CHAPTER 19

RADAR

ON 24th February 1939 the Prime Minister, Mr Lyons, received the following cable from the Australian High Commissioner in London: "Conversations have been carried on from time to time with the Air Ministry on the subject of secret research. They culminated today in the disclosure to the High Commissioners of a new development in defence applicable particularly to air but also probably capable of development for other services. The High Commissioners have been informed that if their Governments send their best qualified physicist to England all information will be placed at his disposal for secret report to Dominion Governments. Utmost secrecy is essential and the choice of a man of the greatest discretion important. I am satisfied that the new development which is the product of the best scientific brains here is of great significance and that the Commonwealth of Australia should be fully advised in relation to it. If you decide to send a man the idea is to attach to him either air or military liaison officer or both in order to obtain knowledge of service operation as well as scientific application of the new development. Utmost secrecy is imposed hence the absence of fuller information here. Air Ministry attaches such importance to it that they ask that details be not communicated by letter. Other High Commissioners are communicating similarly to their Governments."

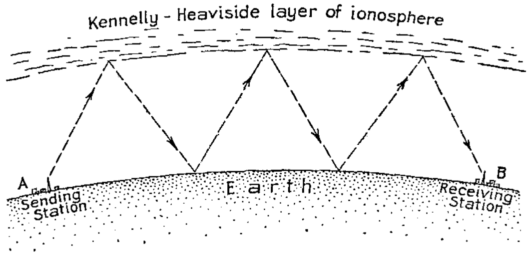
The Prime Minister sought the advice of the Council for Scientific and Industrial Research, and on the recommendation of its chairman, Sir David Rivett, he chose Dr Martyn,[1] an outstanding physicist and officer of the Radio Research Board, for this important mission. To appreciate what lay behind the High Commissioner's cable and to gain some idea of the nature of the discovery that had been engaging the attention of the British Air Ministry for about five years, it is necessary to glance briefly at some of the early history of radio-communication.

When in 1902 Marconi astonished his fellow men by transmitting radio signals 2,000 miles across the Atlantic Ocean, he also greatly puzzled scientists for it was known at the time that radio waves, like light waves, travelled in straight lines through homogeneous matter. What made radio waves follow the curvature of the earth rather than shoot off into outer space was the puzzling question. It was not long before an answer to this problem was given independently by Heaviside in England and by Kennelly in the United States, both of whom suggested that radio waves were reflected by an electrically-charged (ionised) layer of the upper atmosphere[2] acting like a mirror so that the waves reached a distant station

[1] D. F. Martyn, FRS, DSc, PhD. Chief, CSIR Radiophysics Laboratory, 1939-42; Director, Army Operational Research Group, 1942-44; Chief Scientific Officer, Radio Research Board, since 1945. B. Cambuslang, Scotland, 27 Jun 1906.

[2] Later this layer came to be known as the ionosphere.

by a series of reflections from earth and sky, as shown in the accompanying diagram. That this was indeed the correct explanation was demonstrated experimentally by Appleton in England and by Breit and Tuve in the United States, who, in each instance, used the known speed of radio waves to calculate the height of the reflecting layer above the earth's surface. This distance was estimated to be about 60 miles (100 kilometres). Owing mainly to its intimate bearing on problems of long-distance radio-communication, but also because of its purely scientific interest, the nature of the ionised reflecting layer began to be intensively studied all over the world. It was while engaged on some experiments of this kind in December 1931 that several British Post Office engineers noted, more or less by accident, that radio waves were also reflected by an aircraft in flight several miles away. This observation was in due course published,[3] and in the following year was confirmed by engineers of the Bell Telephone Laboratories in the United States.[4]



British defence authorities, faced with the threat of another European war, were deeply concerned about the difficulties of defending the country from great fleets of bombing aircraft. Attacks might be made anywhere on Britain and it would be impossible to fend them off without a vastly greater force of fighters than the Royal Air Force was likely to possess in the foreseeable future.

Perhaps no one was more convinced of the overwhelming importance of air defence than Sir Henry Tizard,[5] a scientist who had served with distinction in the R.A.F. during the war of 1914-18. Tizard called together a committee of physicists to discuss the question of Britain's air defence, and out of their deliberations came a statement of what they regarded as the basic problem: how to obtain adequate warning of the approach of hostile aircraft.

The problem was put to the Director of Communications Development at the Air Ministry, Mr (later Sir) Robert Watson-Watt, who, with the earlier observations of the Post Office Engineers in mind, suggested that it could be solved by the use of radio waves. To test this proposal he immediately set about devising equipment for the study of the reflection of radio waves by aircraft, a task for which he was well prepared since he

[3] F. E. Nancarrow, A. H. Mumford, F. C. Carter and H. T. Mitchell, *Post Office Radio Report* No. 23, Pt V, 3 Jun 1932.

[4] C. R. Englund, A. B. Crawford and W. W. Mumford, *Proceedings of Institute of Radio Engineers,* Vol. 21 (1933), p. 475.

[5] Sir Henry Tizard, GCB, AFC; FRS. (RGA and RAF in first world war.) Rector, Imperial College of Science, 1929-42; President, Magdalen College, Oxford, 1942-46; Chairman, Aeronautical Research Committee, 1933-43; Member of Council, Ministry of Aircraft Production. B. 23 Aug 1885.

had for some years been studying the reflection of radio waves from the ionosphere. It was well known that radio waves would penetrate darkness, cloud and fog,[6] but the problem of detecting an object as small as an aircraft at a distance of 100 miles was a formidable one. At that distance an aircraft would intercept only a tiny fraction of the radiation sent out from the transmitting station and this fraction would be correspondingly diminished when, after reflection, it reached a receiving set adjacent to the transmitter. A rough calculation showed that to achieve detection at this distance a radio receiving set would have to be capable of detecting about one million million millionth of the energy originally sent out by the transmitting set. Transmitters available in 1935 were capable of an output of 10^4 watts; receivers were sensitive to between 10^{-12} and 10^{-13} watts. These figures had to be raised to somewhere in the vicinity of 10^5 and 10^{-14} respectively if there was to be any hope of success. It is a tribute to the pioneers in this field of radio investigation that they persisted in the face of such unfavourable odds.[7]

The concept of radar, born of research into the nature of the ionosphere, appears to have occurred simultaneously and independently in Britain, the United States and Germany, but because of its important military implications it was developed under a heavy veil of secrecy. That each country should have arrived at much the same solution to the problems of military use of radio waves is interesting testimony to the inevitability of scientific discovery once the time is ripe for it, and to the futility of trying to keep fundamental discoveries secret for long. The need to develop a weapon of this kind was most acutely felt in Britain, and that is probably the main reason why it reached its greatest heights there quite early in the war.

In June 1935 Watson-Watt, working with a small team of collaborators,[8] observed radar[9] echoes from an aircraft in flight at a distance of 17 miles. This range was achieved essentially by concentrating the radiation sent out in short bursts or pulses of high energy. Further experiments by Watson-Watt and his team rapidly improved on this performance until an aircraft could be detected 100 miles away, and its distance and position could be measured. The distance, or range, was found by measuring the time it took radio waves to travel from the transmitter and back again to the adjacent receiver. The technique used for measuring the exceedingly small period of time involved was similar to that used for measuring the height of the ionospheric reflecting layer.[1] The time required for radiation transmitted in the form of rapidly repeated powerful pulses lasting only

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[6] The shortest radio waves (shorter than those generally used in radar) do not readily penetrate all types of cloud.

[7] E. G. Bowen, "The Uses of Radar in War". Univ of Sydney Engineering Club Annual War Memorial Lecture, 1946.

[8] This team included Dr E. G. Bowen, who later became Chief of the Radiophysics Laboratory.

[9] This method of locating objects was at first called radio location, or radio direction finding (R.D.F.). The term radar was introduced much later by the Americans. Although the term R.D.F. occurs frequently in the earlier accounts of work done in Australia, to avoid confusion the term radar will be used throughout the chapter.

[1] The method is discussed in Chapter 21.

a few millionths of a second to travel to and from the reflecting aircraft, was registered on the fluorescent screen of the cathode ray oscilloscope.[2] The distance of the vertical trace, or "blip", produced by the reflected radio waves from a zero point 0, was a measure of the distance of the aircraft. The scale was calibrated in miles or thousands of yards.

Aircraft were of course not the only objects capable of reflecting radio waves; ships at sea, and in fact all electrically conducting bodies, possessed this property to varying degrees. The method used by the early "chain" stations in England to obtain the bearing of a reflecting aircraft, for example, was to set two fixed receiving aerials at right angles to one another; its angle of elevation was determined by means of two identical aerials placed one above the other.[3] In order to attain the maximum range for detection of bombers flying at a medium height, transmitting and receiving aerials of the early-warning radar stations that ringed England on the outbreak of war were mounted on very tall lattice towers. From a military point of view it was unfortunate that the towers had to be so conspicuous, but strangely enough the Germans did not single them out for attack. From these towers radio waves were transmitted more or less equally in space, thus "floodlighting" the surrounding region. Standing on guard continually, day and night, this chain of radar stations was a decisive factor in winning one of the great battles of the war, the Battle of Britain.

This, then, in barest outline, was the remarkable and highly secret defence project into the techniques of which Martyn was to be initiated. In company with representatives from other Dominions he visited research establishments of the fighting services and also many of the coastal defence stations to study the system in operation during manoeuvres and the general problems of its tactical employment. He also took part in preliminary discussions on the role Australia was likely to play in radar: whether it would be the passive one of receiving equipment from Britain and merely distributing it or copying it; or whether it would be the more active and positive role of undertaking a program of research designed to fit in with the British efforts. Numerous developments in radar, adapting it to different kinds of military operational requirement, were to take place in the war years, and the decision ultimately arrived at, that Australia should undertake research and development as well as manufacture, was a most fortunate one. Conditions for military operations in the South-West Pacific Area were to prove so different from those in Europe that equipment well adapted for the latter was quite unsuitable in the Pacific theatre.

An important factor influencing the decision to make Australia a radar research centre was the circumstance that Australian physicists had for

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[2] Radar technicians and others often referred to this as the radar "scope". It later became familiar as the screen of the television receiver.

[3] It is quite impracticable to describe these techniques in detail here. The reason for introducing any technical detail is to enable a description to be given of what radar did and its operational significance.

many years taken an active part in the study of the ionosphere, atmospherics and radio-propagation in general. Interest had first been inspired by Professor Madsen in Sydney and Professor Laby in Melbourne, who in 1924 had, with the help of funds provided by private broadcasting companies (2FC and 3LO), arranged for the establishment of fellowships to enable promising students in physics to undertake research. Sydney was to be the centre for the study of the ionosphere, and Melbourne for the study of atmospherics. This was only a beginning. The C.S.I.R., having obtained the promise of cooperation from the universities, the P.M.G. Department and the Services, set up the Radio Research Board under Madsen's chairmanship, with the object of greatly extending the field of radio investigations. For many years to come Madsen was to play a leading part in the encouragement of radio research in Australia.

From the very beginning of its activities the board planned its program of basic scientific research on the assumption that sooner or later the information thus gained would have important practical applications. In its planning it was fortunate in having the wholehearted and enlightened support of Mr Brown,[4] Director of Posts and Telegraphs. As a civil servant in charge of a public utility concerned, among many other things, with radio communication, he might have limited his support to projects assured of practical usefulness; instead, he encouraged to the fullest extent studies directed to a fundamental understanding of the ionosphere and the propagation of radio waves. This policy did eventually yield results of the greatest practical importance in radio communication, but its more immediate consequence was that it brought together a team of highly-trained scientists with a well-established reputation for research on the ionosphere to whom the techniques of radar could be readily and effectively communicated. Australia was therefore peculiarly well fitted to act not only as a subsidiary centre of radar research but as the leading one in the British Commonwealth should disaster have overtaken Britain itself.

Having sent on ahead a detailed report on the subject of radar to the Prime Minister, Martyn set sail from England on 22nd June 1939 armed with voluminous reports and blueprints and a number of important radio valves.[5] Soon after his return to Australia he was called to a conference with Sir David Rivett, Professor Madsen and Sir Harry Brown. On the basis of the information provided by the British Government the conference drew up comprehensive research and development plans for the benefit of the Australian Services. These included a recommendation to the Commonwealth Government for the establishment by the C.S.I.R. of a Radiophysics[6] Laboratory, the policy of which was to be the responsibility of an advisory board consisting of representatives of the three principal interests: scientific research, development and production, and the

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[4] Sir Harry Brown, CMG, MBE. Director-General of Posts and Telegraphs 1923-39. C'wealth Coordinator-General of Works 1940-45; Chairman, British General Electric Co Pty Ltd, Sydney, 1939-53. B. Hylton, England, 28 Dec 1878.

[5] A number of complete equipments were sent to Australia separately.

[6] This name was invented to draw as little attention as possible to the laboratory's real purpose.

user.[7] After this scheme had been laid before the Chiefs of Staff of the three Services and had been approved by them, it was sent forward to the Federal Cabinet. At an informal meeting in Canberra, Rivett, Madsen and Martyn had no difficulty in persuading the Cabinet of the importance of radar for the defence of Australia and in obtaining a prompt acceptance of the scheme as it stood, together with an authorisation to spend approximately £80,000 on buildings, workshops and equipment. Owing to the need for secrecy no record was ever kept of the proceedings of this meeting.

The Radiophysics Advisory Board held its first meeting on 29th November 1939 and at this meeting authorised work on the first defence projects.

In order to provide a building for the work, it was decided to extend the National Standards Laboratory, the first portion of which had just been completed. This plan had the advantage of making the installation of a laboratory for secret work a little less conspicuous than it might otherwise have been. Its construction was pushed ahead with great speed and by the end of March 1940, thirteen weeks after the foundations had been laid, the building was sufficiently near completion for the staff to begin moving in.

The staff had not been idle in the meantime; facilities for the earliest work had been provided by the Electrical Engineering Department in the University of Sydney. The nucleus of a staff had been rapidly recruited from officers of the Radio Research Board and from a number of physicists who had been trained during their earlier association with the board but who had gone into the radio industry, the Commonwealth Solar Observatory or other establishments.

The relatively advanced state of television broadcasting in England just before the war had exercised an important influence on the development of radar since many of the techniques were readily adaptable. Among the recruits to the laboratory's staff was Dr Pawsey,[8] who had for a numbet of years been employed by Electrical and Musical Industries Ltd, the firm that was chiefly responsible for the development of television in Great Britain. The rest of the staff was made up of men who had recently graduated from university departments of physics and electrical engineering.[9] The staff was essentially one of young men, since the science of radio itself was young and younger men were mainly responsible for its develop-

[7] Members of the board at its first meeting were: Chief Executive Officer of CSIR (Sir David Rivett); Chairman of Radio Research Board (Prof Madsen); Director of Posts and Telegraphs (Sir Harry Brown); the three Chiefs of Staff (Vice-Admiral Sir Ragnar Colvin, Lt-Gen E. K. Squires and AVM S. J. Goble); Mr G. A. Cook was secretary. There were many changes on the board. Sir Charles Burnett replaced AVM Goble when he became Chief of the Air Staff. Similarly Maj-Gen J. Northcott replaced Lt-Gen Squires. Prof F. W. G. White served as chairman in place of Prof Madsen from 21 May to 10 Dec 1941 during the latter's absence overseas and became Deputy Chairman on his return. The appointment of Sir Guy Royle as Chief of the Naval Staff involved another automatic change in membership. In July 1942, in view of the possible importance of Australian radar activities in helping the U.S. forces, Maj O. Quanrad attended the meeting of the board, and from that time onwards American representatives took part in the deliberations which were of interest to them.

[8] J. L. Pawsey, FRS, PhD, MSc. Research physicist, EMI Ltd, England, 1934-39; since 1939 research physicist Radiophysics Lab, deputy chief since 1951. Of London; b. Ararat, Vic, 14 May 1908.

[9] In the first year of its operation the Radiophysics Laboratory had a staff of 5 research officers and 8 assistant research officers, with Dr Martyn as Chief of the Division.

ment, both in Australia and overseas. The training in fundamental physical research in communication engineering and electronics provided by Australian universities in the pre-war years, especially at Sydney, proved an excellent preparation for the men needed for this wartime activity. Indeed it is doubtful whether the extensive work which Australia undertook in radar would have been possible had research in allied fields of pure science not been fostered in the earlier years.

On the outbreak of war, and with the consequent dislocation of supplies, the Radiophysics Advisory Board decided that a representative should be sent to Great Britain to discuss future Australian developments and cooperation between the two countries, and also to arrange for the supply of complete units and essential parts. Madsen therefore made a hurried visit to England in December 1939. In discussions with Tizard, Watson-Watt and others he was able to have clarified the functions of the Radiophysics Laboratory. A memorandum was drawn up setting out its role in some detail. To make the best use of the limited number of appropriately qualified physicists in Britain and Australia, and to avoid serious overlapping of work, its research program was to be mapped out in consultation with leaders at the chief centre in Britain: the Telecommunications Research Establishment.

The principles to be followed in this collaborative effort were set out in a document which was presented to the Assistant Chief of the Air Staff, Air Marshal Sir Philip Joubert de la Ferté and communicated to the Secretary of State for Air, Sir Kingsley Wood. The document formed the basis for recommendations from the Air Ministry to the Governments of Australia and New Zealand. The Radiophysics Laboratory was also to obtain and hold reserves of essential parts, technical information and manufacturing designs; to act as a distributing centre for information and as a liaison office. Should the need arise it was to serve as the nucleus of an effective centre of production for the Eastern Group.

While in England Madsen laid the foundations for continuing close liaison between British and Australian scientific authorities in radar research by setting up the Australian Scientific Research Liaison Office in London with Mr Munro[1] as officer in charge.[2] Munro's duty was to keep Australia informed of the latest radar developments in Britain, to buy equipment, and to distribute reports of Australian work wherever they were required. On Madsen's initiative similar liaison centres were established in 1941 in Ottawa and in Washington.

As the potentialities of radar came to be realised, British scientists began to develop it for other operational uses than the early warning of approaching aircraft. Equipment embodying some of these advances was sent to the Radiophysics Laboratory and provided a great deal of information that was of the utmost value in initiating work in Australia.

[1] G. H. Munro, DSc. Research officer Radio Research Board 1929-39; Scientific Liaison Officer London 1940, Washington 1941-45; Officer in charge Radio Research Board Sydney since 1947. B. Clevedon, NZ, 23 Feb 1901.

[2] Others who held this office were Dr H. C. Webster (May 1941 to Jun 1943), Mr F. G. Nicholls (Jun 1943 to Sep 1944) and Mr G. B. Gresford (from Sep 1944).

With the release of information by Britain, the establishment of adequate personal contacts between research centres in Britain and Australia, the provision by the Australian Government of adequate scientific facilities, and arrangements for close collaboration between the Services and the research organisations, a sound foundation was laid for the development and manufacture of radar equipment in Australia.

At the second meeting of the Radiophysics Advisory Board, held on 13th March 1940 soon after Madsen's return from England, the program planned with British authorities for work in Australia was submitted for consideration and was approved. The board sent forward a recommendation to the Government that the Services should send officers to the United Kingdom to learn the operational uses of radar.

Early in 1940 it seemed unlikely that Australia would be subjected to either aerial bombardment or invasion. What seemed more probable was an attack on coastal cities and defences by cruiser squadrons, submarines, or isolated surface raiders. It was therefore decided to investigate equipment for shore defence and gunlaying. Neither the navy nor the air force was greatly concerned about the local development of radar equipment at this juncture; each hoped that it would be able to obtain all the radar equipment it needed from the United Kingdom. The army, on the other hand, in the person of Colonel Whitelaw,[3] commanding the coast defences in Eastern Command, displayed great interest; it was more through his encouragement and his great keenness to have some substitute for optical range finders, then in short supply, than from purely tactical considerations that the first work undertaken by the laboratory was the construction of a coast-watching or Shore Defence (Sh. D.) set. At the army's request the laboratory also began experimenting with air-warning equipment.

The development of the Sh.D. equipment established a pattern for all future activities of this kind. By close collaboration with the Services, in this instance the army, the operational requirements of the equipment were ascertained and the laboratory set to work to find out how far these requirements could be met with the existing radar techniques. A prototype model was then built and tested to make sure that it met operational requirements. For security reasons the manufacture of the equipment was at first confined to the P.M.G's Department.

The operational requirements of shore defence and of early air warning equipments were quite different from one another. The object of an early air-warning set was to detect approaching aircraft at a distance of about 100 miles. Range and bearing accuracy were of secondary importance, so long as they were sufficient to enable an estimate of the speed and course of the approaching aircraft. A shore defence set, on the other hand, was designed to warn coastal defences of the approach of surface vessels at about 20 to 30 miles and to assist gunlaying by finding the ranges of the vessels as accurately as possible. The differences in these two operational requirements were such as to call for radically different design. One set

[3] Maj-Gen J. S. Whitelaw, CB, CBE. (Served 1st AIF.) MGRA, LHQ, 1942-45. Regular soldier; of Upper Beaconsfield, Vic; b. Hawthorn, Vic, 26 Aug 1894.

had to detect a small object at a great distance and altitude; the other a much larger object on the surface of the sea and at a smaller distance. The shape and volume of surrounding space in which a radar equipment could detect a given target depended very much on the design and power of the equipment. Two principal systems of locating a target were in use: in one a relatively narrow beam of radio waves was moved systematically in a scanning process in much the same way as a searchlight; in the other the radar waves had a much wider spread, illuminating all the space to be searched simultaneously after the manner of floodlighting. The British Chain Home stations employed the floodlighting system; all Australian radar equipment was based on the scanning beam technique because of its greater economy in power.[4]

Though it naturally contained features of British equipment, the Sh.D. set was new in its synthesis of these features. It embodied one specially important innovation in its aerial system. Sets with a similar function in England had their transmitting and receiving aerials on separate towers 120 feet high. Pawsey, with the assistance of Minnett,[5] invented a system whereby one tower and one aerial were used for both transmitting and receiving. This enabled a notable saving, since each tower cost about £50,000. The Shore Defence station at Dover Heights, New South Wales, was the first in the British Commonwealth to be equipped with this type of aerial system. The arrangement was adopted in England for naval equipment and later underwent considerable improvement at the Telecommunications Research Establishment. In its improved form it returned to Australia. Quite independently a similar aerial system was developed in the United States. With a subject developing as rapidly as radar was then, simultaneous discoveries were neither unusual nor surprising. There was so much interchange of personnel and ideas that it was sometimes difficult to be sure where a discovery did originate.

The Sh. D. set operated at 10 kilowatts on a wavelength of 1.5 metres (200 megacycles). The short duration of the pulses of radiation employed (one millionth of a second) made it possible not only to discriminate between two ships if they happened to be fairly close together, but also to fix the range of a ship to within about 25 yards up to a distance of about 40,000 yards (about 23 miles). Discrimination and accuracy were gained at a sacrifice of range of detection, which meant that if the set were employed to detect aircraft its range was restricted to about 30 miles, which was totally inadequate for air warning. Sh. D. was greatly superior to the optical rangefinder, both in its range of operation and accuracy, and in the fact that it could operate in darkness and fog. Its coverage was attained by oscillating or rotating its narrow fan-shaped beam so as to cover an arc of about 180 degrees. A prototype of the Sh. D. set built in the Radiophysics Laboratory was erected for test on the army

[4] The analogy between radar and floodlighting and searchlight scanning breaks down at one point: visible light falls in a continuous stream, whereas in radar the radiation is discontinuous, taking the form of a succession of powerful pulses of short duration.

[5] H. C. Minnett, BSc, BE. Research officer, Radiophysics Lab, since 1940. Of Sydney; b. Sydney, 12 Jun 1917.

testing ground at Dover Heights, and during its first trials in May 1940 it picked up a ship off Port Stephens, a distance of about 90 miles.[6]

In February 1941 an "all radar" shoot with 9.2-inch guns and Sh. D. equipment, perhaps the first of its kind in the world, was held at North Head, Sydney. No suitable ship being available, a small improvised wooden target, fitted with a transmitting set to give the equivalent of a radar echo from a ship, was towed out to sea. When the order to fire was given, blips caused by shells falling near the target appeared almost simultaneously, just where they should have appeared, on the radar scope. The demonstration, successful beyond all expectations, made such an impression on army officers from Malaya who happened to be present, that they began making representations to have similar equipment sent to their own theatre. In August 1941 Dr Piddington,[7] a senior officer of the Radiophysics Laboratory, visited Malaya, Burma and Hong Kong to select sites suitable for Sh. D. and G.L. (Gun-laying) equipment; he was followed by a second officer, Mr Alexander,[8] who arranged the engineering details. All this effort came too late, though there is no reason to believe that the installation of radar equipment would have either delayed the fall of Singapore or made any significant difference to the course of the disastrous Malayan campaign.

While these negotiations had been going on, the manufacture of Sh. D. sets was making good progress. By this time the P.M.G's Department had arranged for commercial industry to manufacture some component parts of the equipment. A first instalment of seventeen sets had been ordered from the P.M.G's Department and a careful survey of the mainland coast to find suitable sites for their installation had been made by Whitelaw and two members of the laboratory.[9]

The army was well satisfied with the Sh.D. equipment and the whole coastline seemed to be reasonably well covered except for one region. Among the places at which it was intended to install the Sh. D. equipment was Darwin, but although Darwin was an important naval refuelling base, it was some time before any headway was made in providing it with an air-warning station. There were arguments as to which Service should bear the expense of the installations, and when war broke out with Japan Darwin still had no radar defence worth the name.

The new phase of the war brought a rapid change in the tempo of work on radar. By now the laboratory had gained useful experience in the general techniques since several other projects had been under investigation. For instance, an Air to Surface Vessel (A.S.V.) set designed for installation in aircraft for the purpose of scanning the open sea for enemy

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[6] This unusually great range was probably due to atmospheric refraction, which is discussed later in this chapter.

[7] J. H. Piddington, PhD, BE. Research officer, Radiophysics Lab, since 1940. Of Sydney; b. Wagga, NSW, 6 Nov 1910.

[8] T. B. Alexander, BSc, BE. Research officer, Radiophysics Lab, 1941-45. Of Sydney; b. Sydney, 27 May 1915.

[9] In all 37 Sh. D. sets were built, at a cost of approximately £290,000.

ships, had been attempted. The intention was to install it in Beaufort bombers, which were then being made in Australia. Four R.A.A.F. wireless operators were given a grounding in the maintenance and operation of the set—the first R.A.A.F. radar operators to be trained in Australia. After the A.S.V. set had been tested with their help it was abandoned because it was by then obsolete.

With these early successes and failures radiophysicists had served their apprenticeship, tested and amended their laboratory organisation, and learned much of the difficult arts of scientific team work and cooperation with the armed services. The laboratory was fortunate in having built up so rapidly a strong *esprit de corps* which was to stand it in good stead in the two anxious years to follow. The staff had grown considerably and now numbered forty physicists.

Radiophysics attained the full status of a Division of the C.S.I.R. with Professor White[1] as its Chief. In 1942 Martyn left to become leader of an Army Operational Research Group, and White, who was at the time Deputy Chairman of the Radiophysics Advisory Board, took over the duties of Chief of the Division. For the next four years White, whose high scientific attainments were matched by his administrative ability, guided the work of the laboratory with remarkable foresight. As the laboratory grew it became clear that there was need for a production engineer on the staff, preferably one from the radio industry. The Gramophone Company Ltd at Homebush, New South Wales, agreed to release its factory manager, Mr Briton,[2] to organise this side of the laboratory's activities, and he was appointed Deputy Chief of the Division from 1st June 1943 for the duration of the war. A second Deputy Chief was appointed in January 1944 when by an arrangement with the Air Ministry Dr E. G. Bowen[3] (who was at that time with the Tizard Mission in the United States) was seconded to the Radiophysics Laboratory for two years.[4]

Until 1942 no one outside the Radiophysics Advisory Board, some senior officers of the Services and the staffs of the Radiophysics and P.M.G. Laboratories, knew anything about radar. Effective collaboration with the three Services had yet to be built up and instructional work on a large scale had still to be undertaken. It was clear that there would soon be a demand for radar equipment quite beyond the powers of the P.M.G's Department to supply. The only solution to this problem lay in mobilising the resources of the radio industry, but events moved too rapidly for the research men to wait for the reorganisation of production. As the swiftly

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[1] F. W. G. White, CBE; DSc, PhD. Prof of Physics, Canterbury Univ College, NZ, 1937-42; Chief, Division of Radiophysics, 1942-45; Chief Executive Officer, CSIRO, since 1949. B. Johnsonville, NZ, 26 May 1905.

[2] J. N. Briton, BSc, BE. Works Manager, Gramophone Company, 1938-43; Deputy Chief, Radiophysics Division 1943-45, Chief 1945-46; Technical Director Electrical and Musical Industries, 1946-55; Chief Engineer, Television Corporation Ltd, since 1955. B. Sydney, 25 Dec 1907.

[3] E. G. Bowen, OBE; MSc, PhD. Air Ministry Research Station, Bawdsey, Eng, 1936-40; British Air Commission, Washington, 1940-42; Deputy Chief, Division of Radiophysics, 1944-45, Chief since 1946. B. Swansea, Wales, 14 Jan 1911.

[4] At the end of that time Bowen severed his connection with the Air Ministry and was appointed Chief of the Division.

moving tide of Japanese invasion overwhelmed regions to the north of Australia, the work of the laboratory was intensified. Its great test was about to come.

The best defence against the bombing attacks likely to be launched by the Japanese was to ward them off by means of fighter aircraft. If approaching enemy aircraft could be detected at a distance of 100 miles, sufficient warning could be given to enable fighter aircraft to intercept the bomber force some distance from its target. Since, owing to their high speeds and correspondingly high consumption of fuel, fighters could not remain in the air for long, a great increase in the efficiency of their defensive use could be expected with adequate air warning. These tactics had been thoroughly tried out and proved in the Battle of Britain. In the face of imminent bombing attacks from the Japanese there was therefore an urgent need for an air-warning radar equipment.

Beginning on 7th December 1941 and working at top speed, a group of physicists under Piddington's leadership improvised an air-warning set from component parts then to hand: the modified receiver of an experimental A.S.V. set built earlier in the year, the aerial previously designed for the Sh.D. set, and none-too-powerful valves (type VT.90, later made in Australia) designed for airborne transmitters, where light weight was of first importance. The air warning set was in effect a radically-modified Sh.D. set. Its greater range, secured at the expense of accuracy and of the ability to discriminate between close targets, was obtained by decreasing the band-width of the receiver and at the same time lengthening the transmitted pulse from 1½ microseconds to 20 microseconds. What this amounted to was putting more energy into the bursts of outgoing radiation and making the receiving set more sensitive. Thus it was possible to avoid the need for increasing the power of the set, which owing to the nature of the valves then procurable in Australia was limited to about 10 kilowatts, a figure well below that of corresponding British equipment. After this neat piece of adaptation had been achieved, an adequate range for air warning purposes was obtained, but successful use of the equipment called for considerable skill on the part of the operator. The set used the same frequency as the Sh.D., namely 200 megacycles per second (corresponding to a wavelength of 1.5 metres).[5]

The set was so hastily put together that normal safety covers were omitted and high-tension wires were accessible and a constant danger to the maintenance crew. But although it lacked a neat factory finish, the set was efficient, as it proved within a week by detecting an aircraft about 65 miles off Dover Heights. For many months this was the only means of warning Sydney of the approach of enemy aircraft. Fortunately, though for some time Australia's fate hung in the balance, the bombers never came to Sydney.

Immediately after successful trials, the construction of six more A.W. sets was begun. These sets were built jointly by the Radiophysics Labora-

[5] This frequency band was later used for commercial television in Sydney.

tory and the Gramophone Company Ltd, where at this time Briton had charge of the factory. The laboratory had only a very small workshop, and it was imperative to have more space and assistance. The pressure of events was great and there was no time to waste, so with the concurrence of the Department of Munitions an arrangement was made with the Gramophone Company: some sets were made in the laboratory with men from the factory helping; others were made (by hand) in the factory with the help of men from the laboratory workshop. The first three sets, with a full supply of spare parts, completed by 4th February 1942, were made to a better general design and finish than the prototype. They were installed at Darwin, Port Moresby and Port Kembla; the next three were completed two months later.

The set sent to Darwin was accompanied by technicians of the R.A.A.F., who, though they were without manuals to guide them, felt confident of their ability to operate it. When an attempt was made they failed even to get the set on the air. While they were still trying to get it working the Japanese made their first raid on the town. Surprise was complete and defence so weak—the only serviceable aircraft round Darwin that day were 14 Wirraways, 17 Hudsons, and some American P-40s passing through on their way to Java—that great destruction was wrought by the enemy. Commenting on the failure of the Darwin defences in his report on the Commission of Inquiry, Mr Justice Lowe[6] wrote: "An installation of the type used in Great Britain was at all these times available but it was only on the last date (September 1941) that a decision was taken to erect another unit, which was described in evidence as a makeshift, at Darwin. But even then the question of implementing the decision was apparently treated with a leisureliness out of keeping with the urgency of the occasion."[7]

There were probably a number of reasons for the early failure of radar at Darwin. It is fair to say that it was not due to a lack of technical competence on the part of the radiophysicists, but rather to their inability to convince the Services of the potentialities of radar. To some extent delay in recognising the value of radar was inherent in the general situation at the time, but it was also due to the fact that the laboratory would rush prototype equipments into operational trials before they were really ready for use. Something would go wrong during the trial, and the physicist would put in a condenser here or a resistance there, when everything would be right again. Incidents of this kind tended to shake the confidence of the Service authorities present and to give them the impression that radar was a tricky device that only an expert could handle. Being an extremely closely-guarded secret, the possibilities of radar had not yet been made as extensively and thoroughly known to the Services as they might otherwise have been.

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[6] Hon Sir Charles Lowe, KCMG. Justice of the Supreme Court of Vic, since 1927, Acting Chief Justice 1950 and 1953; Chancellor, Univ of Melbourne, 1941-54. B. Panmure, Vic, 4 Oct 1880.

[7] *Parliamentary Papers* No. 40 (1945).

There was, however, little time for a post-mortem on Darwin's disastrous bombing. Japanese raids continued to occur daily, and without effective opposition, for some time. An urgent call issued to the Radiophysics Laboratory brought Piddington, the group leader of the air-warning project, and an assistant, Mr Cooper,[8] post-haste to Darwin. After some tense days, not made any easier by rumours of an impending Japanese invasion,[9] the air-warning set was got going on 22nd March 1942. Five days earlier a squadron of American P-40s had arrived. The radar had not been long on the air when at 11.30 a.m. the screen showed an aircraft or group of aircraft 84 miles east of Darwin. This was immediately reported to Fighter Operations Room and subsequently a plot of the course was given. The speed was estimated at 160 miles an hour and the height between 12,000 and 14,000 feet. A few minutes later a second indication was obtained 62 miles from Darwin in the same direction. About 20 minutes after the first warning, Fighter Operations said that our aircraft had engaged the enemy, 20 miles from Darwin. A little later the radar station reported numerous indications of aircraft retreating in different directions and at different distances. One Japanese bomber was shot down.

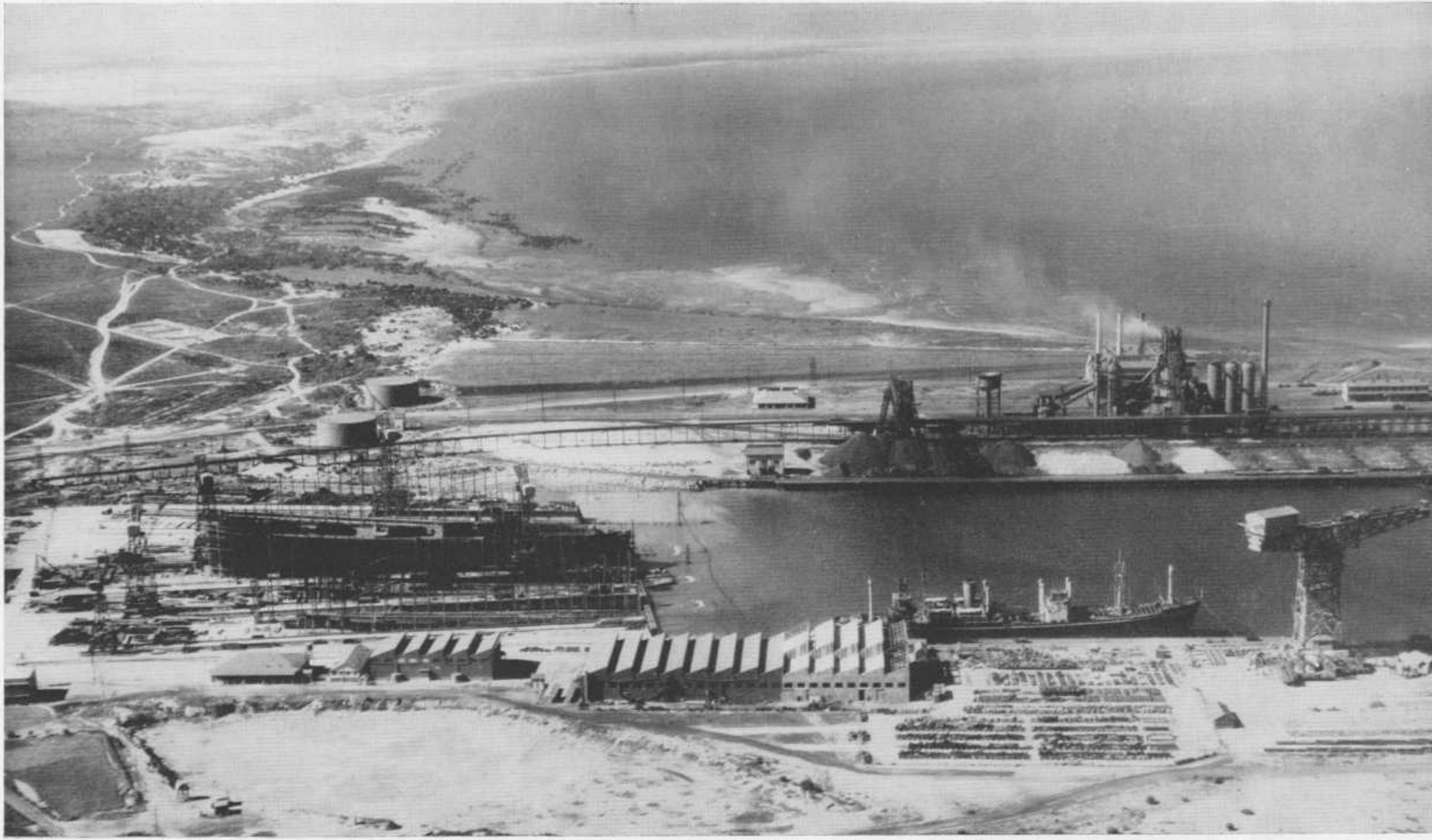
Radar was no longer a new-fangled invention to be regarded with suspicion, but a valuable weapon. Faith in its efficacy grew rapidly, sometimes to limits beyond its deserving. It was well known to the radiophysicists that the air warning set did not, because of the interference of radio waves reflected from the earth, cover regions near the ground. Had the Japanese known this, they could, by flying at a low level, have come quite close in to the target before their presence was detected. Fortunately for Britain, even the German pilots did not know of this trick early in the war.[1] The German pilots did learn it later, and long after the Darwin raids passed the trick on to the Japanese just as their air strength was nearly exhausted.

The only other mainland A.W. station to make contact with the enemy was one at Townsville. An American gun-laying set that had been intended for the Philippines was adapted for air warning by the staff of the Radiophysics Laboratory and sent north. An officer and a party of twelve men were charged with installing and looking after it. This was in the days of extreme secrecy, and the party experienced considerable difficulty with the local commander, who knew nothing about radar. Because members of the installation party were sworn to secrecy they were unable to give a sufficiently convincing explanation of their mission, but eventually they managed to set up the equipment and get it working. With it they observed the first Japanese raid on Townsville—a reconnaissance raid. No guns

[8] B. F. C. Cooper, BSc, BE. Research officer, Radiophysics Lab, since 1940. Of Austinmer, NSW; b. Eaglescliffe, Eng, 15 Oct 1917.

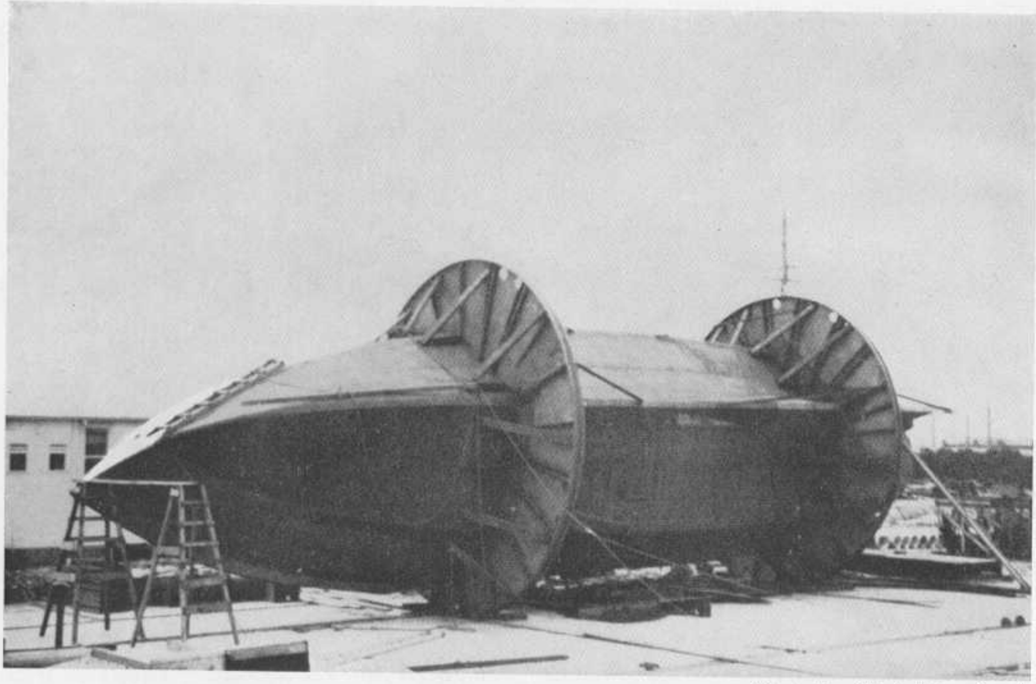
[9] The RAAF reconnaissance aircraft had noted the assembling of 28 Japanese transports at Koepang. Another disturbing observation that lent colour to these rumours was the fact that although they could have destroyed them with the greatest ease, the Japanese had left the oil installations at Darwin untouched by their bombing.

[1] It is almost certain that German scientists were aware of this possibility but it does not appear to have been known to those responsible for tactics. The most reasonable explanation would appear to be that liaison between the two groups was weak or non-existent.



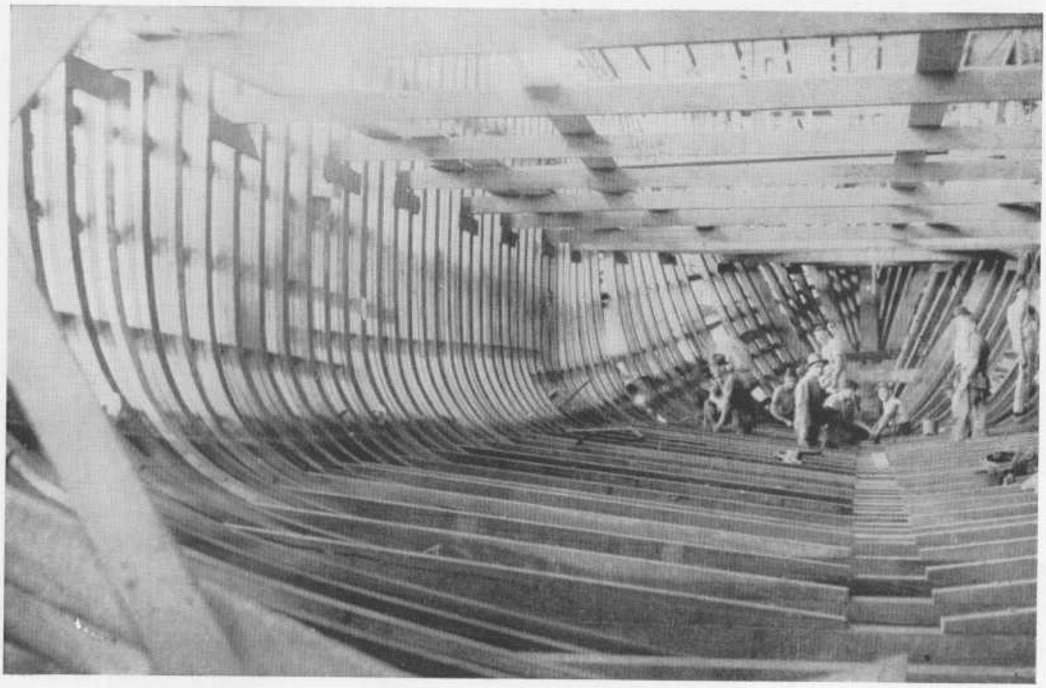
(B.H.P.)

Whyalla, South Australia: a busy industrial centre on a lonely stretch of coastline. In the foreground is the shipyard, and at the right is the blast furnace.



(*Australian Shipbuilding Board*)

Construction of 75-foot tug: roll-over jig for down-hand welding, designed by Mr H. P. Weymouth and by Mr E. F. Hewitt of J. and A. Brown and Abermain Seaham Collieries Ltd and made by Bernard Smith Pty Ltd.



(*Western Mail, Perth*)

Building wooden ships in Western Australia.

were fired, and no aircraft were sent up. In the second raid anti-aircraft guns went into action and the pilot jettisoned his bombs harmlessly out to sea. In the third raid two United States Army Air Force night fighters, whose movements were controlled by radar, successfully intercepted and brought down the bomber.

Many of the A.W. stations on the mainland and on adjacent islands were in extremely lonely spots, with climates ranging from the extreme cold of Wedge Island to the humid tropical climate of Hammond and Mornington Islands. A radar station consisted as a rule of about thirty-five men, including a medical officer, guards, cooks and a clerk or two as well as operators and a maintenance officer. Crews were cut off for long periods in an environment which was often anything but comfortable and where they might suffer tropical ulcers and persistent tineas. Stations had to be operated in shifts throughout twenty-four hours of the day, and even though it was recognised to be of vital importance the work of watching the radar scope in a stuffy cubicle day after day became extremely boring.

An unusually bad station as regards amenities "was the one at Mornington Island of the Wellesley Group in the Gulf of Carpentaria. It was—and presumably still is—a most desolate island, 65 miles long with an indeterminate coastline of mud melting into the sea, the highest point on the land being 80 feet above sea level. It was inaccessible, surrounded by treacherous seas where submerged 'nigger heads'[2] were calculated to rip the bottom out of unwary ships. Here the thirty-two men of the radar station were dumped with twelve months' stores which had to last fifteen months, and here they stayed without relief. Fishing was the one amusement. Bathing was impossible because the waters were infested with Portuguese men-of-war.[3] Mail was the most serious deprivation. At the end of fifteen months the station was withdrawn. In all that time the men had not been relieved."[4]

The Sh. D. sets, which with the help of Dr Myers reached a high degree of efficiency as aids to gun-laying, were never used against the enemy. It was one of the ironies of the history of radar development in Australia that the Service taking the greatest initial interest in it should have found the least operational use for it. This, of course, was no reflection on those responsible; when Sh.D. sets were built no one knew what course the war in the Pacific would take.

Even before the chain of A.W. stations had been completed the immediate threat to the mainland had passed. Having fulfilled a defensive role by means of a relatively small number of hastily-built sets based on an improvised model, radar was soon to be used in a more positive and thorough-going fashion by all three of the armed Services in the islands north of Australia. But before relating this we must return to the story

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[2] Nigger heads are boulders of coral which have been broken off by heavy seas and thrown haphazard upon the surface of the reef.

[3] A colonial jelly fish, one of the most beautiful of the pelagic group *Siphonophora,* found in tropical seas. Its sting is exceedingly powerful and may have serious results.

[4] Marjorie Barnard, "Radar", an unpublished account.

of the laboratory and industry to see how they were organised to meet the swiftly-growing demands of the Services.

While the first A.W. equipments were being built there was considerable discussion whether the Radiophysics Laboratory should continue to build prototype models. In peace time the development of equipment as complicated as radar would be spread out over many years: there would be time for the scientist to complete his work and then hand it over to the engineer to put into the form of a prototype equipment which would be thoroughly tested to see that it met the needs of the user before it went into quantity production. In war each step had to be taken much more rapidly—sometimes before a preceding one had been properly completed. Some way had to be found for accelerating the transition from prototype model to quantity production.

In January 1942, after discussions between Mr Brodribb, Deputy Director-General of Munitions, and the Radiophysics Advisory Board, the Department of Munitions brought into being the Directorate of Radio and Signal Supplies with Lieut-Colonel Jones,[5] a former engineer of the P.M.G's Department, as its Director.[6] Originally intended to deal with radar equipment alone, the directorate's functions were enlarged in July 1942 to cover all radio and signal supplies. In general terms, it was this directorate's responsibility to plan and organise production of radar and telecommunication equipment in commercial industry to meet the requirements of the Services. Its responsibility included opening up new productive capacity, promoting new techniques, selecting contractors, procuring oversea supplies, and encouraging and assisting production generally.

The volume of material relating to technical aspects of research, development and production grew so large that the Radiophysics Advisory Board was unable to deal with it at its monthly meetings. In order to provide a medium for the detailed discussion of the purely scientific and technical problems, the board set up a Technical Committee,[7] which met for the first time on 7th January 1942.

Early meetings of the Radiophysics Advisory Board took place in extreme secrecy. Unusual precautions were taken in the handling of all matters, and for this reason the Chiefs of Staff attended meetings of the board in person until 1942 when service requirements became so comprehensive that it was necessary for specialist officers to attend meetings.

In September 1942 Sir John Madsen resigned from the board and was succeeded by Mr McVey,[8] whose extensive administrative experience as

[5] Lt-Col S. O. Jones, PMG's Dept 1927-39; comd AIF Signals in UK 1940-41; Dir of Radio and Signal Supplies 1942-45; Technical Manager, Philips Electrical Industries of Aust Pty Ltd, since 1945. B. Frankston, Vic, 20 Aug 1905.

[6] Col Jones was director until 30 Apr 1945, when he was succeeded by Mr A. S. Ford. The controllers of the directorate were successively Messrs W. J. Richards, R. J. Bussell, D. S. Ash and F. Tracy.

[7] Members were: Prof F. W. G. White (Chairman); Cdr H. J. Buchanan and Lt T. S. Cree (RAN); Col C. C. Wright, Lt-Col F. N. Nurse and Capt M. R. Buring (Army); Gp Capt C. S. Wiggins and F Lt J. T. Phillips (RAAF); Messrs S. H. Witt and E. J. Stewart (PMG's Dept); Lt-Col S. O. Jones (Dept of Munitions); Mr G. A. Cook (CSIR), Secretary.

[8] Sir Daniel McVey, CMG. (Served 1st AIF.) Dir-General of Posts and Telegraphs 1939-46; Dir-General Civil Aviation 1944-46; Secretary, Dept of Aircraft Producn, 1942-45; Chairman, Radiophysics Advisory Board, 1942-46; Managing Dir, STC Pty Ltd, 1946-49. B. Falkirk, Scotland, 24 Nov 1892.

Secretary of the Department of Aircraft Production did much to assist the board in organising the production of radar equipment by commercial industry.

From the outset Australia had maintained a close liaison with Britain on the development of radar; the time had now come to strengthen liaison with the United States. The growing dependence (especially after the end of 1940) of Britain on Canada and the United States for the supply of radar components, and the greatly increased activity in the United States on radar, were among the reasons for Australia's drawing close to North America in this field. In the latter part of 1942 the staff of the Scientific Liaison Office in Washington was increased by the addition of two scientific officers.[9] Information was coming forward so freely that the main problem was to keep it down to an assimilable—and indeed a despatchable—quantity. Since the material was secret it went by diplomatic bag, and the weight allowed always seemed much less than the amount awaiting despatch. In the interests of efficiency it was necessary to sift the material carefully and send it in order of importance. The work could be done only by men with scientific training, and it consumed a great deal of their time.

The transfer of technical information during the war years through the Scientific Liaison Offices was much faster than in peace time. In normal times it is customary to publish the results of scientific investigations in journals, a process often entailing considerable delay. In war time the results were cyclostyled and were distributed far more rapidly. Information on paper alone was, of course, not sufficient to ensure the transfer of scientific techniques, which could often not be put into writing. Throughout the war, but beginning intensively in 1942, there was a constant interchange of scientists, particularly physicists, between Australia and Britain and the United States. Those who experienced them did not soon forget the valuable opportunities for discussion provided in this way. It would be difficult to assess in precise terms the influence of these interchanges on the development of science in Australia, but it was considerable.

Among the distinguished Americans who visited Australia was Dr Karl Compton, President of the Massachusetts Institute of Technology. He came to investigate the possibility of extending to Australia the activities of the Office of Field Service, a section of the Office of Scientific Research and Development, and of effecting a liaison between it and the Radiophysics Laboratory. His visit resulted in two important developments: the formation of the Research Section General Headquarters, and the sending out of a group of five physicists from the Radiation Laboratory at the Massachusetts Institute of Technology to collaborate with members of the Radio-

[9] The staff at this time comprised G. H. Munro, M. M. Lusby and V. D. Burgmann. The Radiation Laboratory of the Massachusetts Institute of Technology had become such an important centre at the beginning of 1943 that a scientific liaison office was set up there under Burgmann. The Australian contact with the United States was made essentially through the British Central Scientific Office (BCSO) in Washington. The duties of the body were similar to those of the ASRLO in London.

physics Laboratory on radar countermeasures.[1] In return the laboratory undertook work on the development of special equipment for the American forces. The Office of Scientific Research and Development maintained a most generous attitude to the release of secret information to Australia and helped from time to time by sending written information and by providing models of the latest types of equipment.

Similar contacts were made with Canada. The Acting Chairman of the National Research Council of Canada, Dean McKenzie, offered Australian liaison officers and visiting scientists full facilities for obtaining information about the Canadian program and Canadian research and development, especially that of Research Enterprises Ltd, a government organisation set up in Canada for the manufacture of radar and other wartime equipment. Dr W. R. McKinley, a Canadian authority on radar, visited Australia, spending much of his time at the Radiophysics Laboratory and the rest on an extensive tour of operational areas in New Guinea. From time to time Canada provided pieces of equipment urgently needed, either as part of the Australian research and development program or to fulfil the needs of the Australian Services.

Scientific liaison between Australia and Britain, the United States and Canada, established in the first instance to meet the needs for developing radar, gradually extended to many other branches of science, and continuing after the war promised to become a permanent feature in the scientific life of Australia.

During 1942 the problem of instructing members of the Services in handling and operating new and quite unfamiliar equipment, became a serious one and had to be tackled systematically. Not only was the equipment novel, but the continual introduction of modifications and improvements necessitated revision of instructions. For example, the first sets (Sh.D. and A.W.) used wavelengths of about 1.5 metres, but early in 1942 equipment operating on very much shorter wavelengths, in the region of 10 centimetres, and calling for different handling, was introduced. In setting up centres of instruction it was natural that the Services should turn to the Radiophysics Laboratory for help. The laboratory provided courses of instruction for men already partly familiar with the subject who were to become radar instructors at the Service training establishments.

It became clear that although the laboratory could do a certain amount of instructional work, which was of course within its terms of reference, much more would be required than it alone could give. After somewhat protracted negotiations, the help of the University of Sydney was enlisted. Courses were arranged and conducted by Professor Bailey[2] in the Department of Physics. Here men of all three Services who were to become

[1] This group was known as the Australian Group Radiation Laboratory, and was led by Dr S. Seely.

[2] V. A. Bailey, MA, DPh. (Served in RE in first world war.) Prof of Experimental Physics, Univ of Sydney, 1928-52, Research Prof since 1953. B. Alexandria, Egypt, 18 Dec 1895. He was assisted by Dr M. Fraser, Dr R. E. B. Makinson and Mr J. M. Somerville.

officers in charge of radar equipment and who had some preliminary knowledge of physics (up to second year B.Sc. standard) were given instruction in courses lasting six months, comprising lectures and extensive practical work.[3] In all about 300 men passed through this school.

The first notable technical development after the reorganisation in 1942 was the further improvement and adaptation of the air-warning equipment and its commercial manufacture on a relatively large scale. Experience with A.W. sets on the mainland and adjacent islands had shown that considerable difficulties arose when installing it in isolated and inaccessible spots. It was true that these installations were for fixed defences, and however difficult it was to set them up initially, once they were set up they were not usually moved again for some time. Conditions in New Guinea were extremely difficult, and the problem of transporting heavy and complex machinery through swamps and jungles in the absence of roads, railways, airfields, jetties and wharves demanded much thought and ingenuity. No matter how efficient a radar set was technically, it was useless if it was so cumbersome that it could not be got to the place where it was required. On the other hand, the situation was not much better if a set was made so light that, though it could be got to the place where it was required rapidly enough, it was liable to break down after a short time. For use in New Guinea and other tropical regions something between these two extremes was needed; something that could be transported by air and sea, and if necessary by hand through the jungle, without damage, and that could be assembled and put in operation within a few hours of its arrival at the site. Equipment evolved to meet these conditions, known as the Australian Light-weight Air Warning set (LW/AW Mark I), came as near as any made by the Allied countries to being ideal in respect of reliability and portability.

The A.W. sets used at Darwin and other places on the mainland were unusually light for this kind of equipment—not so much as a result of conscious planning to this end as by necessity. The only suitable valves available in Australia at the time the original A.W. set was designed were small and of relatively low power, and by using them it was possible to keep down the weight of the set. The great merit of the design was that it enabled the set to do the work of one equipped with high-powered valves. It was no discredit to the design that its light weight should have been more or less accidental. By deliberate planning still further improvements were effected. The set finally evolved which most nearly met the requirements of portability, weighed, when fully packed for transport, somewhere between 4,000 and 6,000 pounds.[4, 5]. If the weight exceeded the upper limit there was a serious loss of mobility and ease of erection.

[3] The standard was relaxed in later courses to admit men with no more physics than a pass at the school Leaving Certificate standard.

[4] This included power supply—a Ford "10" petrol engine alternator.

[5] J. N. Briton, "Light-weight Warning and G.C.I. Radar in Australia", *Journal of the Institution of Engineers, Australia,* Vol. 19, Jun 1947.

On the other hand, if the weight fell below the lower limit, it was very difficult to meet the full operational requirement for range and reliability.

The size of the aerial system was an important factor in determining the range of a set, and it could not be reduced below a definite minimum. Designing a suitable aerial was one of the greatest problems in keeping the weight of a set down. The problem was essentially one of mechanical engineering and was solved principally by the staff of the Chief Electrical Engineer's Branch (and the Mechanical Engineer's Branch) of the New South Wales Department of Railways.[6] In a discussion between representatives of the Air Force and the Railways it was decided that all components should be small enough to be placed inside a DC-2 aircraft. Saving of weight was effected chiefly by reducing that of the aerials and of the hut accommodating the set. The first step was to design an aerial with the whole of its rotating gear on the top of the hut. The aerial itself was made lighter and was so designed that it could be quickly dismantled into three sections. Previously more or less any kind of hut had been used to house the set; in the new equipment the hut was a pipe framework enclosed by a canvas tent.

These small engineering details helped to produce one of the most versatile and useful pieces of scientific equipment issued to the Services. Whereas the Australian LW/AW equipment weighed only 2 to 3 tons, corresponding American equipment sometimes weighed as much as 40 tons. The LW/AW Mark I set had good qualities apart from its portability. It was simple and rugged in construction, and because its component parts were readily accessible it was easily maintained. Australian radar crews received a much longer training than, for example, American crews, and were able to make practically all repairs in the field.

The first LW/AW Mark I set completed was set up at Dover Heights in September 1942.[7] Extensive tests demonstrated its ease of erection and dismantling. The radar equipment itself made up only 15 per cent of the weight of all the materials, including food for the crew, required to establish a radar station. An assessment of the set's performance by the Army Operational Research Group is shown in the accompanying table.

Although no great pains had been taken to tropic proof the first LW/AW Mark I equipments, once they were erected and put in operation in New Guinea they performed remarkably well. This was due partly to the highly efficient maintenance work of the R.A.A.F. technicians, and also to the fact that heat generated during operation of the equipment was sufficient to prevent the condensation of water that so often put electrical

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[6] Throughout much of the war the NSW Railways made a very valuable contribution to the radar project by designing and manufacturing aerials of all kinds. A special Radar Annexe was established in the Dept of the Chief Electrical Engineer (Mr W. H. Myers). Mr J. G. Q. Worledge and his team did outstanding work in this field.

[7] Details of the set were:
Frequency: 200 megacycles per second,
Peak power: 10-15 kilowatts,
Pulse recurrence frequency: 50 cycles,
Pulse duration: 20 microseconds,
Aerial array: 32-element (4 bay, 4 stack broadside),
Weight: Transmitter 6.5 cwt, receiver 6 cwt, array 2.5 tons (all crated ready for transport).

equipment out of operation in the tropics. Since equipments were required to be in almost continuous operation, their satisfactory performance was ensured by switching on electrical heaters for the short periods when the sets were switched off for maintenance. From experience with the first

Range of detection by LW/AW Mk I (in miles) against twin-engined aircraft—front aspect

Mean height of array above surrounding sea or land	Height of aircraft in feet 500	2,000	5,000	10,000	15,000	20,000	25,000
	miles	miles	miles	miles	miles	miles	miles
15 ft .	10	20	30	45	55	62	65
45 ft .	15	28	48	70	88		
150 ft .	25	48	75				
300 ft .	35	65	88				

model some tropic-proofing measures were incorporated in later models (LW/AW Mark IA). These latter sets performed so satisfactorily that at a much later date the R.A.A.F. was not prepared to introduce a new mark (III) that was not only lighter but had greater range and reliability, being operated with sixteen to twenty times the power used in the Mark IA; the changes in routine involved did not, in the R.A.A.F's opinion, warrant the change-over from one mark to another.

In all, some 150 LW/AW Mark I and IA sets were made for the Australian and American forces.

Except for the aerials, which were made by the New South Wales Railways, LW/AW equipment was built at the Gramophone Company Ltd at Homebush. That is not to say that this company made all the components—far from it. For example the valves (type VT.90) were made by Standard Telephones and Cables Pty Ltd (S.T.C.), whose experience with telephone repeater and high-power transmitting valves used by broadcasting stations proved valuable. At one period the local production of VT.90 valves fell almost to zero owing to the failure in supplies of raw materials. The threat was so serious that to insure against a possible breakdown in the manufacture of the LW/AW equipment, the Radiophysics Laboratory designed a second mark using a then more-readily-available valve. In the event, Mark II was not needed.

The LW/AW equipment was also adapted for use on ships. One of the main problems was to keep the size of the aerial down so that it could be safely installed at some high point (preferably the mast-head) without upsetting the ship's stability. An aerial as large and as light as practicable was chosen, any deficiency in the size of the aerial being made up by increasing the power of the set. A set known as Type A.79 with a power of 80 kilowatts and a range of about 63 miles was built for cruisers and destroyers; for smaller ships such as corvettes and minesweepers a set known as A.286.Q, with a power of 160 kilowatts and a range of 60 miles, was developed.

Once the main strategical approaches to the Australian mainland and the operational bases in New Guinea were covered by air-warning stations, the Japanese air force found it difficult to make any undetected approach to these areas. This cover enabled the Allied air forces to dispose their fighter squadrons to the best tactical advantage. In the absence of such cover more aircraft would have been required than could possibly have been provided at the time. As in the Battle of Britain, fighters were directed to the attack where they were required so that a relatively small fighter force was able to repel enemy attacks made on a wide front.

Radar scored no-less-important successes when the tide of battle turned from the defensive to the offensive. The first air-transportable A.W. station (LW/AW Mark IA) was installed at Tufi, a headland on the north coast of Papua, after being flown from Port Moresby. It could not be landed on the headland itself but had to be carried overland from Wanigela. This station, erected in six days, gave much valuable warning information. About the same time another station was installed at Dobodura, the site of an airfield near Buna. This station gave help in covering the Allied forces besieging Buna by warning them of aircraft coming from Lae. It was also able to pass its information by radio communication on to Port Moresby, 100 miles away over the Owen Stanley ranges.

The difficulties of manning and operating radar stations in the tropics were even greater than they were on the mainland and its neighbouring islands. At Dobodura, for instance, it was noticed that dense vegetation in the neighbourhood of the radar station had a detrimental effect on its reception. An earlier poor performance of radar noticed at Milne Bay was later attributed to the same effect of neighbouring vegetation. The remedy was to clear the surrounding area, which meant practically abandoning all attempts at camouflage. The motto of this and other similar stations became "coverage before cover". Another station installed at Cape Ward Hunt for the purpose of covering the advance on Salamaua experienced a heavy tropical downpour the night it landed. The equipment was protected from this deluge by nothing more than tarpaulins, but it survived in working trim. By this time it had become the rule that a radar station should cover every operation. Before the attack on Lae by the 7th and 9th Australian Divisions, the radar station at Buna was moved to Tsili Tsili, above the Markham Valley. Shifting this equipment and setting it up at its new point of operation was achieved in the remarkably short time of three days three hours.[8] The Tsili Tsili station covered the Nadzab parachute drop and advance. It is a great tribute to the soundness of the design and portability of the equipment that it performed so well in what must have been one of the most difficult regions in the world in which to operate. The incidents related are only a few of many which occurred, but they are typical.

No account of the wartime development of radar in Australia would be complete without some reference to the use of microwave radiation. In the

[8] The radar officer in charge was F-Lt K. N. Bishop.

early days of radar in Britain, equipment operated on wavelengths ranging between 1 and 50 metres. It was, however, realised that a number of advantages would accrue from the use of radiation of much shorter wavelength—down to a few centimetres. The difficulty barring the way to the use of shorter wavelengths was the absence of valves capable of generating such wavelengths at high power. Two British scientists, Dr J. T. Randal and Dr H. A. H. Boot, engaged on fundamental research in Professor M. L. Oliphant's[9] laboratory at the University of Birmingham, solved the problem by the invention of a revolutionary type of valve known as the resonant cavity magnetron. When this valve went into commercial production in August 1940 it gave British radar a lead over other countries. It was a narrow margin of technological superiority, but sufficient to give Britain a vital advantage over Germany in the Battle of the Atlantic. Among the advantages arising out of the use of the magnetron three were of special importance. By reason of the fact that the first lobe of radiation from a set equipped with magnetrons was close to the ground (the height of the first lobe was proportional to the wavelength of the radiation used) microwave radiation enabled the detection of distant aircraft flying at low altitudes. Shorter waves gave greater accuracy in fixing the bearing of distant objects and much clearer definition of images on the scope.[1] Above all, it enabled the detection of small objects such as submarine periscopes and small craft that could not be picked up on a long-wave set. The discovery of the resonant cavity magnetron was probably the most notable step taken in radar since its inception.

In 1940 the British Government decided to disclose to America all British radar information, including that on the latest microwave techniques. Accordingly Sir Henry Tizard, accompanied by representatives of the Services and by civilian technical advisers, among them Dr Bowen, an original member of Watson-Watt's pioneer radar team, sailed for the United States in September 1940. At a conference in Washington British and American radar data were laid on the table without reservation. In the United States the initiative for work on radar had been with the navy and not with the air force as in Britain. Nevertheless similarities between the developments in the two countries were remarkable. There were, however, two notable differences: the Americans had developed neither airborne sets nor microwave radiation. Thus the British had something very substantial to offer. The Bell Telephone Laboratories were given the contract to manufacture the magnetron for the United States. A less direct, but no less important result of the British Mission was the formation by the National Defence Research Committee of the Radiation Laboratory at the Massachusetts Institute of Technology, which became one of the world centres of research on microwaves. When the time arrived for the

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[9] M. L. E. Oliphant, FRS, MA, PhD. Prof of Physics, Univ of Birmingham, 1937-50. Director, Research School Physical Sciences, Aust National Univ, since 1950. B. Adelaide, 8 Oct 1901.

[1] In its later development the presentation of radar information underwent a particularly useful refinement. Radar waves were used to form a crude monochrome image of some of the salient features of the region of space being explored. A ship or aircraft would show up as a small blob, and bays and other features would often be fairly clearly indicated. This system was known as the plan position indicator (P.P.I.).

transfer of microwave techniques to Australia, it was from the Radiation Laboratory that many of them were learned.

The first intimation received in Australia that important results were being obtained in Britain from the use of very short waves (10 centimetres), came through the Scientific Research Liaison Office in London. The question of their possible use in Australia was discussed by the Radiophysics Advisory Board at its eighth meeting on 17th December 1940. About six months later, when it became apparent that very short wavelengths were likely to assume considerable importance, Pawsey was sent to the Radiation Laboratory to study the new techniques.

Although the introduction of microwaves was an outstanding innovation, it did not mean that their use was bound to displace that of all other wavelengths. Each range of wavelengths (metre and centimetre) had its own peculiar advantages, depending upon the operational use for which it was intended.[2]

Microwaves proved most effective for the detection of submarines and other small craft. It was natural therefore that immediately on his return to Australia in October 1941 Pawsey and his group should begin work on a microwave equipment for the navy. An experimental model of a set known as A271L (A for Australian, L for laboratory model) embodying imported magnetron valves, pending the manufacture of these components locally, was first tried out at South Head, Sydney, in July 1942. Propagation conditions were unusually favourable and the set's performance exceeded all expectations: a 6,000-ton ship was picked up at a range of about 45 miles. After this test the Australian Navy needed no further convincing about the potentialities of microwave radar in sea warfare. Sea search equipment (A271L) was developed in two forms, one designed specially for the navy and the other for the army as a coastal defence set, but before the equipment could be put into quantity production it became necessary to arrange for the local manufacture of magnetron valves.

Valves used in domestic broadcast receiving sets resembled electric light bulbs in so far as they contained metal components sealed into an evacuated glass bulb. Many radar valves were of a fundamentally different design. The magnetron, for example, consisted of a metal body to which some glass parts were sealed. It was this feature of its construction that made the manufacture of the magnetron more difficult than the usual run of valves.

Using oversea valves as a guide, Dr Martin and Dr Burhop[3] in the Department of Natural Philosophy in the University of Melbourne, succeeded in making a laboratory model of a magnetron by 23rd May 1942. It is one thing to build a complex device such as a magnetron in the labora-

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[2] To illustrate this point it is worth mentioning that naval vessels carried two equipments: air-warning (operating on 1.5 metres) and sea-search (operating on 10 centimetres). When the versatility of radar came to be fully realised capital ships carried as many as 30 different equipments, each fulfilling some special purpose.

[3] E. H. S. Burhop, PhD. Lecturer in Natural Philosophy, Univ Melb, 1935-42; Acting Officer-in-charge, CSIR Radio Research Lab, Melb, 1942-44; Senior Scientific Officer, British Supply Mission in U.S.A. on Atomic Energy Project, 1944-45. B. Hobart, 31 Jan 1911.
Martin and Burhop had previously been working on problems relating to optical munitions. During a visit to Australia Prof Oliphant persuaded Prof Laby to release them for work on radar.

tory, but quite another to build hundreds exactly alike by methods of mass production. After Martin and Burhop had completed their path-finding work the production engineers of the Amalgamated Wireless Valve Company Pty Ltd and of Standard Telephones and Cables Pty Ltd took over. They split up the process of manufacturing magnetrons into a large number of separate operations, most of which were of a relatively simple character. A few, such as the making of metal-to-glass seals and the final sealing of the metal chamber, called for considerable skill. A vacuum-tight copper-to-copper seal of a plate to a cylinder was achieved by compressing between them at a temperature of 530 degrees centigrade a ring of gold wire.

The problem of supplying the high-conductivity, oxygen-free copper which gave the most successful glass-to-metal seals but which was made only in America, was solved when Metal Manufactures developed a more simply produced manganese deoxidised copper specially for the purpose. Australian-made VT.90 valves used this metal. The VT.90 was the first valve in the world designed specifically for pulse operation in radar equipment and the first to use thoriated-tungsten filament in a high-voltage close-spaced valve.

Metal-to-glass sealing techniques using manganese deoxidised copper developed on the VT.90 were available when magnetrons came to the production stage, and all magnetrons made by S.T.C. were independent of oversea copper. Tellurium copper for the bodies was made also by Metal Manufactures.The high precision required for machining the resonant cavities and the sealing of the bodies by gold diffusion seals were the major mechanical problems encountered by industry. The magnetron was the first Australian-made valve in which oxide-coated cathodes were used to produce very high peak currents during anode voltage pulses of several thousand volts. Production of reliable cathodes for this class of operation presented a manufacturing problem of no mean order.

The local oscillator (or klystron) used in radar receivers operating on centimetre wavelengths was a valve of revolutionary design employing the principle of velocity modulation of a focused electron beam within the valve. This beam reacted with a resonant cavity which was an integral part of the valve and which could be tuned over a limited range of frequency. Most of the 10-centimetre radar equipment and a good deal of test equipment used these klystrons (the CV.35), which were produced in Australia by Standard Telephones and the Amalgamated Wireless Valve Company.

Australian Consolidated Industries furnished glasses possessing specified coefficients of expansion. Manufacture of the powerful, permanent, alnico magnets needed for the operation of a magnetron valve was satisfactorily carried through by Quality Castings (Sydney) and Rola Ltd (Melbourne): Quality Castings was among the first to develop the technique of powder metallurgy in Australia.

Having successfully copied an oversea magnetron, Martin and his team next developed an original design for a magnetron to generate 25-

centimetre radiation. This valve formed the essential element of a greatly improved air-warning set built towards the end of the war.

The greater part of the work at the University of Melbourne, especially late in the war, consisted of the development of pilot models of oversea valves using locally-available raw materials. The intention was to use these as an insurance against emergencies. Had the necessity arisen, they could have been fairly promptly produced on a large scale. As it happened, no major production of radar equipment was completely held up for want of valves.

Some sixty microwave radar equipments were made by A.W.A. for the navy; these, installed in corvettes and destroyers, performed well and reliably.

The Radiophysics Laboratory in Sydney and the P.M.G. Research Laboratories in Melbourne undertook between them the development of some twenty different radar projects. There was the Air to Surface Vessel (A.S.V.) equipment, essentially a straight copy of an English model, which was made on a large scale (1,126 sets, Marks I and II) for the R.A.A.F.[4] There were sets for searchlight control, fire control, ground-controlled interception (G.C.I.), among other radar systems.

Ground-controlled interception was evolved to meet the problem of intercepting night bombers. Such a system supplied to a fighter pilot continuous information of friendly and hostile aircraft both in plan and in height, their relative heights to within plus or minus 500 feet. Twenty-six units (LW/GCI Marks I and II) using 1.5-metre waves were made by the Gramophone Company Ltd and the New South Wales Government Railways for the Australian and American air forces.

One of the few original Australian contributions to the techniques of radar was fated to be stillborn. Ordinary radar equipment, such as LW/AW, could with the aid of a few calculations reveal the speed of approach or retreat of a target. It was generally recognised that a great advantage would be gained if it were possible to adapt radio to measure speeds of objects instantaneously. As far back as 1935 Martyn had worked out theoretically a method of applying Doppler's Principle[5] to radar waves for the purpose of studying movements of reflecting layers in the ionosphere.[6] Equipment working on this principle was built and put into successful operation in the grounds of the University of Sydney by Dr Pulley.[7]

[4] ASV equipment was made by Eclipse Radio Pty Ltd (subsidiary of Electronic Industries, Melbourne) and also by A. G. Healing Ltd of Melbourne.

[5] Astronomers applied this principle to light waves in the measurement of speeds of heavenly bodies.

[6] Martyn applied the principle to the case of a transmitter radiating strong pulses as well as a weak continuous carrier wave on the same radio frequency. "At the receiver a few hundred yards away," explained Martyn, "the pulses reflected from the ionosphere (and weakened after travelling vertically upwards and downwards for several hundred miles) met and combined with the now comparable continuous wave which had travelled only the few hundred yards between receiver and transmitter. A movement of only 100 yards in the ionospheric reflecting layer caused the pulse to vary in amplitude from a maximum to a minimum and back again. A steady movement in the layer therefore caused a continuous 'fluttering' of the echo pulse, the rate of flutter giving the rate of movement of the layer."

[7] O. O. Pulley, PhD, BSc. Senior Design Engineer A.W.A. Ltd; Principal Research Officer Radiophysics Lab; Officer-in-charge of Radar Section Directorate of Radio and Signal Supplies. Of Sydney; b. Wellington, NSW, 5 Sep 1906.

When Martyn took charge of the Radiophysics Laboratory he suggested to several members of the staff that they try to adapt the principle to radar, but the technical difficulties appeared to be too great in those early days. Later, as Director of the Army Operational Research Group, Martyn once again suggested the problem, this time to Messrs M. I. Iliffe and J. W. Hill,[8] who solved it in a very skilful fashion. The equipment they constructed was so efficient that the rolling of the pilot steamer *Captain Cook* in the swell of Sydney Heads could be watched on the oscillograph screen. In point of fact Martyn claimed that a movement of one foot could be detected in an object 50 miles away.

The project, which came to be known under the code name "Flutter", was of special interest to the navy because of its possible application to naval gunnery where quick determination of changes in speed by the enemy was of great importance. To the air force it represented a useful method for identifying aircraft by their speeds, and also for picking out moving aircraft among fixed permanent echoes. Flutter reached the developmental stage about the same time as LW/AW, and much effort would have been required to take it further. The Radiophysics Advisory Board felt that the two projects could not be fully developed simultaneously, and decided, rightly as events were to prove, to go ahead with the LW/AW equipment.

Full information concerning Flutter was sent to the Admiralty, the Telecommunications Research Establishment and to the principal radar centres in the United States. The most important application of Flutter in use before the end of the war appears to have been in bombers, to enable rapid determination of their speed relative to their target. Flutter was described by the Director of the English Army Operational Research Group, in one of the regular information bulletins to sections abroad, as "the only instance which has arisen during the war of the application to radar of a radically different fundamental physical principle".

The Japanese did not take long to find a way of jamming equipment operating on the 1.5-metre wavelength. The Radiophysics Laboratory's reply to this was to develop equipment operating in the centimetre region. Towards the end of the war it evolved a highly satisfactory 25-centimetre air-warning equipment for use against both high-flying and low-flying aircraft, and height-measuring equipment (A.W.H. Mark II) which was considered one of its outstanding scientific and technical achievements. It also advised the navy and the R.A.A.F. on Radio Counter-measures (R.C.M.) and designed special detectors for locating or "ferreting out" Japanese radar sets. These detectors were small, resembling an electric torch in size and appearance, and were used by commando groups landing in enemy-held territory.

When employing radar to control interception by fighters it was essential to be able to distinguish friend from enemy. A blip on the radar scope gave no clue to the identity of the aircraft causing it, and to avoid con-

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[8] J. W. Hill, BSc, BE. Tutor, Radiophysics Training Course, Univ of Sydney, 1942; Research Officer, Radiophysics Lab, 1942-45. Of Sydney; b. Footscray, Vic, 6 Oct 1921.

fusion a system known as secondary radar was introduced, so named to distinguish it from all the primary systems so far discussed. *A Textbook of Radar* defines a secondary radar system as "one in which a particular object to be located (for example a friendly fighter aircraft) is provided with a combination of receiver and transmitter known as a 'responder' which, when triggered or 'interrogated' by a primary radar emits a characteristic reply signal of its own. The responder not only generates more energy than would be returned by simple reflection, but can be made to provide a coded and hence distinctive signal from which it may be readily identified." In other words, the object being located produced a strong, tagged or labelled artificial echo. About thirty Identification Friend or Foe (I.F.F.) sets were made as part of the ground-controlled interception units. The same principle was used in radar beacons. The responder in such beacons, radiating an identifiable signal much stronger than a natural echo, could provide a radio landmark analogous to a lighthouse. Radar beacons were invaluable for guiding aircraft back to airfields and aircraft carriers. Altogether over 200 beacons were manufactured by the Gramophone Company Ltd.

In producing radar equipment worth millions of pounds for the forces in the South-West Pacific Area, the Australian radio industry, backed by the scientific work of the C.S.I.R., did an excellent job. Using an organisation tooled up originally for the manufacture of broadcast receiving sets, the industry, beginning in earnest early in 1942, made a rapid switch to the manufacture of equipment a great deal more complex and exacting in its requirements. The distinctive feature of this effort was the speed of its accomplishment in the face of all kinds of obstacle that might, on occasion, have been expected to bring it to a standstill: the usual lack of skilled manpower and shortage of materials, secrecy and innumerable tangling regulations. Equipment often went into production while research was still being carried out on the prototype. This frequently meant changing the design half way through the completion of a particular order, which was naturally a source of irritation and worry to the manufacturer. The difficulties experienced were those inherent in any attempt to put manufacturing processes into effect at a speed many times greater than would ever be contemplated in peace time. The wonder of it all was that the difficulties were overcome with so little friction and trouble. Altogether 2,076 items of Service radar equipment and 9,085 items of general radar test equipment were manufactured.

Once the demand for Australian radar equipment had passed, as it did when American supplies arrived in great volume in 1944, the staff of the Radiophysics Laboratory began to devote more and more of its time to fundamental research into the problems of radar.

As early as 1943 a research group under Dr Pawsey and a related mathematical group under Dr Jaeger began to devote most of their time to an inquiry into anomalous propagation or superrefraction, a phenomenon first systematically investigated in Britain in 1943. Radio waves, like light, travel in perfectly straight lines in homogeneous media, but on passing from one medium to another both kinds of wave undergo a bending, or refraction. Since under normal conditions the lower layers of the atmosphere are physically and optically more dense than the upper layers, radio waves undergo a slight bending towards the earth, but nothing like enough to cause them to follow the earth's curvature.

Water vapour in the atmosphere exercises a strong influence on the behaviour of radio waves. Unusually large amounts of water vapour sometimes occur in the first few hundred feet of the atmosphere and make it optically dense to radio waves. Thus they are bent to such an extent that they may follow the curvature of the earth. This was known as superrefraction and was responsible for the phenomenally large ranges sometimes observed with sets whose normal range was quite small. For example, a set whose normal range for the detection of a ship was only 20 miles might suddenly be able to detect ships at a distance of 200 miles, and in extreme cases at 700 miles. Superrefraction was caused when a mass of relatively cool and damp air underlay warm dry air, a condition often found on the coast of north-western Australia.[1] Here the hot dry wind from the desert blows out over the sea, which cools the lowest layer and makes it moist. Superrefraction may also occur over the land at night when lower levels of the atmosphere are cooled by the rapid cooling of the land on a fine cloudless night. The phenomenon is so strongly developed off Darwin that air-warning sets (1.5 metres) operating there reported echoes from the coast of Timor, 300 to 500 miles away, several times a month. Similar equipment near Broome, Western Australia, reported echoes from the coast of Java, 900 to 1,100 miles away. In February 1944 a high-flying Catalina was followed almost continuously for a distance of 800 miles on its journey from Perth to Colombo by the air-warning station at Geraldton.

A useful addition to our knowledge of superrefraction was made by the R.A.A.F. and army stations round the coasts of Australia and New Guinea which, following the suggestion of research physicists, made daily observations on the phenomenon as part of their regular duty. As with some of the data of meteorology, these observations on superrefraction could hardly have been made in peace owing to the prohibitive cost of maintaining so many stations at isolated points. The observations and their interpretation by the Radiophysics Laboratory were duly published and in this way became a useful by-product of wartime activities.[2]

There can be no doubt that Australian science made one of its most valuable contributions to the war effort by assisting the introduction of radar. That it was able to do so was to a large extent due to the sound foundations laid earlier by the Radio Research Board in training physicists and providing research facilities. The light-weight air-warning equipment in particular filled a vital need that could not have been met in any other way. Few better illustrations could be found of the rewards that may come

[1] F. J. Kerr and J. K. Strachan, Radiophysics Laboratory Report RP 259/1, Aug 1945.

[2] F. J. Kerr, "Radio Super-refraction in the Coastal Regions of Australia", *Australian Journal of Scientific Research*, Series A, Vol. 1 (1948), p. 433.

from scientific research undertaken in the first instance in the pursuit of knowledge alone. The experience gained in war time was embodied in one of the earliest textbooks of radar to be published in English.[3] A collective work by the staff of the laboratory, it went beyond purely Australian achievements in radar, attempting to consolidate knowledge of the subject up to that time—1946.

[3] *A Textbook of Radar* (1947).