Forty Years of Marconi Radar from 1946 to 1986

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The earliest concept of radar in the Marconi Company came on 20th June 1922 when Guglielmo Marconi addressed a joint meeting in New York of the American Institute of Electrical Engineers and Institute of Radio Engineers, receiving the latter's Medal of Honour on the same occasion. He said:

'In some of my tests I have noticed the effects and deflection of these waves by metallic objects miles away. It seems to me that it should be possible to design apparatus by means of which a ship could radiate or project a divergent beam of these rays in any desired direction, which rays, if coming across a metallic object, such as another steamer or ship, would be reflected back to a receiver on the sending ship and thereby immediately reveal the presence and bearing of another ship in fog or thick weather. One further great advantage of such an arrangement would be that it would be able to give warning of the presence and bearing of ships even should these ships be unprovided with any kind of radio'.

Radar development in the United Kingdom began in the early to mid 1930s. The first Marconi contribution at this time was the design and installation of the aerials of the Royal Air Force 'Chain Home' network of radar equipment so significant in the Battle of Britain. Magnetron development and production was also a valuable Marconi effort. (An interesting side note on the magnetron work: as part of the war effort, U.S. companies were allowed to produce the magnetron to British designs. After the war, Marconi bought the patents from the British Government. The Marconi Patents Manager successfully sued a U.S. company that had continued with unauthorized manufacture, winning costs and substantial damages.)

At the outbreak of war, many of the Marconi Company's most gifted scientists and engineers were seconded to Government Research Establishments for work on radar and allied subjects. At this time, most research and development of radar was carried out within Government units, although substantial manufacturing work was contracted to Marconi. Indeed, even after the war, it was not until the late 1940s that development contracts were placed with industry – and even then on a limited basis, with the Government Establishments retaining the right to put systems together, test them and arrange installation.

Roy W. Simons joined Marconi's Wireless Telegraph Company in 1943 as a member of the Research Division. After an initial period developing special receivers for wartime direction-finding systems, he worked exclusively on military and civil radar systems until his retirement in 1986. He was the first Technical Director of the newly-formed Marconi Radar Systems Ltd. in 1969 and in the subsequent years he took responsibility for all Company development at both Chelmsford and Leicester, as well as – for a period – all Company production. Latterly he had direct control of the Radar Research Laboratory at Baddow. He was appointed OBE in 1986. He is currently Visiting Professor in Priciples of Engineering Design at Sussex University.
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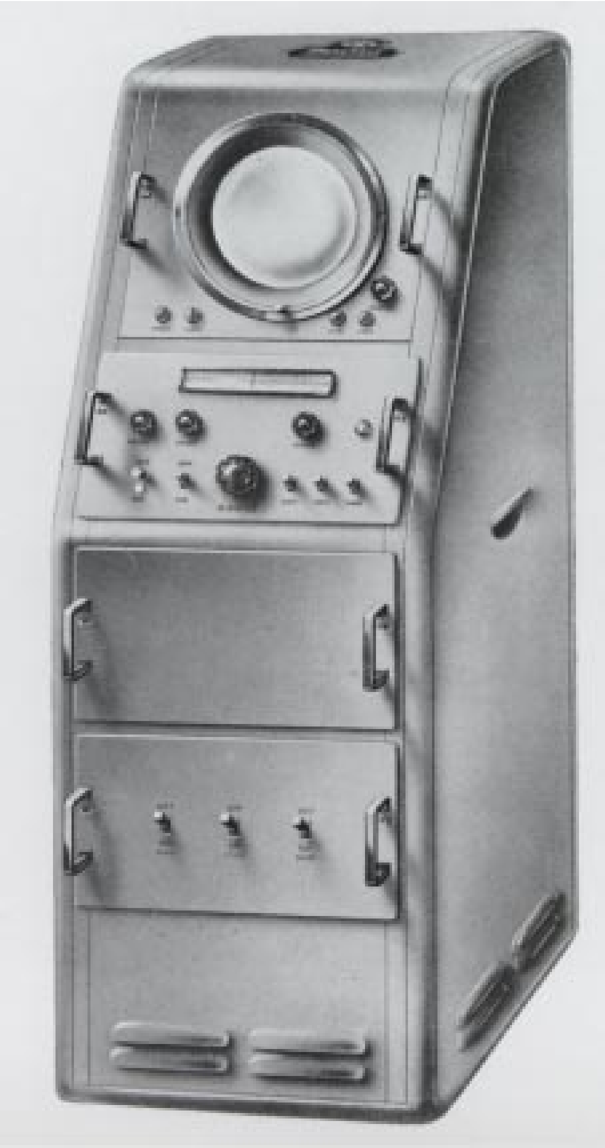
John Sutherland was educated at Queens' College Cambridge from 1941-2 and 1946-48, graduating with a BA in 1947 and MA in 1949. He was a Radar Officer in the Royal Navy between 1942 and 1946, serving in the Mediterranean and the Atlantic. After graduating, he served an engineering apprenticeship with Metropolitan Vickers and became a radar development engineer until joining Marconi as a radar research engineer in 1954, becoming a project manager in 1956, Manager, Defence Projects 1962, Manager Radar Division 1965, Managing Director, Marconi Radar Systems Limited 1969–1982, and Vice-Chairman, The Marconi Company 1982-83. He retired from Marconi in 1983. From 1983 to the early 1990s he was a Director of Acorn Computer Group, plc, Director MTI Managers Limited (venture capital), and Chairman/ Director/Consultant to several high tech companies. He was President of the Electronic Engineering Association 1980-81 and was appointed CBE 'for services to export' in 1980.

The real radar story in Marconi starts in 1946, with the return to the Marconi Research Laboratories in Great Baddow (fig. 1) of 'Marconi men' from Government secondment, having acquired priceless experience in radar design. Development of a mercantile marine radar started

1 ***The Marconi Research Laboratories at Great Baddow, showing the Jersey Airfield Control Radar***

on behalf of Marconi International Marine Company, based broadly on the American radar released by the Ministry of Transport and the Royal Navy – Type 268 and the RCN version, Type 972. The 'RADIOLOCATOR 1' was fitted on SS *Duke of Lancaster* and then moved to SS *Argyll*, on the Heysham – Belfast route. (Ironically the latter was involved in a collision when the ship's Master deliberately ignored a clear radar indication of another ship.)

The next stage, 'RADIOLOCATOR 2' (fig. 2), used the very latest circuit techniques and was the basis for the Marconi International Marine Company's marine radar business for many years. A spin-off from the 3cm wavelength radar work on marine radar was an 'Airfield Control Radar', involving several innovative features, and purchased for use in Jersey. Soon after the war, teams of ex-service personnel with radar experience were formed at Broomfield, near Chelmsford in Essex, and known as the Radar Development Group (RDG). Their role initially was to refurbish and sell abroad radar equipment surplus to RAF requirements, but later to improve and update these equipments, and finally to develop from scratch new radar systems suitable for export. The Services Equipment Division (SED) of Marconi had been formed in 1948 to manage the commercial and contractual aspects of this work.



2 *Radar for merchant ships – the Marconi 'Radiolocator'*

From 1948 to 1950, major Government development contracts were beginning to build up for several surface radar applications, to be undertaken by the teams at Great Baddow. In 1948 Marconi was charged with a study for the complete overhaul and modernization of the RAF radar chain round the whole of UK. Implementation of this study involved hundreds of Marconi personnel. In the 1950s the two teams at Great Baddow and Broomfield continued largely independently, although of course there was liaison and interchange of ideas. Both teams were brought together under Dr Eric Eastwood in 1959. An enormous amount of work was carried out for the Royal Air Force and the Royal Navy as part of their renewal programmes. At the same time, substantial overseas business was coming in from NATO, the Middle East and dozens of foreign Governments. By this time the Services Equipment Division had become Radar Division and had grown rapidly in size. The most remarkable departure was the fact that the Company was funding the development work from its own resources, a concept previously unknown in the field of defence equipment, and one that was to have considerable impact later.

Second Phase

The second phase of Marconi Radar came in 1965. A very significant restructuring of the Marconi Company took place, with the assistance of outside management consultants. The objective was to focus on what were then forecast as potentially growing markets. The Company was split into three main groupings: Electronics, Communication and Microelectronics, each with a General Manager. The existing divisions, including Radar, Aeronautical, Communications and Broadcasting, were joined by new divisions – Line Communications, Space Communications, Computer, Automation, Closed Circuit TV, Mechanical Products, etc. This also created an internal market, with divisions trading with each other on an 'arms-length' basis. It had the disadvantage that the established divisions lost staff to the newcomers, with Radar Division being particularly affected by the transfer of some of the key data-handling personnel to the new units. The new divisions were predicted to expand vigorously, whilst the old ones were expected slowly to diminish. In the event, the forecasts were proven to be very wide of the mark in both respects and within a few years all the new divisions had faded away. The existing divisions – Radar, Communications and Broadcasting – achieved considerable commercial and technical success. The gain to Radar Division over this period was the integration of the two main development teams. Marconi Radar orders received grew quite rapidly, from an average of about seven million pounds each year over the previous fifteen years, to a total of sixty-six million pounds over the four years 1966 to 1969, against a total of thirty-six million pounds predicted in the report that had led to the re-structuring of the Marconi Company.

Third Phase

In November 1967, the General Electric Company acquired Associated Electrical Industries, which included amongst many others, Metropolitan Vickers and British Thomson Houston. The following year, English Electric – parent of Marconi since 1946, and recently owner of Elliott Automation – became part of GEC. AEI had particular expertise in many aspects of radar and electronic control, and on 4th August 1969, Marconi Radar Systems Limited (MRSL), with its headquarters at Writtle Road in Chelmsford, was formed from Radar Division of Marconi, GEC-AEI Electronics (as it was then called) at Leicester Blackbird Road and New Parks, the AEI radar and electronic control activity (having recently been redeployed from Manchester to Leicester) with their Leicester and Rugby colleagues, and the Airspace Control Division of Elliott.

There were MRSL factories at Writtle Road in Chelmsford, Blackbird Road Leicester, and Gateshead; engineering was carried out at Writtle Road and Great Baddow in Chelmsford and at New Parks, Leicester. The integration of management structures and clarification of products, markets and financial objectives was completed as soon as was practicable. It was not feasible to maintain a separate Elliott Airspace Control Division at Borehamwood for any length of time, and as many people as possible were persuaded to come to Chelmsford, and the Borehamwood facilities passed back to other Elliott units.

The markets were by now defined as:

- total systems for ground-based air defence and missiles;
- all aspects of air traffic control;
- naval surveillance and weapon systems;
- electronic control systems for all defence applications; and
- simulation and instrumentation.

The decision had been made to drop out of the civil marine radar business at Leicester, since the scale of activity and trading results did not justify continuation. This involved no reduction in staff or premises; Leicester had already suffered two restructuring exercises in 1968 and rapid action was needed to return to confidence, stability and profitability. Fortunately, several existing contracts and quotations were re-negotiated successfully. All the departments across MRSL had full order books, therefore it was essential to complete the rationalization with as little disruption as possible.

The AEI workload which covered tasks from Trafford Park, Rugby and Leicester included Type 82 (Orange Yeoman – fig. 3), Type 85 high power multi-beam radar for the RAF (fig. 4), tracking radars Type 83 (Yellow River) and Type 87 (Blue Anchor). All these were in-service but being very actively supported through 'Post Design Services' (PDS). There was a major development programme for the Type 40T2 (fig. 5), a 'private venture' (PV) derivative of Type 85, the tracker radar for SEADART, fire and gun control for main battle tanks, and many other electronic control functions. AEI had also contracted to supply a large communications dish for Bude, in Cornwall. Mechanical problems in measuring and maintaining profiles were being encountered. These were

3 ***The Type 82 'Orange Yeoman' radar***

4 *The Type 85 high power multi-beam radar*

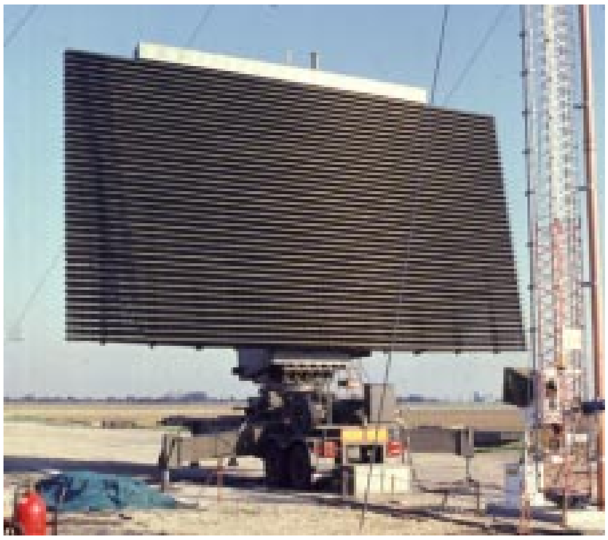
5 *The Type 40T2 surveillance radar*

solved by the intervention of the Director of Engineering of the Marconi Company at that time – but at considerable cost.

At the end of its first year of trading, the outstanding order book for MRSL was £42 million, turnover was £29 million, net profit £2.7 million and there were 3840 employees, plus a few hundred apprentices and trainees. By 1982, the order book was £256 million, with profit of over £13 million on sales of £120 million, and accumulated cash of £31 million. In 1980, Marconi Radar Systems Limited won the Queen's Award for Export and in 1984 won the Queen's Award for Technology in recognition of the Company's work on the development of 'Martello' (fig. 6). In the fifteen years from 1969, Marconi Radar people were awarded several BEMs, four MBEs, four OBEs and a CBE.

Markets and Systems

From 1946 onwards, efforts were concentrated on selling equipment into the air defence market, and shortly afterwards into the air traffic control (ATC) market. ATC opportunities arose and were grasped. At home, the British Government tended to procure the development and supply of



6 *Martello radar, type 723*

individual equipments, and perform the systems design and integration of equipment within their own establishments. Overseas, however, many countries did not have the expertise to do this work themselves and therefore a system capability was built up in the company.

There can be no doubt that the 'system' approach to marketing and selling overseas was highly successful over several decades. In most cases this involved long discussions with customers to help them establish an operational requirement and then to convert this into system and hardware specifications. It could take up to four years of work to establish customer understanding and reach a contract, but once achieved, the rewards were obvious. The ideal was to ensure that the customers' specifications were written around Marconi equipment. Marconi Radar could provide most of the hardware, both general and specific software, the designs for the installation work, could procure civil engineering construction, install and commission the stations, supply training for the customers' staff at Marconi College, write handbooks, specify and supply spares, and provide on-site support and maintenance staff for many years.

There have been many instances of follow-on business to extend and expand customers' defence and air traffic control complexes as a result of this system capability, but also evidence of satisfaction and confidence in the performance of Marconi Radar. In many cases it had been possible to negotiate advance funding on large export contracts, so that the work was self-financing. The effect of this was that Marconi Radar operated for several years (1976 to 1980) with advances exceeding the total of fixed and working capital of the Company.

Naval equipment – surveillance and weapons – was a part of Marconi Radar markets to an increasing degree from about 1950 onwards, and indeed, when the ex-AEI elements joined in, in 1969, this was further extended to include other missile systems, electronic control for guns and missiles, degaussing for warships etc. By the early 1980s most British warships carried a preponderance of Marconi Radar equipment, including Tracking and Surveillance radar and SEADART and SEAWOLF missile equipment (fig. 7), degaussing, cathodic protection, static converters, steering control, gun control and other electronic control systems, together with 'SCOT', a satellite communication system and 'ICS3' an integrated communication system, both from other parts of Marconi.

One essential factor in achieving export success was a wide network of agents across the world. Marconi Radar had a flying start in that the Marconi Company had been building such a network since 1900! (The agents had originally been set up to maintain a Marconi monopoly of world-wide shipboard communication – an objective finally scuppered by the Americans in 1913!) Since its inception, the Company has done business in over two hundred countries, quite a few more than are now recognized by HMG. In many instances the main Marconi agent was ideal for Marconi Radar, but in other territories it was necessary to recruit more specialized people and even to locate Marconi Radar people in territories or regions. As in most export business, the essence of commercial representation is information and discretion – what business is likely to come up and when? How much money is available? Who are the influential people? What will be the secrets of success?

7 *SEAWOLF missile tracking radar*

The factors that affected success or failure in Marconi Radar's overseas business were technical performance and across-the-board capability tailored to customers' needs, after-sales service, price and delivery, financing, local manufacture or 'offset', and political influence. The relative merits of these factors varied from case to case, but above all the customer must be convinced that they are getting a good deal.

The part played by British Embassies overseas changed fairly dramatically over the forty years under review. The participation by Ambassadors and senior diplomats in the commercial activities of the Company in their territory later improved to the point where helpful advice, useful information and practical assistance became normal. The Ministry of Defence organization called Defence Sales was also helpful, particularly at top level. The curious fact was that, in the main, they felt able to support fully only equipment developed at HMG's expense. Furthermore, HMG was always uncomfortable when two British Companies were competing in a foreign country. There was also a strange anomaly in that the Ministry of Technology (later the UK Department of Trade and Industry, DTI) was the electronics industry's 'sponsor' and yet the major purchasing department, surely the ultimate 'sponsor' was the Ministry of Defence.

Marconi Radar created the ability to react very quickly to special needs for equipment, for example, Suez, Christmas Island atomic test, urgent Canadian requirements in Germany and Vancouver, the Falklands etc.

One of the unfortunate aspects of Marconi Radar business was the necessity to maintain two separate ranges of equipment and indeed two engineering groups. The equipment and systems developed under British Government sponsorship for HMG use were, in many cases, not saleable in overseas territories because their added complexity increased the cost. Further, the equipment was often too difficult for less experienced and skilful foreign personnel to operate and maintain efficiently. In reverse, with few exceptions, HMG did not buy equipment developed under private venture funding. There was a two-way spin-off of technology from HMG work into PV development and vice versa. For example, Passive Detection development benefited enormously from the advanced data handling work on FUR HAT, a major display and data handling project for Sweden described later.

UK Air Defence

In the years following the end of the war, several interesting developments were taking place in the UK defence field. An important part of the general modernization programme was the redesign of the RAF Type 11 radar. Work had started at the Nelson Research Laboratory of English Electric at Stafford, but was then transferred to Great Baddow with a small team headed by Dr (later Sir) Eric Eastwood (fig. 8), who shortly became Chief of Research, Director of Research, Marconi, and finally Director of Research for the whole of GEC. The Type 11 work at 600MHz (50cm) was very useful in that many of the techniques explored such as coherent clutter suppression and Moving Target Indication were appropriate to the Marconi Air Traffic Control Radars at 600 MHz – the Types 232 and 264 (fig. 9).

A major event for Marconi was a wide-ranging study contract from the Ministry of Supply in May 1948, covering recommendations for the complete renewal of the RAF radar chain around the UK, to be codenamed 'ROTOR' together with mobile

8 ***Sir Eric Eastwood***

9 ***Type 264 air traffic control radar***

reserves intended for deployment in UK and overseas. This latter was the 'VAST' project and was never implemented in full. The order to proceed with implementation followed very quickly, in August 1948, before the study was complete. The pressure on time scales was enormous as a consequence of the Berlin airlift in 1948, and a little later, the Korean war in 1950. The programme which rapidly grew to 52 separate operational stations was a major logistic exercise, to be tackled by 'Services Equipment Division' of Marconi, shortly to become 'Radar Division'. The volume of equipment was such that a large part of it had to be manufactured outside Marconi using some 100 sub-contractors. Building design work was undertaken by a major firm of civil engineering consultants, who worked in close collaboration with Marconi. The necessary 'installation design' work, that is, the preparation of drawings, specifications and other instructions to enable the Marconi field teams to install and commission the equipment in the new buildings, was carried out at Broomfield. There were different types of station – CEW (centimetric early warning), CHEL (chain home extra low) and GCI (ground control of interception), and several different types of radar – Types 7 (fig. 10), 13 and 14, plus some variants. The earlier displays

10 ***Type 7 radar***

11 ***Consoles Type 64 in a trials environment***

installed were the moving-coil equipment known as Console Type 60. But the decision was made to develop a fixed-coil design for the GCI stations. The engineering work on the sensors and the moving-coil displays was implemented at Broomfield in the Radar Development Group; and the fixed-coil display – Console Type 64 (fig. 11) – and its radar office equipment was done at Great Baddow.

The fixed-coil display work was an important milestone, in that it established a display and data handling laboratory that served Marconi for a quarter of a century and a pattern of engineering that led to products that were reliable and suitable for quantity manufacture. The fixed coil development started in 1950, aiming at completion in 1953. A large team of engineers, some graduates and some with practical Service experience, was set up and dedicated facilities for making prototypes were put in place. The development programme, like all large 'crash' programmes breaking new ground, suffered a few problems. There were some difficulties with the tube, which was virtually being chosen by the Ministry, from alternatives that were in fact physically and dimensionally different, in parallel with the main development. None the less, production went ahead in a time scale that was appropriate for the whole project. The first 1000 or so complete Type 64 consoles and several thousand items of radar office equipment were manufactured by subcontract in the Plessey Company as a result of a very close collaboration. Later, there was retrospective fitting to other stations such as the CEW, together with new stations, and these were produced in Chelmsford.

In the very early 1960s, a development contract was started for a complete mobile and transportable radar convoy for the army, codenamed 'GREEN GINGER' (fig. 12), for use with Thunderbird 2 surface-to-air missile system. The convoy

12 ***Surveillance element of the 'GREEN GINGER' transportable radar convoy***

had a surveillance element consisting of back-to-back S-band and L-band (10cm and 23cm) elements with a C-band (5cm) height-finder and a battery command post. Five convoys were produced for the army, and a similar number were produced and sold overseas. Unfortunately, the latter proved to be very difficult to maintain by local personnel because of the lack of suitable training and experience. Marconi had trained many officers on the maintenance aspects, but in the territories it was 'other ranks' who were expected to do the work. The Company was involved with considerable effort in difficult terrain, mostly at its own expense. The Army found that, although they had prepared the specification in detail themselves, it was too heavy for air-lift by currently-available RAF transport aircraft and it became a tactical radar system for the RAF.

The air defence of the UK for the1970s was set out in March 1959, called 'PLAN AHEAD'. In essence the multiplicity of smaller stations were to be replaced by three massive sites along the East Coast, covering most of the UK, providing substantial volumes of data to a very large operations centre at West Drayton. The name of the project was changed to 'LINESMAN' in 1961. The main radars to be fitted at the sensor sites were already under development: the very powerful multi-transmitter stacked-beam radar Type 85 operating at 10cm was in progress at Metropolitan Vickers; Passive Detection is described elsewhere in this article; and the third major element was the high-power 23cm surveillance radar, Type 84, being developed in Chelmsford.

Long before the designation 'Type 84' was given, the Ministry of Supply funded a programme of research into the use of high-power L-band (23 cm) radar for air defence as part of the 'STAGE 2' programme. The first experimental model was built at Bedell's End in Chelmsford, to prove some of the technology. Then a bigger prototype was built at a new experimental site acquired for this contract in 1955 by Marconi at Bushy Hill, a near-ideal radar site a few miles from Chelmsford. An improved transmitter and receiver, together with a much larger temporary antenna, made the best use of this excellent location. A great deal of work was carried out on the technology and, in particular, the associated signal processing. The final transmitter used a 2.5MW magnetron, as the planned 6MW klystron was not available.

When it was decided to include the L-Band radar in 'PLAN AHEAD', the forerunner to 'LINESMAN', five production radars were ordered in 1958. The technology acquired at Bushy Hill enabled development to make a flying start. The final antenna was a pair of back-to-back parabolic reflectors 60 feet by 22 feet (18m × 6.7m) in aperture, built in sections, using aircraft production methods. Only one side was used for the surveillance radar, the other being designated for secondary radar. The antenna was fed by a vertical stack of horns on the azimuth centre line into which the power was distributed to provide a vertical cover pattern tailored to requirement. The first of the five equipments was handed over at RAF Bawdsey in October 1962 for trials purposes. Three were allocated to the main LINESMAN stations, and a reserve that was subsequently erected in Cyprus.

There were of course many other equipments involved, some from Marconi, some from other companies. In particular, a very large data processing facility from another manufacturer, which virtually dictated overall timescales. Marconi had an interesting task in co-ordinating all the installation design work for the project. Handover (partial!) of LINESMAN took place at the end of 1973.

There were no HMG procurements of large surface radars for 20 years after Types 84 and 85 until the purchase of the privately-developed 'MARTELLO' in the 1980s (fig. 13). The absence of a

13 ***Two generations of Marconi radars – Type 84 and Type 713 Martello***

UK home market in those years, when the US contractors had major government procurements, made Marconi strive even harder to remain competitive!

NATO Business

Marconi Radar had participated in most of the NATO air defence ground projects from the 1950s to the 1980s. Doing business in NATO (and to some extent EUROCONTROL) required a different approach. No business of any size would be awarded to a single company or country, because the work had to be shared around the member nations. This became particularly apparent when an Anglo-French consortium consisting of Marconi, AEI, CFTH and IBM France carried out detailed studies to meet NATO air defence requirements. The commercial grouping called AFCAD (Anglo-French Collaboration on Air Defence) was very close to success. The fully-priced programme, which complied with the SHAPE/NATO requirement, was put before the NATO Infrastructure committee. At that point the United States delegation realized that this was a major procurement without an American participant. The matter was put to the NATO Council and AFCAD was dismissed.

This was the origin of the 'Balance of Payment' or BOP principle. From that time, the early 1960s, any medium or large contract was let on the basis that revenue would be provided to each of the NATO member states in exact proportion to their contribution to NATO infrastructure funding. Preparing tenders to fulfil this precise requirement was tedious and costly; it certainly did not represent value for money, but was insisted upon by the NATO Council.

Marconi had achieved success in NATO in building a very substantial chain of sixteen early warning radar stations around Europe from Turkey to North Cape. Each site had the large static S247 surveillance radar, each with high-power back-to-back S-band and L-band antennas, and most had S244 S-band height-finders. This was in partnership with CSF of France, before the time of application of BOP.

During the early 1960s NATO had been discussing a massive air defence project called NADGE (NATO Air Defence Ground Environment). There were many discussions with industry NATO-wide, and it was obvious that only a consortium of companies from several countries would succeed. Marconi Radar finally joined Hughes Aircraft of USA, Thomson-CSF of France, Selenia of Italy, Hollandse Signaal of Holland and Telefunken of Germany to bid for the task, in competition with two other consortia, led by Westinghouse and ITT.

A consortium company called NADGECO was formed by Hughes, Marconi etc. based in Feltham in Middlesex, close to Heathrow, and was ultimately the successful bidder, winning a contract in 1966 worth between £80 and £90 million, of which the Marconi share was about £8 million. British Government had agreed to release the Passive Detection system to NATO for incorporation in NADGE. The odd situation was that Marconi Radar was sole supplier of this unique system, and provided identical bids to each of the consortia. The first overall bids exceeded budget by a fair margin, and therefore it was no enormous surprise that Passive Detection was cut out of the specification for the final round of bidding.

After the successful award to the Hughes consortium, separate contracts were negotiated by NADGECO in nine different NATO countries, and payments were made in almost all NATO currencies. The value of work had to be balanced very closely between all sixteen countries of the Alliance, which meant some quite unsuitable and inefficient sub-contracts had to be placed. The programme lasted for almost five years and work was executed on eighty-four different sites. The Marconi content was somewhat diverse, consisting of up-dating and improving the 'early warning' stations it had supplied in previous contracts, supplying fourteen long-range high-performance radar height-finders (Type 269), plus substantial quantities of various relatively small pieces of equipment.

In 1969, Marconi Radar 'inherited' a small but vital contract placed by NADGECO on Elliott for the NADGE programme. This contract absorbed a disproportionate length of management time and extra cost to get it executed satisfactorily. During the course of the NADGE contract, there were significant changes in currency exchange rates and unpredicted inflation, as a result of which the consortium made a large claim for extra finance that was ultimately granted. Following on from NADGE, the partnership of companies persisted, creating a new company UKSL (UK Systems Limited) based in London to win the contract for United Kingdom Air Defence Ground Environment (UKADGE) and later formed a small marketing company in Brussels called ACCSCO to bid for more business in NATO.

UKADGE was the first UK radar project paid for out of NATO infrastructure funds and as such was a milestone. In June 1973, a study team known as ADET was set up in the Ministry of Defence, to determine the requirements and outline specifications for the scheme, and papers were submitted to ADET by Marconi among others. UKADGE began in earnest in 1975 as a multi-national project.

Marconi Radar was to be designer and supplier of all the operator interface equipment, involving a large amount of special hardware and software. The competitive contract was awarded to the UKSL consortium which had basically the same membership as UKADGE.

Other Major Marconi Radar Projects

Marconi Radar had a long involvement in Saudi Arabia. In 1963, a British Government-backed consortium of BAC (now British Aerospace, BAe), Airwork Services Ltd. and AEI Leicester was bidding for a massive air defence project. AEI were to supply radar, communications and display and data handling systems, using Marconi as a sub-contractor for the last two. The AEI portion of the overall project was known as SAGEU (Saudi Arabian Ground Environment Unit). A letter of intent had been received by the consortium from the Saudi Arabian Government in 1965. However, after visits to sites, AEI discovered that their costs had been substantially underestimated, and set about trying to negotiate an increase in the price, but this was not possible at that time. The contract was finally signed in April 1967.

In 1969, Marconi Radar took on responsibility for the whole AEI content, including the buildings. A new project team was set up and a new building contractor engaged. A successful claim for a sizeable increase in price was negotiated in Taif with the Saudi Arabian Defence Minister, Prince Sultan in July 1972. The agreement concluded with the words:

> 'The Government and AEI have entered into this in the spirit of mutual compromise and friendship with the intention that shall result in closer co-operation and collaboration in carrying out promptly the objectives of the contract'.

The project involved many logistical and technical problems. There were five main radar stations with very large AEI surveillance radars to be installed, together with Marconi display and data handling systems, and a Marconi tropospheric scatter communications network, with many enormous antennas. Eight sites in all were involved. AEI had done very well logistically. At each major site, a well-equipped camp was set up, with good accommodation for staff, some recreational facilities, good catering and medical resources, and these served well throughout the duration. The climate and terrain were a constant problem.

The next major Marconi Radar project in Saudi Arabia was called SIMCATS. This was a massive project launched with the Saudi Arabian Ministry of Defence by the US company Lockheed, using ITT of US and Marconi Radar as principal sub-contractors. The overall contract was worth about $600 million, and the objective was the provision of an air traffic control facility for the Kingdom by the modernization and modification of the major Marconi Radar installations to give them a joint Air Defence and Air Traffic Control function, the provision of new ATC radars, together with extra signal and data processing. ITT supplied a country-wide dedicated communication network. This was, by value, the largest contract undertaken by Marconi Radar. The co-ordination of the project by Lockheed was less than perfect, and there were difficulties in getting some of the buildings and services, that they were contracted to supply, on time. Nevertheless it was successful.

Another territory in which Marconi Radar carried out large projects in the 1950s, 1960s and 1970s was Sweden. The first, which was codenamed FUR HAT, consisted of two very large underground operations centres, with equipment that, at the time, was at the forefront of technology. The Royal Swedish Air Force was a very different type of customer, particularly because of the high level of technical ability of the people involved and the ability to take decisions quickly and efficiently. It was a collaborative programme from the outset.

The study contract was let in 1957 and implementation started in 1959; the first site was handed over in December 1963 and the second in March 1966. The data handling technology was significantly more modern than the contemporary UK project LINESMAN; the work started at about the same time on LINESMAN and FUR HAT but FUR HAT went into operational service seven years before LINESMAN. FUR HAT was the first operational military digital data handling system, enabling innovations such as tabular data displays, marked radar displays (fig. 14), large screen colour synthetic displays, digital radar data links etc. to be put into operational use.

The second phase, codenamed TOR, was a matter of update of the system and provision of a transportable facility, with a considerable volume of new software. Marconi Radar experienced some difficulties on the software side, but completed a technically-advanced and successful system.

14 ***'FUR HAT' – marked display in typical operating position***

S600 Series and 'Martello'

In the early 1960s the product range of 'private venture' radar systems – that is, those developed entirely at the Company's expense – was ageing and increasingly difficult to sell. The organizational upheavals of 1965 provided the spur and the opportunity to plan and implement a completely new range of equipments. As a result of a short period of intensive, often informal, study and discussion amongst a small group of very senior people in the newly reconstituted Radar Division, all of whom had been involved in radar all their working lives, a proposal for the way ahead emerged and was given the generic name of S600 Series (fig. 15). The concept was based on a modular, building block, approach enabling systems to be configured for each application. Design criteria were: cost-effectiveness, flexibility, clutter suppression (including man-made jamming) and a combination of reliability and ease of maintenance. The military markets to be attacked included early warning and surveillance, weapon control radar for surface-to-air missiles (SAM), ground control of interception (GCI), coast watching, and military air traffic control. The civil air traffic control – airways en-route control radar and terminal area radar – would evolve a little later.

15 ***S600 series modular radar***

The building blocks were developed quickly; the first were transmitter/receivers at S-band (10cm), L-band (23cm) and C-band (5.5cm) and a display and data handling system. EEV Ltd. produced magnetrons with the required performance. The first configurations to be tackled were for radar stations fitted in several cabins, which could be air-lifted by helicopter (typically Sea King), by transport aircraft such as C130, or towed across reasonable terrain by a Land Rover. Surveillance and height-finding antennas with the same transportability/mobility capability were developed at the same time.

The firm prediction that the S-band radar, which was prepared for production first, would be the most popular proved wrong, and indeed the L-band sold in much greater numbers. The transmitter/receivers proved to be valuable products in their own right as a replacement item for earlier transmitters, and also for integration with existing and some new large radar antennas in the Marconi Radar range. The first public announcement of the S600 series was on 3rd May 1967 at the Marconi Overseas Agents' Conference, followed by a Press demonstration at the Bushy Hill test site near Chelmsford.

A fully-operational system was demonstrated at the SBAC Air Show at Farnborough in 1968, by which time firm prices and deliveries were available. This generated world-wide interest – particularly in respect of performance, simplicity and reasonable prices – and orders were soon flooding in. It is perhaps extraordinary that HMG should not have purchased this equipment; at one stage the Ministry of Defence (MoD) produced an Air Staff Requirement (ASR 1514) for a rapid deployment radar, and the S600 series met all the requirements. This however proved to be too good to be true; before an order could be made, the MoD revised the ASR, requiring a significant increase in performance and facilities which no commercially-available equipment could meet.

As the S600 programme evolved, improvements were made on a continuing basis. New features were added, new and updated antennas for static systems became available, and display and data handling facilities were increasing in complexity and performance – notably by the addition of the LOCUS 16 processor. The initial development investment was expected to be between a quarter and half a million pounds, but it was soon apparent that the S600 had caught the market at the right time with the right performance and right price and was selling fast all around the world.

The rate and scope of development was stepped up, and substantial orders for stock were placed. The anti-clutter and anti-jamming features, the close integration of C-band height-finder with S-band or L-band surveillance, and the mobility of the system gave operational flexibility and a good data-rate of three-dimensional information at a price that was unprecedented. The eventual total development spend was just over one million pounds, but the S600 systems were sold in well over twenty countries and sales comfortably exceeded the hundred million pound mark during the ten years or so of its market life.

The vast majority of the S600 series equipment was made in Marconi factories; the larger precision mechanical structures at Gateshead, transmitters etc. in Chelmsford, together with display and data handling equipment. Good working prototypes were maintained at the demonstration site at Bushy Hill a few miles from Chelmsford, and were of great interest to visiting delegations from overseas. Several features were unique; for example the surveillance radar antennas were fitted with linear feeds, which enabled the beam shape to be accurately designed and controlled to minimize both clutter and jamming.

Up until this time, the problem of such feeds had been 'squint' – the movement of the beam as the frequency changed. A 'squintless feed', which eliminated the problem, was developed largely by the Marconi Research Centre at Great Baddow, initially for the S600 series, but later for wider application (fig. 16); the use of computer-aided design and numerically-controlled machine tools to manufacture the feeds made them cost-effective. The use of sensors at different frequency bands in the same system provided valuable frequency diversity, again assisting in the defeat of jamming.

16 ***'Squintless feed' for the S600 series radar***

At the peak of the S600 market in the early 1970s it was appreciated that, by the end of the decade, the systems would become obsolete, and furthermore attacked only a part of the Air Defence market. Electronic Counter Measures (ECM or 'jamming') were becoming more sophisticated, and a need was seen for 'state-of-the-art' technology to be applied to the design, development and production of a substantially larger radar system with reasonable mobility, to succeed the S600 with much higher performance, and even more important, to replace the large, vulnerable, static and obsolescent sensors, with limited performance in ECM, which had been installed over the previous twenty years. A key requirement was integrated height-finding capability.

Marconi Radar took the decision to invest heavily in a new range of three-dimensional air defence radars with the family name of MARTELLO. The anti-jamming features, which had also typified earlier Marconi Radar products, included very careful control of beam shape to minimize off-beam jamming, and the use of frequency diversity in various combinations. The vertical beam-forming network was cardinal to the development. The work started simultaneously with the emergence of solid-state power sources. Initially, to advance the technology, a high-powered 23cm 'twystron' transmitter was used, with power splitting and multiple receivers; but as the solid-state devices, became more readily and cheaply available, a completely distributed system was possible.

A significant factor in MARTELLO development, was the provision of several million pounds of support from the Department of Trade and Industry. MARTELLO was first demonstrated publicly at the Farnborough Air Show in September 1978 and attracted a great deal of attention from the world's air forces, and from the international Press. The first major order was for three systems for the British Ministry of Defence, linked to four systems for NATO. The first was handed over at the beginning of April 1982.

Air Traffic Control

The earliest venture of Marconi Radar into the Air Traffic Control (ATC) market was a relatively small airfield control radar for Jersey about 1948, which was successful in its own right, but did not lead to any more business. However, considerable work was going on at Great Baddow on 50cm (600MHz) radar technology, as a part of the RAF

Type 11 modernization, and from this emerged the basis for a range of equipments suitable for the ATC market. The 600MHz band was available for ATC at that time, although it was ultimately withdrawn some twenty-five years later and re-allocated to television. The great advantage of this band was the ability to penetrate the heaviest precipitation (Rayleigh's law – the reflection from a conducting sphere is inversely proportional to the fourth power of the wavelength). The disadvantage was the relatively wide beamwidth, but this could be managed with a large aperture antenna, and in the data handling techniques.

The first radar in the family was the S232, which had a centre-fed 'slice' of a parabolic reflector with a 27 foot (8m) aperture, but the main market success was achieved with the S264 and its variants, using a large linear-fed reflector, versions being produced at 45 feet (13.5m) and 60 feet (18m). This was installed in many countries around the world, in versions as terminal area radar and as en-route radar and was widely used in Britain by what later became known as the Civil Aviation Authority (CAA). Once it became clear that availability of the 600MHz band would be coming to an end as a civil radar frequency in many parts of the world, ATC radars in the 23cm band were produced and sold reasonably well. These were incorporated in the Saudi Arabian 'SIMCATS' project, among others (fig. 17). Also in the ATC market, as an interesting and profitable instrumentation project, Marconi Runway Visual Range, developed at Leicester, was installed on a substantial number of airfields.

17 ***Typical air traffic control radar in a desert environment***

Civil Air Traffic Control was making increasing use of Secondary Radar, which triggers a transponder in the aircraft and relays data such as identity, height etc. to the controller on the ground; in the 1970s this dependence was growing. Marconi Radar designed and made a secondary radar called SECAR in co-operation with CFTH of France. Unfortunately, in spite of encouraging market studies, it did not 'take off' in the market, primarily because it aimed to provide two technical solutions in one equipment.

In the 1980s Marconi went back into the ATC market, as many airfields world-wide started to procure radar systems. New solid-state modulators and a cost-effective tower-mounted antenna made up the Radar Type S511 (fig. 18).

The tragedy in the UK ATC business in 1980 was the failure of British industry to win the replacement radar business from the CAA. The CAA specification was put together from the ideas of several individuals, each putting down the maximum achievable performance for their

18 ***Type S511 radar***

element (antenna, transmitter, signal processing, mechanical structures etc.). This appeared to the UK industry to have been done with insufficient thought for compatibility or cost. Plessey Radar and Marconi Radar offered at this time to pool their resources and put forward a combined bid which would result in a truly British radar with enormous export potential as well as satisfying the CAA requirement. A submission was made, but was regrettably declined by the CAA. The MoD examined the offer in minute detail using distinguished experts in RRE and in Whitehall. A Deputy Under-Secretary of State was involved at this stage. Without reservation, MoD declared the Marconi-Plessey bid technically compliant and reasonably priced, and undertook to monitor costs. The whole situation was also examined in depth by the Parliamentary Trade and Industry Select Committee. In spite of expert advice and persuasion by the Parliamentary Committee, the Chairman of the CAA, when examined at the Committee's public hearing, declared his intention to purchase a compromise solution from a German/Dutch combination. It may be interesting to quote from the Trade and Industry Committee report:

> 'There is always a certain wariness about buying a product of a completely new design, and it is a great asset to a firm with such a product to be able to show potential customers an example of it at work – giving innovators a 'shop window' for their product.' ... and ... 'We, Central Government, will be examining our own purchasing arrangements to ensure that full use is made of Government purchasing to help UK suppliers become more internationally competitive. The nationalized industries and local authorities would similarly look at their purchasing practices with the same objective in mind.'

The CAA and MoD collaborated in the system, called MEDIATOR, which aimed to use the combined data from military and civil radar sources to establish a national ATC network. Marconi provided substantial services and equipment for MEDIATOR at the main site at West Drayton and elsewhere, including the system for Middle Air Space (MAS) (fig. 19). Marconi Radar also provided a large Flight Plan Processing System (FPPS), involving considerable numbers of marked radar and tabular displays for the RAF control of the middle airspace and crossing tracks. FPPS was driven by three Marconi Radar MYRIAD computers; there was a large amount of new software, and the handover of the project was delayed because of this, but in service the system as

19 ***Middle Air Space (MAS) system at West Drayton***

specified worked continuously and without a single period of down-time throughout its operational life.

The CAA had purchased very large quantities of data processing equipment from IBM in the US, but an opportunity came to break their grip with the CAA decision to build a new Scottish Air Traffic Control Centre at Prestwick. The Marconi Radar LOCUS 16 processor and latest display technology were ideal for this application; and the Marconi tender for the whole task was accepted, and the installation was completed on time, within cost estimates. The CAA were pleased to allow distinguished visitors at Prestwick and it became a useful showcase for Marconi systems, software and project management.

Passive Detection

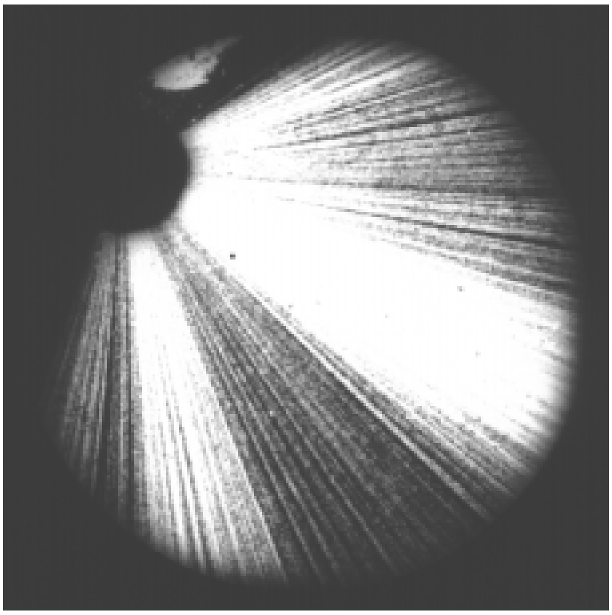
Passive detection was one of the most fascinating and innovative developments in air defence technology since the war, and yet one of the least publicized. The air defence requirement in UK in the early 1950s was for a system alongside the main conventional radars which would be able to detect and locate individual 'jamming' targets in a mass raid, the majority of which were also jamming, with the same discrimination in range, bearing and height as the 'active' radar. A brilliant concept by George Clarke at the Royal Aircraft Establishment in Farnborough, skilfully analysed and proven feasible on paper by Norman Bailey at TRE in Malvern, started the research and development programme.

In essence, jamming signals were to be detected at each end of an extended baseline, of the order of a hundred miles. One signal was transmitted to the other end of the baseline, and the two signals compared in a 'correlator'. A correlator is a device which will give an output when two identical signals (including white noise) are fed into the device in the same phase, that is, without any time difference between them. Therefore, after compensating for the delay in transmission, a variable delay can be introduced into one signal until correlation is achieved. Rapid laboratory trials were carried out to prove that a suitable correlator could be designed. A test link was set up between Great Baddow and Great Malvern to demonstrate that correlation could be achieved after a signal had been carried on a microwave link with repeaters. The whole project carried the codename WINKLE.

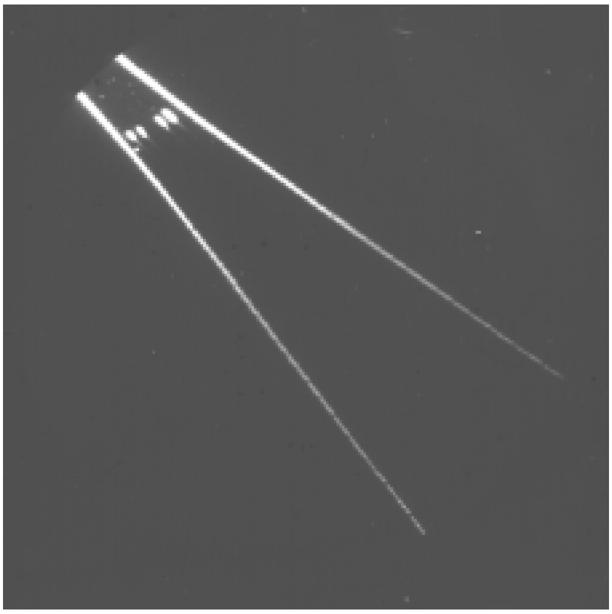
The majority of the development work for the project was carried out by Baddow Research staff. In 1956, a link was rapidly set up between a test site at Bard Hill in Norfolk and an RAF station at Bempton in Yorkshire and a programme of detailed trials began. Initially a static test jammer was placed on a tower mid way along the baseline, which enabled a great deal of experimental work to be done, improving correlator design and moving towards the practical implementation of a working passive detection system. Historic tests with four closely-spaced jamming aircraft showed that Clarke and Bailey had got it right. The full system had to be automatic with a high data rate and a very low false-alarm rate, which meant a massive increase in the amount of equipment needed.

The final design involved signals detected at one end in the conventional radar, and at the other end by a specially designed 'high-speed aerial' (fig. 20). This scanned a fixed angle in the horizontal plane once for each beamwidth of the main radar; it was mounted on turning gear so that the fixed angle of scan could be moved for optimum coverage. Correlation when a target was at the coincidence of the two beams achieved the objective by giving its position with the same accuracy and data rate as the radar. The positional data on jamming targets was three-dimensional because the main radar had a 'stacked-beam' configuration and passive detection was installed on each beam. This is of course a considerably simplified description. Substantial (for that time) computer power was involved in each installation, to extract data reliably in parallel with the main radar (fig. 21). Operational tests proved that Passive Detection fulfilled all its requirements. The full system listened in silence for many years as a vital part of the UK air defences.

20 ***High-speed aerial for passive detection***



a)



b)

21 ***Early passive detection (PD) trials:*** **a)** ***jammed radar display, and*** **b)** ***four jamming aircraft approaching the East Coast, accurately located by passive detection***

Naval Systems

At Leicester, the contract which became the Type 909 SEADART tracker started in 1962 as an order for the provision of two target indication radars for weapon trials at the Aberporth firing range and for the Admiralty establishment at Portsdown. The electronic expertise existed because of earlier work on the two land-based systems for surface weapons, known as Blue Anchor and Yellow River. Very soon after the initial experimental contract, a development contract was placed for the design of an extremely complex radar for the SEADART missile system to be installed in HMS *Bristol*, a new class of warship known as Type 82, and in fact the only ship of its class to be built. Its somewhat similar successor was the Type 42 ship, which was to be the main platform for SEADART. The combination of shortage of MoD funds and rushed timescales left the programme in difficulties. Indeed, financial and time constraints led to the installation of the only prototype model in HMS *Bristol* and prevented retention of a working prototype for the engineering team, which was a serious drawback. Nevertheless, because of vigorous concerted efforts, the programme did eventually overcome the early set-backs and led to production contracts and fitting in Type 42 ships and carriers of the HMS *Invincible* class, achieving the required in-service performance.

In the 1960s the Royal Navy were seeking a replacement for the SEACAT missile system and were analysing the threat posed to warships from small, fast, anti-ship missiles. They had the concept of an automatic, ship-borne, close-range, self-defence missile system that could destroy such a target with a very high probability of success (something like 99.9%) under difficult weather and sea states. In 1967 Marconi Radar was contracted to study the feasibility of such an installation – the code name of the study was PX430. This was principally carried out by Marconi Research Centre personnel. In 1969 this led to a development contract for the radars for what became SEAWOLF – also known as GWS25 (fig. 22).

22 ***Arctic testing of a GWS25 surveillance mount in the Marconi Radar environmental test chamber at Writtle Road***

Marconi Radar was also Ship System Contractor to integrate the efforts of the suppliers of the missile launcher, the missile handling equipment, and the computer and software elements of the system. The whole of the ship system was a Ministry of Defence contract, but the contract for the GWS25 missile itself was let and managed by the Ministry of Technology and had started about a year earlier. The missile was under command guidance from the ship throughout its flight. The system was required to detect the incoming target automatically, initiate the launch, 'lock on' to both missile and target, and to guide the missile into contact or extremely close proximity to the target.

The main elements of the radar system during the period covered by this article comprised the mast head surveillance radar Type 967 and 968 (fig. 23) which combined L-Band and S-Band radars back-to-back, also fitted with IFF (identification friend or foe). The tracker was Type 910 and, in addition to the radar tracker antenna, it was co-mounted with a command link to steer the missile and low-light television for use in certain conditions. Anti-ship missile data were passed automatically to the tracking radar to put it on the correct bearing; the tracker nodded to acquire the correct elevation and locked on to the target, followed immediately by the launch of the missile. The SEAWOLF missile carried a beacon which enhanced the tracking, and the system used 'differential tracking', simultaneously tracking the incoming target and the ship's missile, measuring the angle between the two, and transmitting a guidance signal to bring the two together.

Extensive trials, not without their set-backs and delays – as could be expected in breaking new ground, proved the system met its requirements. The tests were carried out both on the Australian missile range and with prototypes fitted in a warship. In fact, the missile range trials were very satisfactory and a second model was not required before fitting in HMS *Penelope* for sea trials. As the sea trials evolved and the bugs were taken out of the system, SEAWOLF was regularly intercepting a 4.5″ (114mm) shell fired from another ship, with a probability of 90% – a target far more difficult than anything envisaged at the outset.

In the early 1980s, in order to meet a changing threat, to facilitate SEAWOLF vertical launch, and to minimize top-weight, a lightweight tracker radar was developed. This was based on the Marconi private venture-designed type 805SW and the TV channel was replaced by the millimetric radar elements of 'Rapier'.

Postscript

Over the period covered from 1946 to 1986 Marconi was successful in supplying virtually all the surface radar systems for the RAF and most surveillance and missile radars for the Royal Navy, and at the same time exporting – on average – half of its output. Financially it generated very substantial profits and cash. The authors are convinced that continuity of personnel, policy and establishments was the main contributor to success.

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23 ***Type 968 mast head surveillance radar for the SEAWOLF missile system***