The Early Days of Radar in the UK
Notes for talks

by

Dr W.H. Penley

This is a fairly comprehensive summary of the early days of radar in the UK from May 1940 to May 1942. These notes were prepared for talks to organisations in Dorset about the significance of the research and development work done in Purbeck for the RAF. (11th Oct '93 Rev 1).

Penley Radar Archives
web: www.penleyradararchives.org.uk
e-mail: info@penleyradararchives.org.uk

Copyright:
For educational purposes only, other use may require agreement of author or other provider.
Further information: www.penleyradararchives.org.uk/copyright

Document ref:
www.penleyradararchives.org.uk/documents/penley/early_radar/ 15th October 2002

THE EARLY DAYS OF RADAR in the U.K.

Notes by Dr W.H. Penley (11 Oct 93 Rev1) for talks to local Organisations about the significance of the R and D work done in Purbeck for the RAF from May '40 - May '42

INTRODUCTION

"Radar" has become a household word; it conjures up all kinds of ideas - Speed Traps - Weather forecasting - Air Traffic Control - Collision Warning at Sea - Space Travel - Defence against Ballistic Missiles - Smart Weapons - and much more. However, it seems to be little known or appreciated that some of the most far-reaching developments were carried out in PURBECK. This is a great pity, as what was achieved, particularly at Worth Matravers, Langton and Swanage, from May 1940 to May 1942, played a critical role in avoiding our defeat in WWII and then continued to swing the balance of War in our favour throughout its various stages, until the Allies were ultimately successful. Subsequently it also led directly to most of the present uses we now take for granted.

I am glad to have this opportunity to tell you a little about this amazing Saga, in which I was very fortunate to have been involved. I shall, of course, only touch lightly on the vast range of activities that grew out of the initial events which started it all off and shall try to avoid technical matters, except in the very broadest terms, even though they were at the very heart of what was being done.

In these days when you all hear about computers, lasers, smart bombs, and all the rest of the miracle of electronically operated devices, it is difficult to imagine what things were like in the 1930s before WWII. It subsequently transpired that the basic ideas for Radar type equipments had been put forward earlier in several other Countries, and also had been the subject of a secret Patent taken out by the Admiralty in 1928, and some work in the Army Signals Experimental Establishment in 1931. However, in 1934, nothing had been done in this Country to develop the ideas for military use, and, of course, what was being done in other countries had been kept very secret.

How RDF/RADAR Development started in the UK

To start the Saga then, you must visualise the situation in 1934. In 1922, Mr. A. P. Rowe had joined the small RAF laboratory at the Imperial College, headed by Dr Wimperis, and had trained as a meteorologist. A few years later Dr Wimperis became the first Director of Scientific Research in the Air Ministry with Mr. A. P. Rowe as his junior Personal Assistant, or in Rowe's terms, "dogs-body". The position of civilian scientists in the other Services was very subservient to the Naval and Military personnel and though, in the Air Ministry, which depended entirely on modern technology, these attitudes were not so strong, the civilians there too had to be very careful not to overstep the mark!

Mr Rowe recalls that there was a continuing attitude of "no war for at least ten years", and a general view that "the bomber will always get through", which had been enunciated by Mr Baldwin. Professor Lindeman (Lord Cherwell) was pressing strongly for the development of balloon barrages and aerial mines to combat the bombers, and work was going ahead to improve searchlights and listening devices. Rowe says that he visited a site on the Romney Marshes to see a tremendous concrete acoustic mirror 200 ft long and 25ft high arranged with sensitive microphones at its focus to pick up sounds from aircraft approaching over the sea, together with 30ft diameter steerable mirrors to determine direction. His visit was in preparation for a demonstration to Air Marshall Dowding who was to inspect it. While he was walking round the site with the Director Dr. Tucker, a milk cart came rattling through. Tucker stopped the milkman and said, "you won't be here this afternoon will you?" as the noise completely wrecked the operation of his equipment! These devices eventually achieved about 15 miles detection ranges but no positional data and so were hopelessly ineffective, even when working.

During 1934 a large-scale exercise had been held to test the defences of Great Britain. Mock raids were carried out on London, with the Air Ministry, the Houses of Parliament and Buckingham Palace being especially targeted. In spite of the fact that the targets and the routes of the bombers were known in advance, well over half the bombers reached their targets with little or no opposition. In the opinion of the umpires the Houses of Parliament, the Air Ministry and other key Establishments were eliminated!!

Rowe, even though the Directorate was excluded from research into radio and armaments, was so concerned about the situation that he collected together all the files he could find on the subject of Air Defence. There were 53 of them. What he read appalled him so much that he wrote a formal minute to Wimperis to say that if we became involved in a major war within the next ten years we would lose it unless something new could be discovered to change the situation! He proposed that the best advisors obtainable should review the whole situation and see whether any new initiatives could be found.

Setting up the Tizard Committee

Wimperis agreed and on 12th November 1934 wrote an historic minute to the Secretary of State and all the senior people in the Air Ministry, on the lines suggested by Rowe. It was quickly agreed to set up a committee as Wimperis had recommended, under the chairmanship of Tizard, (Sir Henry). The other members were AV Hill, PMG Blackett and Wimperis with Rowe as the Secretary.

The idea of using rays to kill or disable people or machines was very popular at that time, and many submissions were made by crackpot inventors to say that they had "black boxes" which would do what ever was required. Their bluff was called by offering £1000 to anyone who could kill a sheep at 100 yards with such a device, with no questions asked about the inside of the box. The mortality of sheep remained unaffected!

To start things off, Wimperis consulted Professor AV Hill about the possible effects of radio transmissions on the human body and the energy levels needed to cause physiological damage and Hill had estimated the levels that he judged would be necessary. With this information Wimperis wrote to Mr. Watson-Watt (Sir Robert) who was the Superintendent of the National Physical Laboratory Radio Research Station at Slough, to ask his views on the possibility of developing a radio "Death Ray" with enough energy to melt metal or incapacitate an aircraft pilot.

Watson-Watt passed the query on to one of his senior staff - AF Wilkins, who did the sums and reported that there was no possibility of achieving significant destructive effects at a distance with foreseeable radio techniques. However, he indicated that there ought to be enough energy reflected from an aircraft to enable it to be detected at useful ranges.

This paper was presented to the first meeting of the Committee on 28th January 1935. They were very interested and instructed Rowe to get quantitative estimates for detection. On 6th February wrote to Watson-Watt to ask him to provide these quantitative for the possibility of detecting aircraft as distinct from their destruction. The further calculations Wilkins made gave favourable results and Watson-Watt wrote his now famous memorandum in which he proposed "by the extension of known means" a system of radio-location using a pulse/echo technique. This was presented to the Committee in draft form on 12th February and after its very favourable reception Wimperis, on 15th February, proposed to Air Marshall Dowding, who was Air Member for Supply and Research, that £10,000 should be expended to investigate this new method of detection. Dowding was very interested but asked for a simple practical demonstration to show feasibility before committing scarce funds to the project.

The Daventry Experiment

For this demonstration, Watson-Watt and Wilkins decided to make use of transmissions from the powerful BBC short-wave station at Daventry, which broadcast 10kW of radio power on a wavelength of 49 metres in a beam about 30 degrees wide and inclined up at about 10 degrees. The plan was to fly a Heyford bomber up and down this beam and attempt to measure the amount of power reflected from it at various ranges. Radio receiving equipment was quickly installed in a van and this was positioned, late on 25th February, in a field south of Weedon about seven miles away from the transmitter. The receiving aerial was arranged so that signals coming from the direction of the transmitter could be reduced to a suitably low level which would not saturate the receiver, whilst retaining good sensitivity for signals from the direction of the bomber. The strength of the combined signal after detection by the receiver was to be shown on a cathode ray tube.

Next morning, on 26th February, Watson-Watt and A. P. Rowe joined Wilkins, and the Heyford bomber was flown at heights of 6,000ft down to 1,000 ft along the beam. The results were immediate and conclusive - "beats" between the direct and reflected signals were detected up to distances of over eight miles. This confirmed the predictions Wilkins had made. Watson Watt was so impressed by the results that he turned to Rowe and said: "Britain has become an island again!”

AM Dowding was now convinced that urgent action should be taken to exploit this effect. It was designated MOST SECRET and he obtained the £10,000 requested for the urgent investigation of these ideas. Watson-Watt was authorised to form a small team from his NPL staff at Datchet and chose A. F. Wilkins and E.G. Bowen as his senior assistants. They decided that it was essential to carry out their detection experiments over the sea and on 1st March Watson-Watt visited and approved a site at Orford Ness in Suffolk for the work.

Design work started, using the experience the team had built up in the Radio Research Labs, particularly in investigating radio interference from thunderstorms.

The BBC transmitter had sent out the radio waves continuously, but Watson-Watt's proposal was to transmit short bursts so that the distance to a target could be found by measuring he time taken for each pulse to travel to a target, be reflected, and return to a receiver. A cathode ray tube was to be used to display both the transmitted and received pulses and show the time delay between them. Radio waves travel at 186,000 miles a second, so take 10.75 millionths of a second to go and return over each mile of distance to a target.

Move to Orford Ness

Design and construction of equipment was quickly put in hand and the small team of Wilkins, Bowen and a few others moved to the hastily provided accommodation at Orford Ness on 13th May 1935. Detection ranges of 17 miles were quickly obtained and were rapidly increased to 30 and then 40 miles by July. The aerials were mounted on three pairs of 75ft wooden lattice masts, one pair was sited near the building used for transmitter work, and the other four masts were set at the corners of a rectangle within which the receiver building was situated. It was decided to refer to this activity as "Radio Direction Finding" or "R.D.F." This was already a well-known technique, and so, if it should by accident happen to get referred to, it should not excite public interest. (The term RADAR was introduced during the War)

In the initial discussions it had been decided that the "Tizard" Committee should be set up within the Air Ministry rather than as a part of the machinery of the Committee of Imperial Defence. The Admiralty and War Office were immediately informed, and Wimperis was instructed to tell their Scientific Directors personally what was proposed. He was to find out what sort of help they would be able to give, ascertain whether they were studying similar problems, and see whether they might wish to put forward suggestions for more direct collaboration. These initial contacts were made, and in July with the clear success of the early trials, requests for assistance were made to the Admiralty and War Office. In addition, some recruitment had been authorised, and as a result more staff began to arrive.

The Admiralty Signal School was the only source of silica transmitting valves and undertook to make them for Watson-Watt. They concluded that it would be better to do their own equipment development work at HM Signal School rather than join the team at Orford Ness, because of the very special engineering problems presented by the fitting of this kind of equipment on board ship. The Board of Admiralty gave approval in September 1935 and a team was set up under R.F. Yeo at HM Signal School in October.

In July Col. Worlledge of the Royal Engineer and Signals Board visited Watson-Watt, and as a result of this meeting, Dr Paris was subsequently attached to the team, to report on the suitability of the new techniques for Army use. However, it was not until October 1936 that he was officially detached from the Army Air Defence Experimental Establishment (ADEE) as head of a small Army Cell to concentrate on Army related needs under the direction of Watson-Watt. The two Scientific Officers in his team, Butement and Pollard, were from the

Signals Experimental Establishment where they had proposed a system for ship detection in 1931!

The experimental work was initially carried out using a wavelength of 50 metres as this, at the time, was considered likely to give the best reflections from aircraft. Interference with commercial radio traffic was severe and 25 metres was tried - then 12 metres, new transmitters receivers and aerials being required for each of these wavelengths.

To enable our defending fighters to be directed to the best positions to engage the enemy it was essential to get positional information. So, in addition to achieving the best possible ranges of detection, bearing and height were also needed.

To find the angle of elevation of a target it was decided to attempt to measure the time difference between signals received by aerials placed at different heights, by determining the difference in phase. Equipment was set up and an apparently successful demonstration was given on 21st September. However, when the effects of the reflections of the signals from the ground were considered carefully, it became clear that a comparison of the signal strengths received by the aerials, rather than the phase difference, would be a much more satisfactory method, and this was subsequently used.

To achieve the longer detection ranges needed (over 100 miles) it was calculated that much greater transmitter powers would be needed together with higher aerials. It was judged that to avoid saturation problems, it would be necessary to site each receiver several miles away from a transmitter. The scheme envisaged, therefore, was to have a central transmitter which "flood-lit" the area in front out to about 100 miles and to place receivers on each side about 15 miles away. The map position of a target was to be calculated by using the time differences between receiving the reflected and direct signals at each receiver.

Watson-Watt's proposal for the Chain

On this basis, in September 1935, Watson-Watt submitted proposals for a chain of stations to be erected round the coast to provide warning of attack and positional information which would enable defensive fighters to be "scrambled" and be told where to engage the attackers, and thus avoid the need to maintain "standing patrols". In this historic report he discussed the effects of height of target, height of aerials, wavelength of the transmissions, power transmitted and receiver sensitivity on the detection ranges possible. He concluded that using a wavelength of about 10 metres and aerial heights of under 500ft he could meet the RAF's requirements. He proposed that a full scale station to demonstrate this should be built at once, to be followed, if successful, by a group of stations to cover the Thames estuary and then by a final chain covering the south and east coasts.

The move to Bawdsey

The research and design work now needed to be stepped up. To provide extra space and a suitable site for the separation of the transmitter and receiver equipments, Bawdsey Manor, about 10 miles down the coast from Orford Ness was proposed. On 16th September 1935 the Air Defence Committee of the Committee for Imperial Defence sanctioned its purchase as the centre for research work and also as the headquarters for the organisation of a chain of stations.

Approval to construct 5 stations

On 24th October 1935 the Deputy Chief of the Air Staff held the first conference on the problems of using RDF and on 19th December the Treasury sanctioned a scheme to provide a chain of five stations covering the approaches to London. Each station was to have a central transmitter site with receiver sites in each side. Sites were chosen and surveyed by Wilkins, approved by Watson-Watt and construction put in hand. They were to have 240ft high wooden towers for the receivers and a similar tower for the transmitter.

A 250 ft guyed lattice mast was erected at Bawdsey and receiver aerials installed in February 1936. Early in March ranges of 75 miles were obtained which Watson-Watt was able to report to a meeting on 13th March, set up to consider whether to proceed with the giant acoustic mirror project. This was cancelled! Two further 250ft guyed masts were erected at Orford Ness to support a six element transmitter array, and performance was still further improved.

In May 1936 Bawdsey Manor became the centre for the work, and very soon after this a solution was found to the receiver saturation problem so that transmitters and receivers could be operated in reasonably close proximity. Watson-Watt then devised a method for measuring the target bearing by using a pair of crossed dipoles for the receiver aerial. Wilkins showed that two pairs of crossed dipoles, mounted at different heights, could also be used for height finding, and so complete stations could now built on one site and the confusions of attempting to find the map positions of many targets by complex range calculations avoided. This was very significant as the problem of identifying and calculating the positions of many targets by range cutting methods would have been impracticable then and would be extremely difficult even with modern day computing methods.

Sites for the first group of stations had been chosen on the original basis of separated transmitters and receivers, and work had already started. To save time, it was decided to use these sites for the new design of stations, even though it might have been possible to find a better disposition. Industry was now playing a major part in the design and the construction work for these operational stations, under the overall supervision of the staff at Bawdsey. The first five stations were to be at Dover, Dunkirk, Canewdon, Bawdsey and High Street in Suffolk.

Tizard was sure that aircraft positional information would become available much sooner than was generally thought. He convinced the RAF that theoretical and experimental studies of fighter control and interception techniques should start immediately. A study group was therefore set up at Biggin Hill and arrangements made for trials to start as soon as there was a fully operating RDF station.

Bawdsey was the first station to become operational and plans were made to test the new interception procedures, which had been worked out theoretically. To avoid any possibility of complicity, conscious or otherwise, it was decided to intercept a completely unsuspecting aircraft rather than use another RAF aircraft as the target. Bawdsey had been plotting civil airliners flying into Croydon and so, on the trial day, a KLM flight was selected and a perfect interception was made. Our fighters continued on course to counter the impression that they had come out to meet it. To avoid suspicion no further interceptions of civil aircraft were made. On the strength of the results being obtained Watson-Watt was able persuade the Government to earmark ten million pounds for a coastal chain of stations, an unheard of sum in those days!

Soon after this successful demonstration, the stations at Canewdon and Dover were completed. This revealed that the sites were sufficiently close to give considerable overlap in their cover, and because of the relatively low accuracy of the positional data derived, the reports from adjacent stations on the same aircraft could be mistaken for several different ones. It was clear that if this information were fed straight to a central situation map considerable confusion might result. It was therefore decided to introduce a preliminary map on which all information received (from the Observer Corps and the fighter D/F system as well as from RDF) was plotted and assessed by experienced observers. They had to produce a weighted average and as far as possible determine the nature of each "plot" - i.e., friendly, hostile, number of aircraft, etc.

This intermediate step was called “filtering”. It was carried out in a "filter room" and the results were passed to the General Situation Map in Fighter Command so that the AOC could decide the action to be taken. Each Squadron then had to be given precise instructions by a Controller watching the "plot". Clearly they could not all be sitting round the General Situation Map at HQ Fighter Command, so the relevant parts had to be relayed back to lower levels of command. From there the flight orders were transmitted, initially by telephone, but once airborne, by Radio. As you may imagine, a lot of work was done to determine the most effective form for these various maps, and the display of other essential information. A large flat table map marked with "grid squares", on which "plotters" placed and moved blocks to represent groups of aircraft, was usually in the centre of the Operations Room. Other maps and displays giving more general information, and specific data on fighter readiness, were on the walls. Senior officers and the aircraft Controllers could view all this from a balcony.

Fighter Command was set up in 1936 and A.M. Dowding was made the first AOC in C. He therefore remained directly responsible for the implementation of the Biggin Hill studies and for the RAF training unit that had been set up at Bawdsey. He took a very direct interest in these developments and because of his close involvement in the development of RDF this had a major bearing on our success in the "Battle of Britain" in 1940.

In his memorandum, Watson-Watt had explained the propagational effects that would reduce the detection ranges possible for targets at lower heights. He had indicated that the use of shorter wavelengths would improve matters if adequate transmitter power and receiver sensitivity could be obtained. A wavelength of 26 metres had been chosen for the initial development as the power available below this wavelength tailed off very quickly. However, Watson-Watt realised that even though his proposal to use wavelengths between 10 and 15 metres for the main development might satisfy the RAF's initial requirement to give warning ranges of over 100 miles, there remained many other promising and important applications, especially Naval and Military, for which shorter wavelengths were essential. Experiments were therefore carried out at wavelengths down to 50cm and suggestions were made for the use of beamed aerials rather than the "flood-lighting" provided by the initial chain proposals. The concept of having a "RDF Lighthouse" with a continuously rotating beam to pick up targets and our own aircraft was put forward by E.G. Bowen but its realisation was then beyond technical possibility.

The start of Airborne RDF

Meanwhile, Tizard had become convinced from the Biggin Hill trials, that even though effective interceptions should be obtainable by day against the mass raids expected if hostilities commenced with Germany, the relatively crude positional data which could be obtained from the CH stations would not provide the accuracy necessary to direct our fighters in poor visibility or at night. He therefore pressed for the development of RDF equipment to go into fighters so they could find and engage targets when placed within a few miles of them.

In September 1936 a staff of three, led by E.G. Bowen, who had been investigating shorter wavelengths, started working on the development of airborne RDF. This investigation was called RDF2 to distinguish it from the ground based equipment programme that was called RDF1. Initial trials were done using a wavelength of 6 metres with a large (TV) transmitter on the ground and a receiver and the large aerial required in the aircraft. (This arrangement was called RDF 1a). A range of 10 miles was obtained but it was clear that much lower wavelengths were needed to reduce the size of the aerial and equipment and that, if possible, the transmitter should be in the aircraft, not at a distance on the ground.

The experimental work was therefore continued on higher frequencies, for airborne use. Bowen favoured a wavelength of 10cm but the transmitter power and receiver sensitivity possible were totally inadequate. He therefore built a crude equipment working on a 1.25 metre wavelength with both transmitter and receiver installed in an Anson. This was first tested in the summer of 1937. Aircraft and ships were detected with this equipment, and in demonstrations that autumn, HMS Rodney and HMS Courageous were located, in vile weather conditions, at ranges in excess of 5 miles. Development of equipment for both of these functions now called AI (Air Interception) and ASV (Air to Surface Vessel) respectively now went ahead with priority given to AI. A wavelength of 1.5 metres was chosen as considerably higher transmitter power and reasonable receiver sensitivity could be obtained.

The start of Army RDF

The small Army team that had been sent to Bawdsey towards the end of 1936 had been put to work with various members of the resident team on the most pressing problems of the day. This was part of the learning process, and was intended to encourage a free and easy exchange of ideas. The policy was quickly to prove most fortunate. The Bawdsey Research Station staff now had to concentrate on the development of the main Chain Stations with their associated reporting and command system and also on the development of equipment for aircraft use, with all the major new problems involved. The Army team therefore concentrated on equipment to aid anti-aircraft guns, search light control and coastal defence against ships.

By the end of 1937 Pollard had a prototype anti-aircraft gun ranging equipment working which, after further development, went into service in 1939. Butement was placed in charge of a Coastal Defence sub-section and after seeing tests of Bowen's AI equipment on the roof at Bawdsey decided to use this as the basis of his CD set. He was able to use a lot of the techniques developed for the AI equipment but was not restrained to the small size of the aerials allowable on aircraft. Instead of Yagi type aerials (like present day television aerials) he opted to use large broadside arrays, about 24ft wide and 10ft high which gave much sharper beams and a higher gain.

The Start of Naval RDF

At the Admiralty Signal School, they decided that the flood-lighting system being used for the CH stations would give serious blind spots in cover, and that to operate over the full 360 degrees, beamed rotating aerials at mast head level were required. Experiments were carried out at various wavelengths over 1936/7 and finally a wavelength of about 7 metres was chosen as this was judged to be the longest for which useful aerials could be made which could be fitted at the masthead. Two were required for transmitter and receiver and these had to be rotated in step. Development went ahead and the first installation was in HMS Sheffield by August 1938 and the second in HMS Rodney by October. Meanwhile, work was also in hand to develop equipment for locating surface vessels and for improving range finding for the main guns.

Extension of the Chain

By the end of 1937 the International situation was deteriorating rapidly. Plans to extend the Chain were hastily made and a final design for the main stations was prepared. It was intended to operate on four wavebands as a safeguard against enemy jamming or accidental interference. Four 360ft steel towers were to be used at each station for the transmitting aerials and four 240ft wooden towers for the receivers. Progress in erecting these stations was disappointingly slow especially for the steel towers, and as the situation continued to worsen stations were put into operation with just wooden towers. In some areas, using mobile stations with portable 70ft towers that had been designed for use overseas by the Army provided emergency cover.

Though remarkable progress had been made by 1938, it became clear to Tizard and Watson-Watt that in the event of War there would be a tremendous demand for scientific effort to cope with the vast range of scientific and technical problems that were arising. Watson-Watt moved to London to deal more effectively with policy matters and in May Rowe took over from him at Bawdsey. In addition to the limited amount of recruiting that was underway for Bawdsey, a list was prepared of suitable people who were at Universities. Tizard approached Cockroft (Sir John) to see whether some of the eminent researchers in the Cavendish Laboratory at Cambridge might be persuaded to help. He told him a little about RDF, and explained that in the event of War "nursemaids" would be needed to make the equipment work well and keep it going. He particularly invited him to consider what might be done to produce large transmitter power at very short wavelengths. Little happened as the Admiralty was handling valve development.

In August 1938 the RAF carried out an exercise to test the air defences. This clearly showed the need for better low cover, as Watson-Watt had originally predicted, but no specific requirement was stated until June 1939 when the RAF asked for equipments based on the 1.5 metre coastal defence set being developed by Butement. The Army team was therefore expanded to provide 24 CHL (Chain Home Low) equipments for the RAF in addition to their CD programme. The CHL stations were to consist of a pair of broadside aerials 28ft wide by 10ft high on searchlight turntables mounted on pairs of 20ft high wooden gantries over huts for separate transmitters and receivers. "Binders" used crude bicycle chain drives to turn the aerials and had to keep them in step to within 2 degrees. After detecting a target they had to inch the receiver aerial round to point straight at the target so that the direction could be read off and, with range given on a CRT, enable the map position to be plotted. During this development Wilkins and Larnder tried to establish the RAF's requirements. It was agreed that the need was to detect aircraft flying at 500ft at least 50 miles away. The original CD set achieved about 35 miles but Wilkins calculated that, with improved transmitters becoming available, 50 miles could be achieved it the aerials were sited 200 ft above sea level. The RAF wanted the CHLs to be placed at CH stations, but many of these were inland or on low sites, so mounting the CHL aerials on towers was proposed. (This was my first task after joining the team!)

Towards the end of 1938, after "Munich", Cockroft visited Bawdsey where he was told what had already been done on RDF and was shown the experimental and development work going on. In the spring of 1939 he took a group of the leaders of the Cavendish to Bawdsey, and the senior "old hands", Wilkins, Bowen, Larnder, Whelpton and Williams gave them a comprehensive exposition on the situation. Shortly after this they were asked to consider ways of jamming or confusing RDF systems. It was agreed that Dr W.B. Lewis should join Bawdsey straight away to take charge of the research. Arrangements were also made for parties of physicists, totalling 80, to be introduced to RDF by spending a month on Chain stations, starting on 1st September.

Evacuation of Bawdsey

Concern that the Germans might be aware of the work going on at Bawdsey was heightened by a visit from the Graf Zeppelin. This, for almost a whole day in August, hovered 20 miles out to sea and also flew inland over the coast. It was (correctly) thought to be trying to monitor the RDF transmissions, and it was assumed that if the Germans knew Bawdsey's function it would make it one of their earliest bombing targets. In the few days before the declaration of war, therefore, most of the BRS staff was evacuated to the Teacher's Training College in Dundee. Bowen had been given the task of providing a squadron of AI equipments before the end of 1939 and the first MkI was delivered to the RAF in August. To carry out the installation, Bowen's airborne equipment team went to Scone near Perth - a grass airfield without runways - and then to St. Athan, a maintenance aerodrome in South Wales where they were bombed by a JU88! It was very fortunate for Lovell (Sir Bernard) and Hodgkin (Sir Alan) that the bomb didn't go off! The equipment was flight tested in December.

The Army team was moved to Christchurch to a site on the cliffs at Steamer Point, very suitable for the work on CD equipment.

On 14th November, six weeks after war was declared, U-boat U-47 sank HMS Royal Oak in Scapa Flow. Admiral Sir James Somerville, who had seen a demonstration of Butement's CD set tracking a surfaced submarine at Bawdsey, asked for three of these equipments to be made immediately to help protect that vital area. Cockroft was asked to undertake this task. He drove a lorry to Bawdsey and collected equipment which had been left in the stores there, took it to Cambridge, and mobilised a team from the Cavendish to do the design and construction. These sets were called CDU's (U for U-boat). After a short time Cockroft and his team moved to Christchurch to continue the work. The first station was operating on site early in December and the other two before the end of February. Performance on submarines was up to 25 miles, and on aircraft up to 70 miles. They detected low flying aircraft at much greater ranges that the CH stations.

Early in this period the first magnetic mines had appeared off the East Coast and were causing many wrecks. Cockroft was asked to provide two stations for the Thames Estuary. The first of the CHLs was erected at Foreness Point and was operating by 1st December. There Cockroft saw W/Cdr Pretty (Sir Walter) control the first interception of a low flying mine laying aircraft. As a result it was agreed at a meeting at Aerial House on 19th December, that the use of single stations for this task was better than tracking target and fighter with separate equipments. This had a profound influence on the development of Ground Controlled Interception techniques (GCI). Air Ministry now required many more CHL stations and instructed the BRS team at Dundee now called the Air Ministry Research Establishment (AMRE), to take over the task from the Army team.

For the AMRE team Dundee was most unsuitable, the work had been disrupted, and the distance from London prevented the close contacts with the RAF which had been so important. However, three of us completed the installation of an experimental CHL on the 200ft platform of the 360ft steel tower of the CH station at Douglas Wood and showed that it gave good detection of low flying aircraft as had been predicted. Another team under RA Smith was able to design and test changes to the CH transmitter aerials and achieved a valuable increase in the range of detection possible. We were all greatly relieved when we heard we were to move to a new site which was being constructed for us near the CH Station being set up at Worth Matravers. Most of those in Dundee packed up and moved to Worth on 8th May, and were joined by many of Bowen's aircraft equipment team. Quite a significant number from both teams moved to HQ, or joined the RAF, to help deal with all the new technical tasks and problems presented.

<u>The move to Worth Matravers</u>

At Worth Matravers, towers and huts, some with earth barriers for protection against air attack, were being erected in a field next to Renscombe Farm and the rudimentary CH station that was already in place. Huts for offices, workshops, drawing office and experimental labs were being provided - a vast improvement on Dundee and St Athan. Arrangements were made for us to use the airfield at Christchurch for equipment installation and experimental flying until Hurn was ready.

We were just coming to the end of the "Phoney War" and daylight raids were building up. Construction of the RDF Chain, both the main CH stations and the new CHLs based on Cockroft's design, was going ahead apace, but there were many technical and operating snags. Our prime task was to improve performance and make it more consistent. In particular the CHL stations were not performing as hoped. The task of keeping two aerials pointing in the same direction within a couple of degrees seemed too difficult and the requirement for two turntables at each station was slowing the rate of construction.

Many different aerial designs were tried in the attempt to operate the transmitting and receiving aerials on the same turntable but, though giving some improvement, none gave the performance we were seeking. There was no way of checking the performance of a station other than getting aircraft to make "calibration" flights. With the increasing number of stations, the small number of aircraft that could be made available and the risks of enemy action over the sea, this was clearly very unsatisfactory. A lot of effort was put into devising test equipment to enable effective setting up to be achieved without aircraft. We found that the performance of the CHL erected in the main CH compound near Renscombe Farm was no better than the CH for low flying targets, so we had an experimental set erected at St Aldhems Head. This gave very good performance and, as a result, a RAF operational CHL station was quickly installed there.

At Dundee, Dummer and Franklin had been constructing a "radial time base" CRT display to show the map position of targets. Lewis had visualised this being used with an RDF set with a sharp beam rotating like a light house. He had given the task of developing a suitable RDF equipment to a team of senior research scientists who had just joined, and they were struggling to do the job on a wavelength of 50cm. Soon after we got to Worth, Dummer was ready to try out his display but the 50cm equipment was not yet giving adequate performance. I was therefore asked to set up a 1.5m CHL type equipment for the trials and a very successful demonstration was given to AM Sir Phillip Joubert, who was very impressed. The Plan Position Indicator (PPI) was born! Much development of our basic RDF equipments to make use of this new display technique was clearly needed, but France had been over-run, and the evacuation of our Forces from Dunkirk shocked us all. We had to concentrate immediately on whatever was needed for the immediate defence against invasion. Daytime attacks were building up and it was essential to ensure that the best use could be made of our relatively small force of fighters. We stopped our research work at Worth and went out to the CHL stations being set up to do what we could to ensure that they gave the best possible performance. We converted many of them for single turntable operation, put in various technical improvements, checked the performance, found that several were in poor positions and for these chose better sites which would give good low level detection.

During this time the daylight blitz was at its peak. The CH chain with the CHL additions and the complex but very effective control and reporting system that had evolved enabled the Hurricane and Spitfire Squadrons to stay on the ground until the raids were approaching. They were then directed to the most favourable positions to attack - often from a higher altitude and "out of the sun" which gave us a tremendous advantage. Losses of about 10% were inflicted on the enemy, who could not sustain this, and so, as Tizard had predicted, turned their main effort to night attack. It was quickly found that the Chain system was unable to direct our fighters against the scattered targets with the accuracy needed for the crude AI to pick them up. The loss inflicted on the enemy was about 1% - mainly by AA fire!

Our operational research group had been using the "inland" CHL equipment on the main CH site at Worth to develop more accurate methods of directing aircraft. One project they put a lot of effort into the task of dispensing the Long Aerial Mines in the path of incoming raids. Professor Lindeman was very keen on this concept. It was visualised that if an aircraft flew into a long length of steel wire trailing below a small parachute, the drag of the parachute would pull the wire up across the wing, and bring an explosive charge fitted to the wire into contact with it. This "LAM" concept, whether dispensed from aircraft or by rockets, did not give attractive results.

Their other main project was to find a way of using the high accuracy that it should be possible to obtain from a CHL type beam station to direct a fighter to the best position from which to engage an incoming bomber. Many schemes were tried using the split-beam plotting techniques with various mechanical navigation computing instruments. These certainly did better than could be achieved with the main CH station but were not good enough for operational use.

In August 1940, just after we had returned from our trip round the CHL stations, we heard that special equipment for Ground Controlled Interception (GCI) suitable for inland use, and capable of being moved easily between sites, was to be evolved. The design was to be based on the Worth trials and what had been achieved at Foreness and take into account a suggestion that using low aerials in a saucer shaped site with higher ground about half a mile away might greatly reduce the level of ground returns which severely degraded overland tracking from standard CHL stations with gantry mounted aerials. It had been decided to use CHL aerials mounted on cabins designed by the Army team for their Gun Laying sets and the Army team at Christchurch would be making the aerial trailers. The two aerials would still have to be swung to and fro and kept in step, but a PPI would be fitted as well as a standard "A" scope.

The first equipment was installed at Durrington, near the Poling CH station, on 18th October 1940 but the urgency was such that the RAF had decided that six more were needed before Christmas, and work on these had been put in hand before any testing had been carried out.

Duckworth and I went to Durrington to see how the equipment was performing. We found that the plotting rate was too slow for accurate control and that height information from the CH at Poling was ineffective. There were also gaps in cover - targets being lost at critical times. Nevertheless, it provided better control than the Chain. Gradual improvements were made, step by step, by changes to the equipment. The receiver aerial was divided into upper and lower sections at about 7.5ft and 12.5ft and the "split" switch used to switch between them so that the different vertical polar diagrams could be used for elevation determination. The transmitter aerial was sectioned in the same way and arrangements made to feed these sections either in phase or in antiphase to alter the vertical pattern. These two changes effectively overcame the serious gaps in cover and enabled some rudimentary height finding to be achieved, but plotting rate and height accuracy were still inadequate.

Meanwhile at Worth our team was struggling to overcome the many shortcomings of the CHL technology. We wanted to use the same aerial for transmitter and receiver, and to do away with the twisting feeders and cables so that aerials could be rotated continuously. We also needed an effective way of determining target height. The 50cm "Lighthouse" set was still a long way off so Lewis asked me to design a highly mobile equipment on 1.5 metres which would include all our new technology. This was first called the Ground Rotating Beam or "GRB", and later "The Field Gun". While this was being developed the team got satisfactory design answers for common aerial working and rotating joints for both transmitter and receiver. We also showed that height finding could be satisfactorily achieved by switching between aerials with an electronic switch that worked at the repetition rate.

I was asked to design 50cm aerials to be mounted on the rear side of the CHL aerials at Dover, for an experimental station. The idea was that, as we now knew the Germans had RDF equipment, we might avoid jamming if we used the same waveband.

Goodier and Wiblin were using early ASV equipment to make a very small "Pack Set", which could be easily transported by air. This was for use in the protection of overseas airfields.

In October, because of the night blitz, the RAF was pressing us to make major improvements on the Durrington type equipments. It was agreed that we would have a free hand to make whatever changes we wished to the station to be installed at Sopley. Work on the "GRB" was slowed so that the technological improvements we were making could also be applied quickly at Sopley as well as to the CHLs. Like Durrington, Sopley had a two aerial system and John Duckworth was given the job of incorporating our new technology as soon as possible. Installation of this station started on Boxing Day with some of the improvements, and work continued, to produce the continuously rotating, single common T & R aerial, with height finding and gap filling, which was our aim.

Critical technical innovations were made such as the rotating coil magnetic PPI (Tutchings), a means of height finding without stopping the rotation of the aerial (Tutchings and Hopkinson), and the spark-gap method of using the same aerial for transmission and reception (Banwell and Lees). The first enemy aircraft shot down from Sopley was on 5th March and when HM the King visited the station on 7th May, he saw a successful engagement and also witnessed the enemy aircraft dive to the ground in flames. During the final stagers of the interception the Controller Sqn/Ldr Brown told everyone, including the King to “SHUT UP!”

Another operational GCI was set up at Sturminster Marshall and further development work was carried out there as well as at Sopley.

Most of the successful changes (except common T & R ?) were introduced quickly into the other GCIs, with the result that our Beaufighters could now be directed consistently to where they could pick up enemy targets with AI MkIV - an improved version of the 1.5 metre equipment. Our success rate increased rapidly, and reached about 10% during March/April. This, for the time being, effectively countered the night blitz. However the handling capacity of our defences was inadequate to cope with massed night attacks, which we knew could overwhelm them. The AI, because of massive signals reflected from the ground, could not pick up targets much beyond two miles. The use of Electro-mechanical switches for gap filling meant that each GCI could only do one interception at a time. Performance also rapidly tailed off as the attacking aircraft came in lower - a very worrying situation.

For the "GRB", my team and I had tried many mechanical and electronic methods for switching the transmitter between aerials at high speed without success. When Dr Westcott showed us that, theoretically, a variable capacitance would switch a feeder network. I immediately designed an experimental capacity switch, to handle the high voltages involved. It rotated at 50 revs a second and sounded like an air-raid siren! However it worked very well, and so the BTH Company were contracted to design and produce one to my basic design. Transmitter and receiver could be switched between aerials a thousand times a second.This later enabled us to evolve a very versatile GCI for installation on permanent sites. This used three aerial heights to give better low cover and could handle many interceptions simultaneously. The aerial rotated continuously at 6 rpm and the operations room was nicknamed the “Happidrome”. Installation of these was just about starting as we left Swanage in May 1942.

Fan Beam Height Finding

The problem of getting accurate height information on a target was a long standing one and the idea of using a fan beam which could be wagged up and down in elevation, had seemed attractive. To do this Banwell and Bacon devised a system of putting aerial elements all the way up a 200ft tower to give a beam width of about 1-degree. This could be wagged up and down with a phase shifter – the groups of dipoles were also tilted in maintain a good beam shape. As soon as the spark-gap common aerial system was devised several of these Variable Elevation Beam (VEB) equipments were constructed and put onto CH sites.

Towards the end of May 1941 the work on 50cm was showing more promise. I was asked to design aerials for mounting on CHL 20ft gantries. Lewis suggested that height finding might be possible by using a 10cm equipment! This was my first introduction to this possibility. Duckworth and Bacon moved to be near the centimetric teams, and we initially used the new techniques to do model experiments on aerial designs for 50cm equipments. In October, when the "GRB" was cancelled, I was given full responsibility for all the 50cm developments. In addition to the "Radio Lighthouse" now called AMES Type 11, I started work on a 50cm VEB. From model experiments on 10cm we decided on a wire-mesh reflector dish about 30ft high by 10ft wide. This gave a 2 degree fan beam which could be moved up an down slowly and scanned over + and - 5 degrees quickly by moving the dipole feed up and down to give a good "paint" of the target return on the display. By then Duckworth and Bacon had found that, instead of using complete paraboloidal reflectors, a section of a parabolic cylinder covered with flat plates to form a "cheese" shape would make a satisfactory aerial for operation on 10cm. They used "cheeses" about 15ft by 2ft for both a height finding "VEB" like equipment and plan position equipment. These were called AMES types 13 and 14.

All these basic equipments were greatly developed and played a very important part in the invasion. They were brought together in various combinations to make best use of their differing capabilities. On 50cm we were able to develop a system which would eliminate interfering ground returns and so provide very effective over-land operation.

Centimetric Equipment & the Magnetron

When Bowen had started working on airborne RDF he had said that a wavelength of about 10cm or less was really needed, but there was very little power available and receiver sensitivity was poor. However, Randall and Boot working under Oliphant at Birmingham University had been asked to see whether they could generate much higher powers for us at these low wavelengths. They achieved a phenomenal "break-through" by devising the cavity magnetron. On 21st February 1940 the first experimental model was switched on and gave around a kilowatt of power - several orders of magnitude up on what had previously been obtained. The GEC were given the task of designing a sealed version and the first of these arrived at TRE in July.

Since about 200 of us had arrived at Worth in May, there had been a large influx of top-level research scientists to TRE. Even though he was under extreme pressure to put all his effort onto immediate tasks, Rowe agreed with Lewis that a team should be given the job of developing and exploiting the new possibilities. They decided to say as little about it as possible for the time being, so it was kept very much "under wraps". Lovell says that he got the first echoes from an aircraft with a crude set-up which used separate 3ft diameter paraboloidal aerials for transmitter and receiver in August, and this was quickly increased to about 6 miles. It was clear that a lot of work would be have to be done to devise the components needed for a working system, and the Admiralty Signal School people, who, of course knew about the valve work, were kept fully in the picture. This was very fortunate as they immediately decided to develop operational equipment for use at sea and the basic parts of this were subsequently used for ground RDF too.

Centimetric AI

For the TRE team the task was to convert the very large, crude, experimental set-up, kept working by scientists, into small reliable airborne equipment which Service personnel could operate. It was judged essential to use the same paraboloidal aerial for transmitter and receiver and that this should be installed in the aircraft nose in a plastic dome. A dish of about 28" diameter gave a beam width of 12 degrees. A fighter needed to be able to detect targets over most of the forward hemisphere, so it was clear that this beam would have to be scanned by moving the dish. Experiments were done with both spiral and helical methods, and the former, evolved by Alan Hodgkin, was chosen for development, as it seemed simpler to manufacture. An experimental equipment was installed in a Blenheim at Christchurch in April 1941. Performance predictions were confirmed, 4 miles detection range being obtained down to very low altitudes. This was called AI Mk VII and a production run of 12 was ordered immediately, and then another 100. The initial sets began to arrive in the autumn and the main production early in 1942. These sets, with the improved GCI, accounted for over 100 enemy shot down in the very reduced attacks made during the early part of 1942. An updated design - AI Mk VIII - was brought out early in 1942. A further design (AI Mk IX) with scanning and "lock-follow" functions to allow "blind firing" attacks to be made was started and completed after the war, while the USA developed a helical scan equipment (AI Mk 10) which was very successful in the later stages.

ASV Development

After the autumn demonstration in 1937 when HMS Rodney and HMS Courageous were located, the development of ASV went ahead in parallel with AI, most of the techniques, except for the aerials and displays, being very similar. Three ideas were worked on - forward looking, sideways looking and all-round looking. These required very different aerials and displays. The biggest aerials could be mounted along the length of the fuselage and gave a sideways looking beam. In a trial of this equipment between 10th and 12th May 1938, when units of the Home Fleet passed from Spithead to Portland, photographic records were taken of the display as the sideways looking beam swept past the Fleet. The aircraft returned and took off several times and the films were shown to those in command. Detection ranges of 30 miles were achieved on capital ships, and up to 15 miles on smaller ones of about 5,000 tons. Also coastlines were clearly recorded.

However, Coastal Command decided to have the forward looking equipment first as they hoped that this would allow aircraft to home onto ships for direct attack. Intensive work on ASV only started after the delivery of the first AI equipments in August 1939 as these had priority. Trials of an experimental version took place at Gosport in December 1939 against surfaced submarines. Signals returned form the sea were very strong and when flying at 5,000ft detection was only possible between 4.5 and 5.5 miles. When flying at 200ft detection was between 0.5 and 3.5 miles. Ranges on big ships were up to 30 miles.

Deliveries of 200 for installation in Sunderland Flying Boats and Hudsons started in January 1940. They were used until the end of the year to search for enemy shipping and for anti-submarine patrols. They did not help much as the enemy shipping at this time was hugging the Norwegian and Dutch coast lines and great difficulty was experienced in separating the echoes from ships and those from the many islands. Its main use was for rendezvousing with convoys (which were usually out of position) in poor visibility, and to give warning of coastlines to avoid the cliffs of Norway and the mountains of Scotland. A responder beacon had been installed at Leuchars in April 1940 to enable aircraft to find their way back in bad conditions. Many more were subsequently provided for operational use to help aircraft find their way back to aerodromes in bad conditions, for finding convoys and for air/sea rescue. These aids to navigation were highly regarded and so kept interest alive.

The Royal Aircraft Establishment (RAE) was given the task of engineering the main units for full production and to give higher performance and good reliability. They began to come off production towards the end of 1940, and were called "ASV MkII". These units were subsequently made in many parts of the world, including the USA, and were used in many different equipments. In addition to aircraft installations these included air-transportable pack sets, search light control equipments, etc., and eventually, in gliders used in the invasion, to provide immediate warning of air attack after they had landed.

For ASV longer ranges were wanted, particularly on submarines, so the sideways looking system was reconsidered. The initial production of the MkII boxes was used for forward-looking sets but sideways looking LRASV sets were quickly introduced in Whitleys, Wellingtons, Sunderlands and Catelinas, and by April 1941 Coastal Command was operating with 50 sideways looking and 60 simple forward looking sets. From 2000ft the LRASV detected surfaced submarines beyond 3 miles out to 8 miles; 60 miles on coastlines; 40 miles on larger ships; and 20 miles on destroyers. The forward looking sets were not much better than the early sets, and better aerials were fitted which brought the range to about 80% of the LRASV. To fill the central gap, combined installations were introduced, with a means of switching between aerials that greatly improved the search and attack capability. These equipments were used in patrol and reconnaissance and particularly on the colossal task of protecting the shipping routes to the UK. One detected the escaping Scharnhorst and Gneisenau on 12th February 1942.

Their greatest contribution was in the early phases of the battle of the Atlantic. The Germans were using the French Atlantic ports they had captured in 1940 to provide bases for their U-boats. Coastal Command's major task was to intercept and destroy these U-boats as they passed to and from their bases. Initially ASV greatly increased detection and attack rates by day, but the Germans quickly began surfacing at night to charge their batteries. The ASVs could detect them at night, but the aircrews were unable to make visual contact unless the boat could be silhouetted in the moonlight. A visual was essential because of the large number of French fishing boats. Experiments were quickly instigated to provide illumination. Pyrotechnics were unsatisfactory because of release height and position and the difficult aircraft manoeuvre required to bring the suspect between the flare and the aircraft. Most promising was a 20" diameter naval searchlight - the Leigh Light - mounted on a retractable turret and remotely controlled in azimuth and elevation. Trials in the Summer and Autumn of 1941 showed that an ASV homing run on a target followed by exposure of the light at a range of about one mile should be successful. Extensive training of the whole aircrew was essential to form a skilled team.

Use of this system started in the Bay in June 1942. It was very successful and U-boats reverted to daytime surfacing. U-boat kills rose rapidly but fell in the autumn, when the Germans introduced effective warning receivers to tell them of the approach of an ASV aircraft. Many schemes for overcoming this setback were considered such as floodlighting the whole area from highflying aircraft with powerful transmitters on the ASV band. But, clearly, a much more efficient ASV was needed. Fortunately, an attempt was already being made to use the new centimetric waveband, and trials of an experimental equipment had started in March 1942. This used a rotating beam scanner and a PPI and had given four times the detection range on submarines.

It was decided that the first installation should be in Sunderland Flying Boats, but this presented considerable problems as two synchronised scanners mounted under the wings with complex switching were required to provide all round cover. Because of the urgency, Dee and Lovell suggested that a modified version of the ground mapping equipment they were developing (H2S) should be used. They produced a modified design very quickly and Lovell and his team personally modified six equipments and took them down to Chivenor in North Devon. The reluctant Station Commander was ordered to fit and fly modified Wellingtons over the Bay against the U-boats. This operation started in March l943, and by the end of April the use of these half dozen sets had resulted in the sinking of well over 20 U-boats. Such was the importance of this programme that Sir Robert Renwick said he would immediately report any trouble we had to the Prime Minister! The Germans did not guess the frequency change for a long time, even though an H2S fitted bomber had fallen into their hands in March. The U-boat Command became aware in September - and then quickly introduced warning receivers on the new band. The initial design was ineffective and was soon replaced with another type, yet the crews were convinced that something else was causing their large losses. Their morale became very low and never really recovered.

Our shipping losses had risen from about 40,000 tons in November 1941 to a catastrophic average loss of nearly 500,000 tons per month for the whole of 1942. The initial use of ASV gave a dip to 200,000 tons in January 1943, but losses rose again to 300,000. When the centimetric equipment became operational there was a rapid drop to less than 20,000 tons a month from June 1943 onwards. The Battle of the Atlantic had been won and the way for the USA to supply troops and equipment for the invasion was opened!

Equipment operating on much shorter wavelengths and countermeasures to confuse any new listening receivers produced by the enemy were developed to counter any resurgence of the threat. These maintained our ascendancy.

Sunday Soviets

Soon after we arrived in the Swanage area Mr. Rowe, who knew all the senior people in the RAF and The Air Ministry as a result of his period in London, invited senior individuals to visit Swanage at weekends to see and discuss what we were doing. The attraction of a day or two by the sea in the Grosvenor Hotel may have helped, but this quickly evolved into what Rowe called his Sunday Soviets. At these, C's on C with their senior staff would come and discuss their problems with senior members of the Establishment, and would accept the complete freedom of comment and remark that marked the discussions. Junior staff working on projects would often be called in to discuss technical and operational details. The mutual confidence and close co-operation built up by these free and completely informal exchanges played a major part in harnessing scientific and technical capability to the war objectives and in bringing scientific objectivity to the study of operational matters.

GEE

Great importance was attached to bombing, particularly by Prof. Lindeman (Lord Cherwell) who became Churchill's personal scientific advisor, and, of course, by AM Harris C-in-C Bomber Command. Photo-reconnaissance had shown that astro-navigation, dead reckoning and the use of navigational beacons was not getting our bombers to their targets, and Harris raised this problem at one of Rowe's Sunday Soviets. He was surprised to learn that a possible solution had been put forward by RJ Dippy at Bawdsey, but had not been developed then because of the urgency to complete the defensive Chain round the country. Next day

Dippy was set up with a supporting team to develop the scheme, and a contractor was quickly appointed to put the designs into production.

In this system a master station and two slave stations transmitted pulses in synchronism. A receiver in an aircraft measured the difference in the times of arrival of each pair of pulses and this enabled the aircraft position to be plotted. The system was called Gee, was introduced into service in March 1942. It proved of inestimable value throughout the whole of the war as a navigational aid which helped to marshal our heavy bomber raids and helped returning bombers find their way home safely. It was, however, not sufficiently accurate for precision bombing, was limited to about 300 miles range and could be jammed.

OBOE

Another bombing system grew out of a proposal made in the autumn of 1940 to use a CHL station fitted with a crystal controlled calibrator for more accurate range measurement to position a bomber accurately over a target... Trials gave promising results and in January 1941 experiments were done in which dot and dash signals were sent to the bomber to indicate its deviation from a central split line for the beam so that the pilot could correct this to fly directly over the chosen target. The time for bomb release was to be given from the ground station. The system of azimuth control was called "Howler Chaser" but one of the team said it sounded like an Oboe, so from then on it was referred to as "Oboe". In the only flight trial recorded, the aircraft reached a point a mile away from the planned target.

In February 1941, after for some time being unconvinced about their existence, the RAF wanted to bomb the German beam transmitters on the Cherbourg peninsula. It was decided to fly back up the German beam and to use range from an “OBOE” CHL station to fix the bombing time. A transponder (modified "IFF" set) was used to enhance the return from the bomber and overcome any likely jamming. Two sorties were carried out but it was not known whether significant damage had been inflicted.

In March a new team lead by A.H. Reeves and F.E. Jones was formed to pursue this application, and the name "Oboe" persisted even though the techniques to be used were considerably different. It was decided to use very accurate range measurement from two stations, and to arrange for an aircraft to fly at a constant range from one station on the arc of a circle over the target. The range from the other station would determine the bombing point. This would be sited to give good positional accuracy. In December, before the full "Oboe" system had been developed, it was decided to attempt to bomb the Scharnhorst and Gneisenau. Great accuracy was called for and so the RAF rigged up a very sharp Lorenz type beam using components from the Beam Approach System and TRE provided an "Oboe" accurate ranging equipment. Raids with over 30 Stirlings were made without loss and this to some extent overcame the fears that the final period of straight and level flying would invite large losses. Schemes were devised to overcome the low handling capacity. One pair of ground stations was required for each bomber for the last 10 minutes of the bombing run so multiple frequency and modulation systems were worked on. But finally the introduction of good target markers that were relatively light and could be delivered by the Mosquito aircraft determined the operational role. The Mosquitos, which were just being introduced, were very fast and could fly over the targets at above 30,000ft, so were relatively safe. This combination then provided a very effective target marking system, and was brought into operational use in December 1942. Further developments to operate on centimetric wavelengths, which were expected to be reasonably immune to jamming, were put in hand as well as methods of using repeater aircraft to extend the operational range.

H2S

In the early summer of 1941 a review of the economic situation in Germany resulted in Bomber Command's attention being concentrated on the destruction of German Industrial targets. Cherwell, who was very much in support of bombing, got an analysis made of our night attacks. It concluded that, whereas 75% of pilots claimed they had hit the target, they in fact had failed to strike within five miles of it. This meant that the effectiveness of our bombing campaign was very poor.

On October 26th 1941 Cherwell came to one of Rowe's Sunday Soviets and told him that it was essential for the RAF to have a self contained device in bombers which would enable them to navigate and strike targets deep in Germany. Dee remembered that the early centimetric equipment, in trailers at Leeson overlooking Swanage Bay, was picking up echoes from buildings in Swanage as well as from the Isle of Wight. He got O'Kane and Hensby to set up the helical scan experimental AI, installed in a Blenheim, so that the beam was depressed at a constant angle of 10 degrees. They got airborne within a week and on 1st November 1941 they filmed returns, shown on a crude "A scope" display, from Salisbury, Warminster and military installations on Salisbury plain.

Dee rushed the film into Rowe's office even before it was dry, and Rowe exclaimed, "This will win the War!" The results were discussed with the Secretary of State for Air on December 23rd 1941. He ordered that six special flights should be made to determine if the echoes always related to specific targets. These flights were ultimately carried out and provided the confirmation required, but, meanwhile on December 29th, Lovell, who was helping to develop the centimetric AI, was summoned to see Rowe who instructed him to set up a team to develop a centimetric navigation and bombing equipment, for use in bombers! Lovell protested to no avail, and so started on the task. The trial had been with a forward-looking equipment, and all round cover was clearly needed. Production of the Halifax Bomber was just starting so Lovell went to see Handley Page on 4th January to get a Perspex cupola mounted under it to house a scanner. This was strongly resisted but Cherwell immediately reported it to Churchill and an aircraft fitted with a cupola arrived at Hurn on 27th March! A three-foot wide scanner was designed and installed, and using the basic transmitter and receiver units designed for the AI, the first successful airborne trial was made on 16th April 1942. This gave ranges of about 5 miles on towns from a height of 8,000ft.

Much development was needed to provide the range of 15 miles from 15,000ft altitude, which the RAF needed. This was made more difficult by the prohibition imposed, at an early stage, on the use of magnetrons over enemy territory. Intensive development of klystrons was undertaken, but even though much higher powers were obtained and other difficulties overcome, the performance achieved did not reach the minimum set by the RAF for effective operational use. The programme was then hit by an overwhelming tragedy just after our move to Malvern. On 7th June the Halifax crashed in South Wales, killing five of the small team and wrecking the equipment. Nevertheless, the pressure of demand increased and Churchill, after reviewing the situation on 3rd July, ordered an all-out effort to be made to fit two squadrons of heavy bombers with H2S by October. Then on 15th July the Secretary of State ruled that magnetrons could be used over enemy territory if the operational situation justified the risk.

Development went ahead with gradually improving performance through many "Marks", and at shorter and shorter wavelengths. H2S played a crucial role in Bomber Commands attacks. These could now be made with high accuracy through 10/10ths cloud and at night.

Countermeasures

During in the development of the Chain, Tizard and Rowe had been very concerned about the possible effect of jamming and other countermeasures upon the operation of RDF. Early on Rowe had told E.K. Williams to get in an aircraft and "do his worst" to jam the system and Cockroft had been invited to get the researchers at the Cavendish to consider the possibilities of jamming. When war started we quickly became involved in helping to analyse the radio signals emanating from the enemy, and to devise means of jamming or spoofing their stations. This activity at TRE was brought together under the title "Countermeasures", with Cockburn (Sir Robert) in the lead. RAE also set up a team. It soon became evident that most of the developments in RDF and radio systems were vulnerable to interference, deception and manipulation, and it was a rude shock to designers to discover how quickly performance in the laboratory could be nullified in operation against a resourceful enemy.

From reconnaissance, intelligence and listening, we were already aware of German Radar - early warning, tracking and airborne - but it was the German navigation and bombing beam systems that first demanded our counter offensive. The first system, code-named Knickebein, used beams that crossed over the target. The centres of the beams were defined by the merging of dot and dash modulations into a continuous signal. Radiating additional dashes that destroyed the accuracy easily fooled these. The Germans soon replaced this system by one on a shorter wavelength that used a bombing computer in the aircraft. We developed new jamming transmitters that neutralised this system too. A third, and much more complex system, was introduced in the spring of 1941. It was countered by adding a similar modulation transmitted from the Alexandra Palace Transmitter!

Our bombing of Germany was building up and our bombers needed protection against the German Radars. Airborne noise jammers were developed for the early warning "Freyas" and the tracking "Wurzburgs". But the most effective counter to centimetric equipments was "Window" or "Chaff". In this, packets of half wave "dipoles" cut from metalised paper or metal foil, when dispersed from aircraft, could simulate many other aircraft and confuse or saturate the radar displays. The first trial was carried out using metal dipoles cut out by hand by Mrs (now Lady) Curran. By March 1942 its effectiveness had been well demonstrated but its use operationally was delayed for fear of similar reprisals until July 1943 when we had helical scanned AI MkX equipments in service. Work on all aspects of countermeasures intensified on both sides and reached its peak in the spoofing and jamming done for D-Day and during the invasion.

IFF

A problem that became more and more significant as the war progressed was the need to distinguish friend from foe without visual contact. Early equipments ("broody hen") had been designed which would modify the signal returned from an aircraft target by using a small receiver and transmitter (transponder). This could pick up the RDF pulse from a Chain station and retransmit a lengthened version of it that would show up on the ground display. With this arrangement different transponders were required for each RDF frequency - a daunting proposition. It was therefore decided that a special frequency should be used for a "universal" system, and a team was set up under BV Bowden (Lord Bowden of Chesterfield), and IFF Mks I and II were developed. The team moved to Washington when close co-operation with the USA started as a result of the "Tizard Mission" in September 1940.

The Tizard Mission to USA

By the middle of 1940 it had become clear to Tizard and many others, that though the UK had some first class research teams we were woefully short of facilities for development and production. He persuaded the War Cabinet that we should share our defence secrets with the United States of America in the hope that they would provide help in the development and production necessary to meet our war needs. He got blanket authority from Churchill to disclose everything and a mixed civilian and service team was formed with Tizard in the lead. Cockroft, Bowen and Woodward-Nutt were the other civilians and they were accompanied by Col. F.C. Wallace - back from Dunkirk, Capt. H.W. Faulkner, RN, and Grp. Capt. Pearce from Coastal Command.

The Mission arrived in Halifax on 6th September 1940 and Tizard decided to "lay all the cards on the table" with no attempt to trade secret for secret. The Americans heard the civilians speaking with authority on the equipments and systems and their Service friends following with their practical experiences. Any initial doubts by the Americans were soon dispelled and they responded with great speed and enthusiasm. The secrets of our RDF developments including actual equipments (except for Gee because of jamming worries) were all handed over, also many other items such as a jet engine and a proximity fuse. Our trump card was undoubtedly an early production magnetron. This was left at Bell Laboratories on 3rd October, and Bowen saw it working there five days later. It increased by a factor of 1,000 the power available to them on the centimetric wavelengths they had been trying to develop.

A very important unofficial meeting was at a weekend party for Cockroft and Bowen in Alfred Loomis's house on 28th/29th September. Loomis was Chairman of the NRDC Committee on microwaves and he had collected together small party of experimenters who had been working on 10cm wavelengths. The magnetron opened new vistas for them and Loomis proposed the formation of a microwave laboratory, based on the TRE model, to concentrate on the new possibilities. It was agreed that night attack was the UK's direst peril and the first objective should be a centimetric AI. The helical scan system described by

Bowen was considered attractive. Cockroft's suggestion of a centimetric Gun laying equipment was also met with great interest.

The "Radiation Laboratory" was set up within a few weeks. It subsequently played a major role in close co-operation with the UK research and development teams and a section of it joined TRE. Both the AI and Gun-Laying equipments were developed and subsequently played very significant roles in the later stages of the war.

Tizard returned to the UK on 2nd October and Cockroft took the Mission to Canada. He proposed that the Canadians should put the British ASV into production, co-operate with the Radiation Lab in the development of centimetric equipments, and themselves develop a centimetric gun-laying radar to provide for blind firing. This they did, and the ASV was available in North America at the time of Pearl Harbour.

Bowen stayed in the USA; played a major part in setting up the Radiation Laboratory and in the arrangements for developing and producing versions of the equipments we had handed over.

Support and PDS

Within TRE, many specialist teams were set up to handle basic investigations, develop common components, test gear and circuits for general use, and to provide services such as mathematical investigations and aerial design. These were to support the development of the widening range of equipments. In addition, of course, there was a drawing office to help turn concepts into manufacturable form, and work shops to make the experimental equipment. Firms were brought in as early as possible to engineer experimental designs for production, and as they learnt about the new techniques, to take responsibility for some initial design. All these activities were supported by an administrative system, security and police and many other activities such as “riggers” for erecting towers and aerials, a “heavy gang” to move things about, cleaners, telephone service and a library to deal with technical books and reports etc.

For the RAF it became clear that quite a small number of equipments made to exploit a new concept could have a major effect on their operational success. These early equipments were often little more than lab experimental models and members of the scientific staff would be sent out with an equipment to set it up and make sure it operated when required! This activity continued to be of vital help, even when improved designs had been made, and so a special team was built up for this purpose. This was called "Post Design Services". A special workshop "The Radio Manufacturing Unit" (RPU) was set up North of Bournemouth by Sieger, who headed our design and workshop teams, to make pre-production quantities of equipments to achieve the earliest possible introduction into Service.

Our rapid expansion with staff from Universities, the Post Office, the Services and elsewhere, made things very tight at Worth and when we began to attract bombing and machine gunning raids, two schools, Leeson House and Durnford in Langton Matravers were requisitioned. Rowe and Lewis with the top administration moved to Durnford and the bulk of the centimetre work to Leeson. It had been found that training in the use and maintenance of the equipments in Service was a crucial part of making them operationally effective. Another school, Forres in Swanage, was also requisitioned and became a training school for the Service operators and maintenance staff as well as our own people. This was set up by Ratcliffe, and when he went to do the same task for the Army at Petersham, was taken over by Huxley (Sir Leonard). A mixed civilian and service teaching staff was set up. Section Officer Renie .... (Lady Adams) was one of the first WAAF instructors we trained to teach there, and there was a constant flow of courses of all kinds.

To help with teaching and training, both at TRE and at Service Units, Dummer was building up a team to design and develop simulators and training equipments. Many other tasks were also being undertaken by small teams, such as message decoding, the development of radio altimeters, airborne and ground beacons to respond to Radar signals and research into methods of landing aircraft "blind".

The Bruneval Raid

In February 1942 Don Priest, one of the early team, donned a Flt Lt uniform to go as the technical brains of a raiding party tasked to bring back the most significant parts of a German RDF station which had been photographed at Bruneval. He was ordered to remain on the landing craft to reduce the risk of him being captured. Under his direction a lot of very important pieces of the equipment were brought back to TRE. We were shocked at the high quality of the engineering. How fortunate it was, as we found out after the war, that the relationship between the German Forces and their scientists were those of master and servant, and the views of the civilians on operational matters were not wanted! This was in sharp contrast to the very close co-operation that had evolved between TRE and the RAF. Very fortunately for us, the German equipment, thought excellently engineered, was not operated in a way that would make full use of its undoubted potential.

The Move from Purbeck to Malvern

Shortly after this it became known that a Parachute Division had been assembled on the Cherbourg peninsular and it was widely believed, by the Prime Minister and Cabinet, that they intended to descend on TRE to capture us and our equipment. Night after night the trailers holding the centimetric equipment being worked on at Leeson were driven out of Purbeck and brought back the next morning! At the end of April the team leaders were called together and told that we had to leave before the next full moon! Malvern College had been chosen for our new home, and a few of us went straight up there to plan and arrange the modifications - benches, power supplies, telephones etc. - to convert the buildings into laboratories. Pickfords arrived in force; we packed up, and after one false start, left for Malvern early in May.

About 200 people came in May 1940 and around 2,000 left in May 1942! In Malvern the Establishment grew to nearly 4,000 and continued to play a crucial role in the conduct of the war. Except for the initial work on the Chain our time in the Swanage area is judged to have been the most significant and creative period in the history of RDF or RADAR as it is now called. It played a major part in winning the battle against the night blitz and a crucial role in the battle of the Atlantic and provided a sound foundation for the future developments that played so important a role in the invasion on D-Day and in the battle to regain Europe.

Subsequent developments such as Air Traffic Control, Storm Warning, Weather Radar and Guided Weapons together with a myriad of other electronic developments such as microchips and computers grew out of the activity. The techniques were used by many of the Scientists when they returned to their own research fields, to very great advantage. Several became Nobel Prize Winners and achieved the highest eminence in the World of Science.