristics but which entailed the deposition of layers of optically transmitting material with periodic variation of refractive index on the glass surfaces. (The layers acted as a very narrow band filter which reflected the monochromatic light from the instrument panel but transmitted virtually the whole of the broadband spectrum from the external scene.) The research group at Baddow was able to show that layers of gelatine with the required refractive index profiles could be produced by holographic techniques and prototype optical systems were fabricated and demonstrated. This led to the receipt of a further order from the US Air Force and to a decision by Marconi Avionics to set up their own factory at Rochester to make production systems.

Research continued in the 1980's on improvement of holographic techniques and in particular on the generation of holograms (i.e the patterns contained a layer of film which when illuminated by monochromatic light would generate a specified wavefront) by computer assisted printing techniques.

9.16 Bragg Cells and Spectral Analysis

An interesting merging of two techniques, quartz delay cells and lasers, explored in the early 1970's led to the Bragg cell spectral analyser. In this the signal to be analysed was launched into a quartz or lithium niobate cell via an electric/acoustic transducer and the laser beam was passed through the cell in an orthogonal direction. The acoustic wave induced changes in refractive index in the cell which became thereby a diffraction grating travelling through the cell and having a periodicity depending on the frequency of the applied electrical signal and its velocity in the quartz. The laser light therefore emerged from the cell as a diffraction pattern with a first order maximum at an angle dependent on the frequency of the applied signal - or at a series of different angles each one corresponding to one frequency in the applied waveform.

Two types of analyser were studied. In one the acoustic wave was launched by transducers mounted on the cell ends and travelled as a longitudinal wave through the bulk of the material; in the other interdigital structures, similar in type to those used earlier for pulse compression delay lines but in this case having a uniform spacing, were used to launch a shear wave through the cells. By using optimised design techniques bandwidths exceeding 1 GHz, centred on a frequency of about 2½ GHz were achieved. Data for both types of cell were passed to Marconi Space and Defence Systems at Stanmore for embodiment in analysers which they were designing for systems use.

10. THE EARLY 1980's

10.1 Project Universe

In 1980 the laboratories were approached by staff of Rutherford and Appleton Laboratory who were discussing with several universities a project to be carried out under the auspices of the Science and Engineering Research Council, in which local networks in each of the participating organisations were to be linked via satellite. In order to bring some applications experience to the project, industrial participation was invited. Cambridge University had been involved in design of a network "the Cambridge Ring" and other forms of network existed or were commissioned within the laboratories of Marconi, Loughborough College of Technology and University College, London, the British Telecom Research Laboratories and Rutherford and Appleton. Work on the collaborative project began in January 1981 and all the partners were linked via the European Space Agency's OTS satellite during that and the following year, using ground stations supplied by Marconi Communications Systems Limited. Many successful experiments were carried out until the satellite was switched off in December 1983 and under a parallel contract from the Department of Industry the Marconi Laboratories investigated and reported on potential applications of linked networks, using the results of the Universe studies.

10.2 Robotics

In 1981 a programme of research aimed primarily at improving the productivity of GEC factories was initiated in the research laboratories. Mass production was rarely a feature of GEC units, many of which were concerned with relatively small production runs often of very complex equipment. It was necessary therefore that manufacturing processes should be capable of modification at short notice and in minimum time, i.e. should be compatible with batch rather than continuous manufacture. In principle these requirements should be compatible with a suitably programmed (and reprogrammable) robot and work was therefore initiated to study the characteristics of a commercially available robot and particularly its relevance to operations typical of a Marconi manufacturing unit, such as the placing of components in a printed board. It soon became apparent that the robot purchased was not capable of achieving simultaneously the speed of operation required and the accuracy of component placement necessary for this type of work and alternative designs, capable of giving the required performance, were studied. From this work emerged a prototype (called Gadfly) in which movement of the workpiece was via six independently mounted motors on a circular frame, thus avoiding the necessity of moving large masses at the end of supporting arms as was the case in most of the robots of the period. This device excited considerable interest and a number of them were made for evaluation in GEC Laboratories.

In parallel with this work designs were evolved for a number of manipulators ("hands") which might be used in the placing of components or the assembly of devices and the necessary software for control of the robot and manipulators was developed.

10.3 1982 Re-organisation

At the end of 1981 some re-organisation of the GEC-Marconi Group of Companies took place. Sir Robert Telford, until that time Managing Director of the Group, became its Chairman and Mr Arthur Walsh became Managing Director of the Marconi Company with responsibility for overall management of all the companies in the GEC-Marconi grouping other than Marconi Avionics, of which Mr J. Pateman was Managing Director with Sir Robert again as Chairman. The organisation of the Baddow Laboratories was reviewed in the light of these changes and two major modifications were agreed. The first was that the laboratories should become part of the GEC central research organisation, responsible to D.H. Roberts as GEC Director of Research, instead of being a unit of the Marconi Company as had been the case since their inception. The second was that a precedent set at Hirst Research Centre, whereby specific laboratories were associated with particular product companies, should be followed at Baddow; thus the Communications Research Laboratory was directly associated with Marconi Communications Company, whereas it had previously been a unit devoted to communications research with its output directed to any product company able to make use of it. Avionics and Radar Laboratories were also set up and in all three cases the Laboratory Manager was transferred to the staff of the associated company, while his team remained on the strength of the research laboratories but with objectives closely aligned to the needs of his company. (At that time Marconi Space and Defence Systems had an associated research team within the Hirst Research Centre and elected not to have one at Baddow, but that decision was changed some two years later when a laboratory devoted to their needs was set up. At about the same time the microwave group, which was involved in research and development for a wide range of passive microwave components was formally associated with Marconi Electronic Devices Ltd., which become thereby its prime marketting outlet although it still continued to give a direct service to local Marconi Units.

In May 1982 Dr. J.C. Williams moved from Hirst Research Centre to Baddow as Deputy Director and in September of that year he took over as Director, replacing G.D. Speake who became Deputy Director of Research for GEC, reporting to D.H. Roberts.

Coincident with this re-organisation it was decided that while the laboratories would continue to assist the product companies, particularly those in the Chelmsford area, on more advanced projects, greater emphasis would be placed in longer term research and less on support to development in product companies than had been the case hitherto. In addition to the units associated directly with product companies there were therefore some laboratories on more general topics, mainly in the longer term research area. The opportunity was also taken to integrate the research programmes and the administrative structure more closely with those of the Hirst Research Centre, with accounting and commercial functions being common to the two units.

The procedure whereby a proportion of the funding of the laboratories (about 20%) had been collected from product companies as a research contribution not related to any specific project was terminated and companies were invited to sponsor individual projects as agreed between their managements and their representative (Laboratory Manager) within the centre. Longer term work and projects not immediately identifiable with a particular product company were supported from

GEC Central Funds but over 80% of the work continued to be financed either by product companies or by contracts obtained from customers such as Ministry of Defence, Department of Industry or European Space Agency.

In order to establish a "customer/contractor" relationship for the centrally funded research, arrangements were set up for 6-monthly technical audits of projects, the audit team being selected from people with interests and expertise in the topic, and usually containing members from product companies and/or Hirst Research Centre. They were expected to comment on the effectiveness of the work and to offer suggestions for improvement where appropriate.

10.4 Software Engineering and Artificial Intelligence

The 1970's had been a period of increasing demands for software with virtually all projects within Marconi Systems Companies making extensive use of computers and using teams of qualified staff to produce the necessary software. Software writing became not only one of the most costly items on production of a new system but also the most hazardous. In general the work could only be entrusted to people who were highly skilled both in the subject, e.g. radar or communication, and in software production. Such people were in short supply and tended to move around within the industry and because the disciplines for software design and recording were less established than for hardware the effect of staff turnover was more serious. By 1980 research was therefore being devoted to software engineering, i.e. to the design of tools and procedures whereby software could be developed by people with lower skills (or more effectively by the higher skilled people) and documented in ways which made it possible for responsibility for its creation to be handed from one designer to another.

In 1981 this work was extended to embrace "artificial intelligence" which had been conceived and abandoned many years previously but was beginning to attract new attention from researchers because of the much wider possibilities which had been opened up by increases in storage capability and processing speed of digital computers.

During the next three or four years a team was built up to study techniques for the development of "expert systems" in which the computer would store, process and utilise data in such a way that someone of lower skills could, with its aid, carry out a task as effectively as an expert in the particular field. A typical application to which the research was applied was the "programmer's assistant", a system in which the computer utilised acquired knowledge to assist a software writer in producing programs more easily and more reliably. Many other applications could be foreseen, some of which became the subject of studies carried out as collaborative exercises with other companies.

10.5 ESPRIT and ALVEY

In 1981 a group of 12 of the largest European companies involved in storage, processing, transmission and utilisation of data met under the auspices of Viscount Davignon, Commissioner for Industry in the European Community, to consider the desirability and practicability of a collaborative programme of pre-competitive research in information technology. (The 12 companies were GEC, ICL and Plessey from U.K., CII Honeywell-Bull, CGE and Thomson-CSF from France, AEG Telefunken, Nixdorf and Siemens from Germany, Philips from Holland and STET and Olivetti from Italy.) Senior executives of the companies and of the Commission formed a "Round Table" which agreed that such a programme should be initiated and a Steering Committee from the same companies was set up to propose areas for research and devise a 5-year workplan. Five specialist panels covering the areas selected, which were microelectronics, software engineering, advanced information processing, office automation and computer integrated manufacturing, were set up. Both Hirst Research Centre and Marconi Research Centre contributed to the specialist panels, with MRC being primarily concerned in those concerned with software engineering and office automation (but taking over from HRC in computer integrated manufacturing work at a later stage).

In order to gain experience in the application of collaborative programmes a number of pilot projects were initiated in 1983, with 50% support from Community Funds, the remainder of the cost being borne by the companies concerned.

Baddow was involved in three projects. They were in the following categories: Software Engineering (A Basis for a Portable Tool Environment), Office Automation (Standarisation of Integrated LAN Services and Service Access Protocols), Computer Integrated Manufacturing (Integrated Electronic Sub-Systems for Plant Automation).

In 1984 proposals from industry and universities were invited via the Commission's Official Journal. As with the pilot projects, participation from at least two Community Countries was a condition of acceptance and both Marconi and Hirst Research Centre formed associations with companies from the Round Table and with others not previously involved as well as with universities. However, although a number of proposals involving the two centres were accepted, work did not begin until well into 1985, primarily because the Commission was unable to formulate conditions of contract acceptable to all the participating nations.

In 1984 the workplan was revised to take account of progress made in the pilot phase, and of contracts expected to be placed, and a further set of proposals was invited in announcements made at the end of that year. Again both centres submitted proposals in April 1985 and at that stage some GEC operating companies also began to become involved.

While ESPRIT was being conceived as a Community Project, the UK Government decided to set up a committee chaired by John Alvey of British Telecom to advise on national policy in information technology.

The committee recommended a similar programme of pre-competitive research work in four areas; very large scale integration (VLSI) of semi-conductor circuits, software engineering, man-machine interface (MMI) and intelligent knowledge based systems (IKBS). The recommendations were accepted by Government and a Directorate (The Alvey Directorate) was set up in the Department of Trade and Industry to implement them. In 1983 proposals were invited from UK industry, research associations and universities and again there was a response from both main GEC Research Centres.

10.6 Other Collaborative Schemes

Collaboration was the order of the day during this period. The Department of Industry had several other schemes in operation including two (CADCAM and CADMAT) to encourage computer aided design in the mechanical and electrical/electronics industries respectively. A scheme called JOERS (Joint Opto Electronics Research Scheme) involved both Marconi and Hirst Research Centres, with partners from other Companies and Universities. The European Commission also took a lead in a major exercise in telecommunications, aimed at standardization of systems and equipment across Europe and increased competitiveness for European industry in the world at large. Industrial support for the studies carried out came principally from the twelve Companies who had helped to form the strategy for ESPRIT. The main GEC input was from GEC Telecommunications, Coventry and Hirst Research Centre, with assistance from Marconi Communications Systems and Marconi Research Centre. The PTT authorities collaborated, together with the European standardization authorities CEN/CENELEC and CEPT. From the activities of the groups so formed a programme called RACE (Research in Advanced Communications for Europe) was devised and expressions of interest from organisations who wished to participate were invited in May 1985. Proposals were put forward by both Baddow and Wembley.

Yet another activity promoted by the European Commission was BRITE (Basic Research in Technology for Europe). Expressions of interest for work under this label, which covered a number of areas regarded as strategically important for Europe, were invited in 1983 and ideas were put forward from HRC, MRC and the Whetstone and Stafford laboratories. There was then a long delay while the agreement of the political and financing bodies across Europe were obtained. However in the Spring of 1985 formal proposals were requested and responses were submitted from HRC, MRC and Whetstone.

10.7 GEC Research Limited

In 1985 the association between the Hirst and Marconi Laboratories; which had existed since the GEC and English Electric mergers in 1968, was strengthened by the inclusion of both in a newly-created GEC Research Limited, with D.H. Roberts, the GEC Technical Director, as Chairman and Dr. J.C. Williams, Director of Baddow, as Managing Director. The Whetstone and Stafford laboratories of GEC Power Engineering were also transferred into GEC Research Limited, which thereby had three Research Centres -Hirst (Wembley), Marconi (Baddow) and Engineering (Stafford and Whetstone).

Later in the same year, Roberts was appointed to the position of Deputy Managing Director (Technical) of GEC and nominated Dr. C. Hilsum, FRS, who had joined the Hirst Research Centre from RSRE in 1982, as the group's Director of Research, to work alongside Dr. Williams in the formulation and implementation of programmes in all the laboratories of GEC Research Limited.

11. CONCLUDING NOTE

Research is essentially a speculative activity. In most companies it becomes development as soon as the emergence of a marketable product can be predicted with reasonable confidence and, although the Great Baddow Laboratories have at times in their history made major contributions to development, particularly in the radar field, a substantial part of the work has been exploratory in nature. It is not surprising therefore that this account contains examples of ideas which have led to successful products, manufactured and marketed by Systems Companies; of others which have been technically successful in the research phase but were not pursued into development because the commercial benefits forecast were not thought to be commensurate with the investment in money and manpower required; and of some which have been abandoned in the research phase because they proved to have less promise or to be more difficult to exploit than had been anticipated initially.

Most research workers, as well as the organisations providing the money for the activity, would prefer all their ideas to be in the first category, but if that were so they would in effect be development staff under another name. (There are indeed many examples of straightforward development which have ended in commercial disaster!) Nevertheless there is an obligation on researchers, as much as on their colleagues in other parts of the company, to seek to give value for money, and this involves financial control as well as technical judgement on a consistent basis. The Centre has had a small commercial unit since 1965, when it was set up to negotiate and monitor its own external contracts - a service which had previously been provided via one of the Marconi Trading Divisions (usually Radar Division). From the same date it has also had its own accounting staff and personnel department although until 1981 some services in both these categories were provided from the Marconi Company headquarters in Chelmsford. From the early 1970's it has had a Quality Manager and a small supporting unit to ensure that in all areas, but most importantly those which are engaged in work for Government Departments or other external customers, the necessary standards of equipment and software reliability are maintained.

For many of the activities described the services of high grade mechanical designers and draughting staff and of a precision model shop have been essential. Until 1965 the Drawing Office and Model Shop were under the control of Marconi Company headquarters staff. When this arrangement ended the Model Shop was administered by Marconi Radar Systems, whose development team shared the site with Research, but from 1981 (when they left to join their radar colleagues on the Writtle Road site) control was assumed by the Centre Director, and allocated to the manager of the Engineering Laboratory (L.W. Gill), together with the Design Office, Library and Quality Department.

Two other important services, the maintenance of the site and the management and operation of the canteen were also administered from the Marconi Company headquarters for many years. In the early 1970's maintenance became a local responsibility and the process was completed with transfer of the canteen in 1983. Thereafter, the site became self-sufficient within the overall GEC central research organisation.

Thus in its first four decades the research centre has grown from a hundred or so staff, many of whom were highly inventive and well skilled in practical matters but not necessarily academically qualified and whose main tools were a soldering iron and a multi-meter, to a self-sufficient unit of over 1000 people of whom nearly half are qualified to university degree standard, and who operate in an environment of sophisticated electronic instrumentation. The ways in which an individual can express his or her creativity have changed dramatically but the need to do so is at least as vital in the highly technological competitive world of the 1980's as it was when the idea of a new laboratory in the green field site at Great Baddow was conceived.

12. ACKNOWLEDGEMENTS

My personal knowledge of the Great Baddow Laboratories dates from December 1950 when I joined as a radar systems engineer and thereby renewed acquaintance with Eric Eastwood, with whom I had served as an RAF officer during the 1939-1945 war, and several other wartime colleagues. For all the information prior to that date, and for much of it since, I have depended on conversations with, or letters from, former members of the laboratories, and on a limited amount of research into such documentary records as are readily available. I would like to thank everyone concerned.

I am particularly indebted to George Grisdale, Mervyn Morgan, Roger Shipway and Roy Simons who read an early draft and offered many helpful suggestions, and to Roy Rodwell who has fed me from time to time with material from the Marconi Company archives.

I am conscious that, even with their help, I have omitted many important subjects. I also accept that those in which I was personally involved are likely to have received more consideration than others with which I was less familiar. To those people who feel that I have done their work less than justice I offer my apologies. Others, who have been involved in projects on which security restrictions still apply, will appreciate why they do not appear in the report.

Finally, some of the dates quoted have been recalled from my own or someone else's memory. I have tried to check them by reference to another source but if there are errors I apologise again.

REFERENCE

Details of many of the topics covered in this history are given in issues of Marconi Review for the relevant period.