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.

In 1958 the 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.

War-time plan position radar displays had used moving coils, i.e. coils which rotated round the neck of the cathode ray tube, in order to produce a rotating time base synchronised to the rotation of the radar antenna. However in the study carried out on behalf of the RAF it was proposed that new displays in which the deflection of the time base in the required direction was achieved by applying voltages to two orthogonal pairs of coils should be used. Thus it would be possible for extra information to be inserted on the display at any required position, in the interval between successive time bases. The Royal Radar Establishment at Malvern had been studying such displays and a project to produce a design for use on operational RAF sites was undertaken in the laboratories. In order to ensure the linearity and directional accuracy of the time bases the currents in the deflection coils had to be controlled to very close tolerances and much original work went into the design of precision analogue circuitry. A successful design was achieved and passed to the Plessey Company for manufacture. By the end of 1953 the first operational fixed unit displays from this design had been installed at an RAF station (Bawdsey).

Further work was then undertaken on the development of the circuitry for displaying data on such displays in positions controlled from a joystick or rolling ball, and on automatic positioning of a nodding height finder by overlaying a strobe marker on a selected target on the display. 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 (a display on which the returned signals from successive transmitter pulses were presented on spatially separated traces) were studied in specially designed equipment. A large (21" diameter) PPI display mounted horizontally so that 4 users could group around it was also developed during this period and stroke-writing techniques for generating symbols on this and other displays were evolved. Thus by the time the Swedish Contract was awarded a considerable background in the display and processing of data from pulsed radars had been accumulated in the laboratories.

However, 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 digital computer light-heartedly christened TAC (an acronym for transistorised automatic computer which also happened to mean "Thank You" in Swedish), and was thereby one of the earliest to employ digital techniques for real time radar data processing. 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 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.

However 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 in 1957 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 one antenna were passed over a radio link to the other and then 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 special purpose digital processor very similar in general characteristics to 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.

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 by a team led by Mervyn Morgan. This was followed in 1950 by a further study of a doppler navigation radar for the Royal Air Force. The emergent equipment, then code named Green Satin, was ready for aircraft trials by September 1951. Later versions of this were developed and widely 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 three applications for such a radar.

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

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.

The advances in radar techniques during this decade were accompanied by similar developments in communication. In 1946? 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. Early work in the Laboratories included the development of links for transmission of data from remote radar sites to control and reporting centres and from one radar head to another, as in the WINKLE system described earlier. However as the techniques became established the activity was transferred to a development team within the Communications Division of the Marconi Company, based at Writtle.

In parallel with the work on microwave links a study was made of the practicability of long distance communication by scatter from the troposphere. Measurements were made on systems operating at frequencies from 80 MHz up to 900 MHz and the Propagation Group developed considerable expertise in the forecast of performance of such systems in a wide range of atmospheric conditions. This was to prove of great value in the 1960's and 70's when the development of oil fields in the North Sea and elsewhere resulted in a considerable demand for tropospheric scatter systems. The propagation team had by now 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 decision was taken to launch independent television in the UK in 19 , 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 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.

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 primarily engaged on sponsored tasks for the Ministry of Defence, thereby making the best use of the total resource for research and development of both civil and military radars. 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. One of these was the Blue Streak inter continental ballistic missile which as first conceived was to have a radio guidance system. The Marconi Centre was invited to make proposals for this system with a view to eventual development and manufacture. Trials of the system, using an aircraft to simulate the missile were to be carried out in the Essex area and a 360 ft mast from the wartime CH station of Canewdon, was transferred to Baddow to form a platform for the control experiments. A team of about 100 engineers was engaged in design of the control system and much of the equipment had been assembled for trial when the decision was taken to abandon radio guidance in favour of inertial guidance, the technology of which had made rapid advance during the period concerned. The mast was therefore not put into use for its original purpose but has been applied to a number of other projects since, such as the terminal for an experimental microwave link bringing live radar signals from a remote unit to the laboratories and as one end of an antenna polar diagram measurement site.

The termination of the contract for the Blue Streak system in 1960? released a substantial number of engineers for other work and the opportunity was taken to reexamine the requirements of the air 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 to be very successful for civil air traffic control, primarily because of 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 delay medium was a quartz block with a series of flat faces angled with respect to one another in such a way that an ultrasonic wave, launched from one face made many transits across the quartz cell, being reflected from one face to another, before reaching the transducer on the output face. 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.

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 period of an hour or so after dawn. The origin of the rings could be determined precisely from the radar display and by visiting the relevant area at the appropriate time the research team was able to correlate the formation of the rings precisely with the departure of flocks of birds from their roosting site at dawn. 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.

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, in a series of articles in the Marconi Review, N.F. Ramsay showed how Fourier Transforms could be used to determine the amplitude patterns on a radiating array required to give a prescribed polar diagram. 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. Many possible variants were formulated but the work was eventually terminated following a decision by the Ministry of Defence not to proceed with the system. However, before this happened the laboratories were entrusted with the task of developing a modulator for a very high power radar transmitter which might be used in such a system.

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 and the team switched to other work.

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 and when the decision was taken to launch the U.K.'s first satellite for defence communication purposes (Skynet 1) the laboratories were invited to submit a proposal. Although this would involve a considerable investment in the capital facilities necessary to design and space-qualify components for use in a satellite a proposal was submitted but was regarded less favourably than that from GEC Laboratories Stanmore, who were awarded the contract in association with a U.S. company (Philco Ford). From this beginning the current Marconi Satellite Systems Company has grown. The interest of the Marconi Laboratories thereafter was confined to specialist activities within the satellite and to the design of ground stations for use in satellite communication.

Mechanical Engineering

There are few activities in electronics research which do not have a significant mechanical content and although it 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 195? 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 1959 Adler took up a new appointment as Manager of the Gateshead factory 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.

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 but in the absence of a firm customer interest it was decided to terminate this work in 1961. However, a number of component and measuring techniques which were to prove valuable when a new project was started in the early 1970's emerged from the programme.

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 inteference-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 Jollife 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.

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