TECHNICAL STAFF MONOGRAPHS 1939-1945

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Radio Warfare

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SIGNAL DIVISION, ADMIRALTY
1949
(S.D. 1080/47)

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ADMIRALTY, S.W.1.
29th August 1949.

S.D. 1080/47

~~C.B. 03209~~, *Technical Staff Monographs* 1939-1945, *Radio Warfare*, 1949, having been approved by My Lords Commissioners of the Admiralty, is hereby promulgated for the information and guidance of all concerned.

By Command of Their Lordships,

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INTRODUCTION

The term 'Radio Warfare' covers all aspects of the use of radio in war. The scope of this monograph is, however, limited to:—

(i) The interception of enemy radio signals of all kinds — commonly referred to as 'Y' work;

(ii) D/F, apart from its use as a navigational aid;

(iii) Radio Counter Measures (R.C.M.), or the means of denying free use of the ether to the enemy. This includes the use of counter-measures to upset the control of radio guided missiles.

This monograph makes no attempt to discuss the 'straight' use of radio communications or radar, to each of which subjects a separate monograph is devoted. Nor is radio deception dealt with except that radar deception is mentioned in connection with R.C.M.

CHAPTER I

THE GENERAL PROBLEM

Object of the Monograph

THIS monograph sets out to give, briefly, the history of the development of 'Y' and D/F, and the inception and development of R.C.M., during the war. The results obtained are discussed, and broad lessons applicable to the future are drawn. Developments in hand at the end of the war which had not yet reached the operational stage are mentioned, but their post-war progress is not dealt with.

The problems of providing and training the necessary personnel are considered and the progress made by the enemy is described. In this respect not only information gained during the war, but the results of scientific search among enemy personnel, establishments and documents, following the Surrender, are available.

In general the object is to put before the staff officer of the future, engaged in making the change from a peace to a war organization, the problems we met, the lessons we learned, the mistakes we made and the experience we gained, all of which should assist him in his difficult task.

The Development of 'Y'

2. The skeleton organization which existed in peace proved a satisfactory basis for war expansion.

The investigation of enemy radar and other non-communications uses of radio, referred to collectively as 'Noises', was an entirely new subject, which grew from small beginnings in 1940 to become a standard feature of 'Y' both ashore and afloat, and was still developing fast in 1945.

The tactical use of 'Y', particularly in connection with the interception of enemy tactical R/T signals, proved exceedingly valuable. This subject is of such interest to the Fleet that a separate chapter is devoted to it.

In general the results of all forms of 'Y' fully justified the effort made.

D/F

3. The shore D/F system was greatly expanded from its peace-time skeleton form. Main difficulties were the provision of personnel, stations and communications to plotting centres. Big advances were made in technique, and in methods of plotting. The results obtained were of great value, particularly in the Battle of the Atlantic.

H/F D/F afloat, a rather disappointing experiment in peace, was improved to such an extent that it became one of the principal weapons in defeating the U-boat.

V H/F and U H/F D/F was developed, mainly afloat, to intercept and establish the identity and source of radar transmissions and other uses of the higher part of the radio frequency spectrum. The results obtained were fairly satisfactory, but the technique was still under development at the end of the war.

Radio Counter Measures

4. Our general policy was to leave enemy radio communications unjammed, as there is normally more to be gained from their interception than from their obstruction, which is by no means simple in naval warfare. War experiences confirmed the wisdom of this policy.

Jamming of enemy radar was increasingly developed as a weapon, especially in connection with amphibious operations; this development proceeded hand in hand with that of noise investigation. By the end of the war the use of electronic and non-electronic jamming, both afloat and in the air, to upset enemy radar, was fast becoming a standard weapon in the Fleet's armoury.

The enemy use of radio guided missiles called for an especially urgent R.C.M. effort to give our ships a reasonable degree of protection. This effort was necessarily limited to the defeat of particular enemy weapons, and the application of R.C.M. to guided missiles generally could not be tackled during the war.

Personnel and Training

5. Since early 1939 the shore 'Y' and D/F organization had been almost exclusively manned by the Admiralty Civilian Shore Wireless Service. Good though this service proved itself it could not be expanded rapidly enough to meet war needs, and large numbers of H.O. ratings and W.R.N.S. had to be trained to fill the gap.

As will be seen from Chapter IX, the organization of personnel was constantly changing. At first ratings were trained in several sub-branches so as to provide personnel rapidly. This scheme proved rather inflexible in meeting the constantly changing requirements, so towards the end of the war efforts were made to convert all personnel into 'all-rounders' capable of tackling any aspect of 'Y', D/F or R.C.M.

The plan for the future is to produce a rating for duty afloat, possibly called a 'Radio Analyst', with a good knowledge of all that is going on 'on the air', who can apply this knowledge for tactical warning purposes and for the control and use of R.C.M.

Actual training was always a difficult problem. Experienced instructors were lacking, the syllabus was changed frequently to meet new developments and suitable establishments were hard to find.

Enemy Efforts

6. The Germans did develop an extensive 'Y' network covering long distance communications. They made the serious mistake, however, of underestimating the value of other 'Y' services in the early days of the war. Until late in the war they devoted little effort to the matter and in consequence fell far behind the Allies in the development and use of some 'Y' services and of D/F and R.C.M. They did develop a V H/F and U H/F 'Noise' network but this was mostly confined to use against Bomber Command aircraft.

The surprising feature was that the Germans failed to appreciate the great damage that our 'Y' service was capable of inflicting on them.

Post-War Development and Reorganization

7. 'Y', D/F and R.C.M. are clearly going to play an important part in any future war, and must therefore be kept going in peace, both to ensure technical progress, to keep the art alive, and to provide a skeleton organization from which expansion can take place when needed.

The probable policy of providing Radio Analysts for duty afloat has already been mentioned (para. 5), but the branch will take time to build up, especially as nearly all the ratings with war experience will be demobilized. As peace-time exercises will inevitably be concerned with counter-measures against our own radar equipment, etc., we shall have to be cautious about drawing lessons from them, and we must be ready for unexpected developments at the beginning of any future war.

Similarly the interception and translation of 'enemy' tactical signals afloat cannot be exercised realistically in peace, and any effort made in this direction would be a waste of manpower and time.

The shore 'Y' organization, though maintained to some extent, is bound to lag behind foreign radio telecommunications development, because a complete interception and intelligence organization capable of watching all foreign transmissions would be much too costly an undertaking for peace-time. Added to this there is bound to be a shortage of research staff for investigating foreign technical progress.

As regards the production of jammers, etc., we cannot pursue detailed development until we know who our enemies may be and can obtain intelligence of their radar, etc.

Development here must be on general lines so that we have the necessary organization ready to produce equipment of the right type when it is needed. The Fleet must be equipped with some jammers capable of working against our own radar, so that operators may be kept in training, radar operators familiarized with working through jamming, commanding officers educated in the possibilities of the art and its reaction on the use of radar generally and research staffs provided with practical data.

CHAPTER II

THE 'Y' SERVICE

General Functions of the 'Y' Service

BEFORE the war the functions of the 'Y' Service, maintained in skeleton form, comprised the collection by shore 'Y' stations of details of certain foreign radio communications traffic, and the maintenance of a very small shore D/F organization. A small amount of traffic was also collected in the Fleet for the 'Y' service.

The 'Y' service expanded enormously during the war, and had added to its functions:—

(i) Interception and analysis of radio non-communication transmissions, mostly on the V H/F and higher frequency bands, known as 'Noise Investigation'. This was carried out both ashore and afloat.

(ii) Interception of radio communications traffic, both ashore and afloat, of special types where immediate tactical advantage could be taken of the results. This work, which is of particular importance to the Fleet, is dealt with in Chapter III.

(iii) Provision of personnel and information for the tactical use of D/F afloat.

D/F in general is dealt with in Chapter IV.

It is not a function of the 'Y' service to carry out the careful analysis of communications traffic necessary to 'break' codes and cyphers, but close liaison is maintained with any central analysing authority set up for this purpose in war.

Headquarters Organization of the 'Y' Service

2. The general control of the 'Y' service has long been a joint function of DSD, who provided the means, and DNI, who makes use of the results. Between the two world wars a single communications officer, appointed for duty with DSD and DNI, was able to look after the skeleton service; shortly before 1939 a special section was formed and was known as Section 9 of both Signal and Intelligence Division. The head of this section eventually became a Captain and a deputy director of the Signal Division. During the war this section was expanded to a strength of about forty, and included several scientific officers.

This section performed the following functions:—

(i) Administration of the shore 'Y' and D/F service, in detail as regards U.K., and broadly as regards the service abroad.

(ii) General organization of the 'Y' and D/F watch kept ashore throughout the world, with detailed control of those stations in the North Atlantic Area where the Admiralty was actually conducting operations.

(iii) Organization of the necessary communications between naval 'Y' and D/F stations, Admiralty and the central analysing authority.

(iv) Close liaison with the central analysing authority to ensure that the latter's requirements for traffic interception were met, and that technical advice was provided as necessary.

(v) Advice to DSD and DRE regarding the provision of personnel and equipment, ashore and afloat, for 'Y', D/F (apart from navigational D/F), and noise investigation; the actual provision of personnel and equipment for use ashore was dealt with by the section following bulk supply by DSD and DRE.

(vi) Collating from the central analysing authority and any other intelligence sources any useful information about technical features of enemy radio, and drawing the appropriate Admiralty department's attention to it.

(vii) Preparing information about enemy radio which would be of value to 'Y' and D/F operators, and circulating it, usually in the form of C.Bs.

Apart from the central Admiralty organization each Commander-in-Chief had a 'Y' officer on his staff and a local 'Y' centre. These were responsible for organizing the 'Y' and D/F services ashore and afloat in their areas, conforming to the general lines of Admiralty policy while meeting any special local requirements. The local 'Y' centres were capable of extracting a certain amount of information of immediate value, and, in important areas, were backed up by local analysing authorities. Communications intercepts which could not be dealt with locally were forwarded to the central analysing authority in the U.K.

Inter-Service and Inter-Allied Co-operation

3. The central analysing authority was a department of the Foreign Office, manned by a mixed service and civilian staff, and served all Government departments besides the Armed Forces.

Close 'Y' liaison between the H.Q. of the Naval, Military and R.A.F. services was achieved through the SIGINT Board, whose members included the three 'Y' directors. This Board shaped general 'Y' policy; liaison was also maintained right down the scale and any station of any Service, intercepting material likely to be of use to another Service, would at once pass it to the appropriate local authority.

For a large-scale operation, such as the Invasion of Normandy, a special inter-Service Board was formed to achieve economy of effort in obtaining the required intelligence, and to ensure that all Intelligence obtained was made available at once to all the Services.

At the time of Pearl Harbour the American 'Y' service was less developed than ours, and much assistance was given in getting the American service swiftly on to a war basis. Thereafter co-operation was very close, and all results were made immediately available to each other. Organization was co-ordinated to secure economy of effort and prevent duplication; and in some cases (*e.g.* Australia), 'Y' was actually organized on a combined basis with mixed staff.

Interception of Communication Traffic

4. The pre-war collection of traffic was mainly carried out in the U.K. at Flowerdown and Scarborough, with overseas centres in Malta and Bermuda. A small amount of traffic was collected by ships, when they had operators to spare, mainly to familiarize operators with the requirements of a 'Y' watch.

The expansion of the interception service ashore is clearly shown by *Diagrams* 1 and 2.

A particular problem of the 'Y' service was the rapid clearance of intercepted traffic to the central analysing authority, and the provision of quick communication between the latter and the overseas analysing authorities (both British and American). Where possible the normal W/T fixed services were used, but in busy operational areas these were already overloaded with normal operational and administrative traffic. In consequence a number of special 'Y' links had to be provided.

The analysing authorities required from the 'Y' stations not only the actual messages but also all possible radio information which would assist in identification and analysis. 'Y' operators were required to add any remarks of value, such as whether transmission appeared to be from a ship or shore station, time, frequency, any enemy operator's idiosyncracies, etc.; D/F bearings and results of radio finger printing also helped.

Intercept stations were in control of, and in direct touch with, numbers of D/F stations, both to guide the latter on to ships' transmissions and to fix the position of new shore stations.

The Results of Communications Interception

5. It is not intended to set out here the results obtained by the analysing authorities, but it can be stated that handsome dividends were paid on the effort put out. The results of tactical 'Y' are discussed in Chapter III.

Noise Investigation

6. At the beginning of the war intercept watch was centred entirely on radio communications, but with the advent of radar and radio navigational aids it soon became necessary to organize intercept watch for these 'Noises' in order to ascertain progress made by the enemy in using these new features of radio, and to turn such use, where practicable, to our own advantage.

The first naval noise investigation was carried out towards the end of 1940 to determine the characteristics of enemy radar in the Pas de Calais, so that suitable counter-measures could be initiated for the protection of our convoys. At much the same time assistance was given to the R.A.F. in elucidating and countering the radio aids used by enemy bombers over the U.K.

The R.A.F. organization expanded continuously from 1940 onwards, since, once they had effectively countered the enemy aids over U.K. they were called on to assist our growing bomber offensive over Europe by upsetting the German radio warning and control systems there.

Naval effort, however, marked time till about 1942, as there were few important German naval noises to work on. The commencement of large-scale amphibious operations was the next spur; it was soon clear that, if assaults were to achieve any tactical surprise and avoid crippling damage from radar controlled coastal batteries, careful pre-investigation of enemy coastal radar and initiation of suitable counter-measures was essential. Obviously the problem would become more acute as we got closer to the heart of enemy resistance, where his coastal defences would be stronger.

The problem was not only one of obtaining intelligence to enable jammers, etc., to be designed, but also to provide noise investigation personnel and equipment to ships concerned so that any jammers fitted could be used to the best advantage.

In most amphibious operations noise investigation equipment and personnel, always in short supply, were specially arranged and temporarily installed, being shifted to other urgent 'customers' as soon after as possible. Towards the end of the war a measure of standardization was achieved in the equipment and personnel supplied to ships, and a policy for future fitting and complements laid down. It was clear, however, that such standardization was only possible for the larger ships of the Fleet and that pools of equipment and personnel would always be needed for supply to landing craft and other special vessels, who would need it during operations but would have neither the space nor the maintenance facilities to retain it on board normally.

Meanwhile the Americans in the Pacific had been faced with a rather different noise investigation problem. There distances were great and, besides amphibious operations, there was more chance of surface engagement and attacks by enemy naval aircraft. Information was sorely needed about enemy coastal radar, both for long-range amphibious assaults and for air strikes on shore targets — particularly to discover 'blind' radar areas in which forces (both sea and air) could approach undetected. Information was also needed about enemy ship and airborne radar so that appropriate counter-measures' equipment could be produced. To obtain this information much use was made of specially fitted 'Ferret' aircraft, and by including noise investigation equipment in ships, and especially in submarines, operating in enemy coastal waters, or subject to attack by enemy surface and air forces. For these reasons noise investigation developed rapidly in the U.S. Navy; their results were communicated freely to us, and steps were in hand at the end of the war to bring the British Pacific Fleet up to the same standard.

A further use of noise investigation under development at the end of the war was the tactical possibility of D/Fing enemy radar transmissions and using this knowledge to evade or to take up an advantageous position; the value of this depended on the fact that radar transmissions can be intercepted well outside radar detection range, and necessitates the force exploiting the method keeping outside such detection range. Although diminishing enemy surface effort precluded operational use of this art, it may well be of importance in any future conflict.

Naval noise investigation started ashore but clearly its future lies mainly afloat and in the air, since radar ranges are comparatively short and shore stations can only intercept them when the enemy is close at hand.

The Results of Noise Investigation

7. Practically all successful R.C.M. work in the war was initially due to noise investigation, and the two are essentially partners.

The main successes were:—

(i) the countering of the enemy coastal radar chain in the Straits of Dover;

(ii) successful jamming of enemy coastal radar in amphibious operations thus permitting a measure of tactical surprise and subsequent protection against coastal batteries;

(iii) masking of feint operations by deliberately inadequate jamming, so that the enemy should 'see' something but be unable to determine details.

(iv) the general success of the U.S. Navy in the Pacific in countering enemy radar.

(v) the countering of enemy radio-controlled missiles (see Chapter VIII).

CHAPTER III

COMMUNICATIONS INTERCEPTION—TACTICAL

General Development

THE possibility of the 'Y' organization being able to provide immediate information of tactical importance was not properly realized in 1939.

Starting in 1940 with the shore interception of German Naval R/T from E-boats operating in the Straits of Dover, this form of 'Y' soon proved of great value; the shore organization was developed to give coverage of coastal waters to the south and east of England, and later extended to the Mediterranean.

'Y' afloat started in coastal escorts as an extension of the shore organization, but it was not long before the Fleet appreciated the possibilities of direct R/T interception especially of air traffic, the immediate intelligence to be gained from the state of enemy operational communications, and the solution of low grade enemy tactical codes used in action.

By the end of the war provision of space and equipment in destroyers, and above, for 'Y' afloat was the established policy.

Interception of German Naval V H/F R/T in U.K.

2. In mid-1940 there was some suspicion that German E-boats were using V H/F R/T; this was quickly confirmed in June when a small intercept station, manned by linguists, was opened at South Foreland. Traffic was mostly in P/L and was clearly of operational value. Further stations were erected round the south and east coasts, eight being ready by the end of 1940. Each station, though sited as high as possible, could give coverage over a radius of about 25 miles only; so many were needed if adequate coverage was to be secured as German operations extended.

As we gained experience it was found possible to close some stations as redundant, and in particular the south coast chain was no longer needed after the liberation of France; the east coast chain continued in operation right up to the end of the European war. A few mobile stations were found of use to cover gaps in the chains when necessary.

Stations were manned almost entirely by WRNS linguists; a few male technicians and some W/T operators (both male and female) were also employed.

At first each station telephoned intercepted traffic direct to the duty staff officers at Naval H.Q. It was found, however, that these officers were too busy to assess the importance of this information, and in consequence opportunities for action were missed. In March 1941 small intelligence centres were set up in the H.Q. concerned (usually alongside the plot) and manned by WRNS with experience of intercepting the traffic. These centres, with quick access to staff and plot, could organize the intercept watches to the best advantage (increasing coverage when trouble was likely and easing it at slack periods), assess the value of information passed in and see that it was presented to the right quarter for action. If they needed further advice they could refer quickly to the central analysing authority.

Diagram 3 shows the U.K. organization at its peak period.

In order to extend the range of the V H/F intercept range to beyond that of 'line-of-sight range', work was undertaken which involved the flying of special intercept receivers on barrage balloons up to a height of 5000 feet. Trials were carried out in 1941-42 in the Cornwall, Dover and Portsmouth balloon barrages and the project was finally taken over by the R.A.F. Little new intelligence was gained by these means, though naturally a larger number of signals were intercepted than with receivers on the ground, but the effort involved did not compare with the results obtained.

Operational Results of V H/F R/T Interception in U.K.

3. Up to 1942 German E-boats talked freely, and the 'Y' organization was usually able to keep Commanders-in-Chief informed of German coastal operations and intentions. Information could usually be given on the following points:—

(i) position of E-boats waiting for convoys (the German habit of leaving transmitters switched on for periods was a great help in accurate D/F);

(ii) tactical handling of E-boats prior to and during an attack;

(iii) withdrawal of E-boats and damage sustained by them;

(iv) positions of E-boats engaged in minelaying.

Swift and obvious action could often be taken by the staff, such as diverting convoys, putting escorts on to the enemy, and initiating minesweeping.

Although after 1942 the Germans realized the dangers of using V H/F R/T so freely, and kept silence except during attacks, the intercept stations could still provide some useful information. The very fact that the Germans had to limit their use of R/T cramped their operations, and improvements to our coastal radar more than offset the decrease of our 'Y' information.

The German Air Force used the same frequency band as their E-boats; this traffic was covered by the R.A.F., with whom a close liaison was maintained so that naval traffic picked up by R.A.F. stations, and vice versa, could be quickly passed to the right quarter.

It is of interest to note that the German Navy made no technical V H/F progress during the war, and never moved from the 35-50 mc/s band, thus greatly simplifying our task.

V H/F R/T Interception in U.K. Coastal Escorts

4. The success of the shore organization pointed to the desirability of providing somewhat similar 'Y' facilities afloat in the frigates and destroyers countering the enemy E-boats; this would give increased coverage to seaward, and would also provide commanding officers with immediate interpretation of traffic from nearby E-boats.

It is of particular interest to note that the whole idea of 'Y' afloat sprang from its success ashore in these operations, and it might well be that, had E-boats kept silence when near our coasts, a very long time would have elapsed before we started 'Y' afloat at all.

Starting in April, 1941, the Service (and later other sources) were combed for linguists who were given a very short course and then rated Writer (Sp). As linguists were normally of above average intelligence the proportion of officers was fixed at a third of the total numbers. The majority of frigates and destroyers engaged on coastal duties round the south and east coasts of the U.K. were fitted with special intercept receivers (code name 'Headache') and a target of one officer and two rating linguists per ship was set, though the practical exhaustion of supply of linguists by 1943 seldom permitted this target to be achieved. Apart from actual interception duties afloat the officer linguists were responsible for maintaining close touch with the shore organization, and seeing that the results of operations were properly analysed.

Many ships were fitted with V H/F D/F as well — FV3 at first and FV7 (a much more sensitive set) later. Ratings with some linguistic ability, but not fluent enough for R/T interception, were used to operate these sets.

If at first commanding officers were inclined to regard the 'Headache' organization as another encumbrance, they soon appreciated its value in revealing enemy intentions before the latter even began to execute them. Many actions were brought about solely through 'Headache' information, and timely warnings of torpedo fire saved several escorts.

V H/F R/T Interception in the Mediterranean

5. Although U.K. requirements had priority some 'Headache' receivers and linguists were sent to the Mediterranean in early 1942, and a number of ships were fitted. Shore stations were also erected in areas where it was thought enemy E-boats might operate.

Most enemy R/T traffic took place during early 1943 between Philippeville and Cape Bon, and thereafter traffic decreased. In actual fact the 'Headache' parties were found of most value in reading air traffic in this theatre.

The majority of the personnel were withdrawn for the Normandy Invasion, the few left being formed into a Fleet pool from which small parties could be supplied to ships engaged on special operations.

'Y' in the Fleet

6. The successful use of 'Headache' parties in coastal escorts soon led to demands from the Fleet for temporary parties whenever operations in enemy coastal waters were contemplated. At the same time the value obtained by the R.A.F. from enemy air traffic (largely P/L R/T) led to demands for suitable interception parties whenever Fleet units were proceeding into waters where heavy air attack was likely, as for instance Malta or North Russian Convoys. At first these air interception parties were provided by the R.A.F., and included personnel trained in breaking tactical codes; later naval parties were also trained for these duties.

From 1942 onwards it became common practice to embark some or other of the following special personnel whenever large-scale Fleet operations were expected:—

(i) officers and ratings trained to provide warning and intelligence from the state of enemy operational W/T traffic;

(ii) linguists trained in the interception and immediate interpretation of air and ship P/L R/T;

(iii) parties trained in simple code breaking;

(iv) 'Y' operators to gather material for (i) and (iii).

Linguists proved of value to any ship, but it was found that other special 'Y' parties were best placed in flagships. In private ships the secrecy of their work tended to militate against its effectiveness as there was no operational staff to appreciate what they were doing and see that they received proper consideration and facilities; also the results of their work took too long to reach staffs who could act on them (especially with congested communications and the need to cypher their reports).

Useful results from 'Y' afloat were obtained in all operational theatres, but the organization reached its maximum development in the Pacific, partly because immediate interception of the heavy Japanese air traffic was of the greatest tactical value, and partly because the shore 'Y' organization (of necessity rather 'far back') left gaps which the Fleet had to fill.

Whenever 'Y' parties were employed afloat some means of providing them with immediate information from the shore 'Y' organization had to be devised, so that they could be given up-to-date guidance on the general state of enemy traffic, etc.; eventually a special shore-ship broadcast, read only by ships with 'Y' parties, became a standard feature of Fleet W/T organization.

It was also found necessary to maintain close personal liaison between the ship and shore 'Y' organizations; ships' 'Y' parties returned periodically to shore 'Y' centres so that they could obtain information regarding latest enemy practices.

Thus, from being an extemporised accessory, 'Y' afloat became an essential feature of Fleet W/T organization; this was recognized by the provision of space and standard equipment in flotilla leaders and above. As regards 'Y' personnel experience showed that it was best not to lay down rigid complements, but to provide Commanders-in-Chief with pools of personnel who could be lent to ships as necessary.

Mobile 'Y' Equipment

7. Various extemporized mobile equipments were at first provided to fill gaps in the U.K. coverage, and later to enable stations to be set up rapidly in the Mediterranean. Eventually a standard mobile station, known as a 'MONWHY' was evolved.

'Monwhys' were used in Normandy but produced little result as the German E-boat reaction to the Invasion was so feeble. They were also supplied for the Far Eastern campaign, but the sudden end of the war prevented them from demonstrating their value.

Lessons Learned

8. (i) 'Y' afloat for tactical purposes, both in the 'Headache' form and in the provision of 'Y' parties, has come to stay. Space must be left in ships so that the necessary personnel and equipment can be supplied as soon as those features of enemy W/T most likely to yield tactical information have been determined.

(ii) As a corollary to (i) the organization to design and provide suitable 'Y' equipment quickly must be kept in embryo.

(iii) Direct interception of P/L R/T can be of value to any ship, but other 'Y' parties are best placed in flagships.

(iv) An exclusive shore-ship 'Y' broadcast is a requirement in future Fleet W/T organization.

(v) 'Y' personnel are best organized in Fleet pools, from which the C.-in-C. can draw ship parties as necessary. This also enables the ship 'Y' personnel to be attached to the shore 'Y' organization and brought up to date between spells of duty afloat.

CHAPTER IV

D/F

General Development

WAR development of D/F was chiefly concerned with the H/F and higher frequency bands. All nations had made considerable progress in L/F and M/F D/F between the two world wars, practical results were common knowledge, and everyone knew that an accurate fix was likely to be taken of any ship transmitting in these bands.

As regards H/F D/F, British Service and commercial interests had made considerable progress before the war, and many of the results had been published. The Germans, however, had taken little interest in it and completely failed to appreciate its tactical possibilities. In consequence the U-boat W/T organization permitted the free use of H/F for communication, and it was a long time before the Germans realized the value we were getting from their transmissions. When the enemy did appreciate the danger, his operational methods precluded him from abandoning the use of H/F, though steps were taken to make our D/F task as hard as possible. H/F D/F by shore stations showed its strategic importance early in the Battle of the Atlantic, when it enabled danger areas in the immediate vicinity of D/F fixes to be indicated. Much experience was necessary, however, before a tolerable degree of accuracy in fixing was achieved. H/F D/F in ships quickly proved a valuable tactical weapon of which it was said by the Director of Anti-U-boat warfare:—'H/F D/F was the first device to enable A/S escorts to take the initiative.'

V H/F and U H/F D/F were entirely war developments, arising from the need to fix the source of radar and V H/F communications transmissions. Valuable results were obtained, but the art was still in its infancy at the end of the war.

This chapter deals with the development of the D/F organization ashore and afloat, and the uses to which it was put. Chapter V deals with technical development.

L/F and M/F D/F

2. In the very early stages of the war German ships and U-boats occasionally made M/F transmissions, apparently to assist in homing consorts, but they quickly found such tactics were dangerous. We had a skeleton shore M/F D/F organization in 1939, and it was retained throughout the war in case the enemy again used M/F. It proved, as expected, of little practical value, but it often fixed our own ships (on request) to assist them in navigating in thick weather near the U.K. The remarks on control and communications of D/F stations (para. 3) apply equally to these stations.

L/F-M/F D/F sets were a standard feature of all our own destroyers and larger ships, but were used primarily for navigation, to home on aircraft shadowing U-boats, and to check the position of units in contact with enemy surface forces (an L/F reporting wave was included in the Fleet W/T organization for this purpose, though the primary channel for reports was H/F or V H/F). In at least one engagement with enemy major units (*Scharnhorst*) our main body was homed on to the enemy by L/F transmissions from shadowing units.

H/F D/F Ashore

3. Although it was generally known pre-war that shore stations could take bearings of H/F transmissions, and in fact a few firms (like Marconis) had developed

equipment for the commercial market, so many factors introduced errors at long ranges that the enemy had been led to discount the value of H/F D/F. In consequence German and Italian U-boats were very free with their use of H/F, and even surface vessels and raiders used it to a greater extent than was strictly necessary.

The reasons for German neglect of the subject in the early stages of the war, and for their subsequent failure to develop the art satisfactorily, are given in Chapter X, but it was a very fortunate thing for us that they were so ignorant and unappreciative of its capabilities.

On the other hand, we had devoted a lot of effort pre-war to the subject, and had found that, given good sites and equipment, coupled with skilled operators, we could take reasonable bearings of long-range transmissions. Our knowledge of D/F plotting was, however, rudimentary, and we had not yet appreciated the necessity for statistical analysis of performance.

As a result of our experience we had a skeleton shore organization in 1939 comprising several stations, in the U.K., with others at overseas bases (*e.g.*, Malta) and in the Dominions. This skeleton organization gave us rough fixes of raiders and U-boats in the early stages of the war.

This skeleton organization was rapidly expanded to provide world-wide coverage, and by the end of 1941 H/F D/F stations were in operation as follows:—

U.K. and North Atlantic	16
Mediterranean	5
Indian Ocean	4
Far East	4
West Indies	3
South Atlantic	3

The problem of control of D/F stations was a difficult one, as the early D/F stations could watch only one frequency. It was therefore necessary, wherever possible, to place a number of D/F stations under the control of a main Y station, so that the latter could quickly guide the D/F stations on to any particular frequency on which an enemy ship might be heard. In some cases, where central control was impossible, small Y stations had to be set up in association with a D/F station so as to extend the number of frequencies with which the D/F station could deal. Later D/F stations were designed to enable four frequencies to be watched simultaneously, and this facility proved invaluable for stations abroad.

By 1942 it became evident that the results achieved, particularly on the North Atlantic network, were not showing an improvement commensurate with the increased resources devoted to D/F. After a thorough investigation, measures were taken, which resulted in a gradual improvement. It may be of value if the main lessons thus learnt are listed.

(a) *Maintenance*

The selection and training of maintenance staff had not kept pace with the expansion of the network. A highly-qualified engineer from Cable and Wireless was now made responsible for the technical efficiency of Y and D/F stations. Under his direction, a staff of properly-qualified civilian radio engineers was recruited, and a comprehensive maintenance scheme, with periodical reports, was instituted.

(b) *Analysis of performance*

A statistical and scientific section was formed in 1942 to study and advise on ionospheric data. The work of this section soon developed into an analysis of performance of stations and of operators, which immediately proved invaluable as a check on maintenance and operating standards. As the work of this section developed, it formed the basis of the first approach to a scientific method of D/F plotting, which is dealt with at length later.

(c) *Siting of stations*

It was decided to abandon the policy which had led to the erection of a large number of single stations in the United Kingdom in favour of a small number of group stations, each consisting of four or five huts separated by a few hundred yards. The main reasons for this were:—

(i) An improvement in performance which was expected to result from using an averaged bearing from several D/Fs.

(ii) Better maintenance should result from a simplified organization.

In pursuance of this policy, four D/F group stations were opened in 1944. Insufficient information was available by the end of the war to establish whether the optimum spacing of huts in a group had yet been discovered.

Communications

4. Rapid communication between a control centre and its group of D/F stations was an obvious necessity if the latter were to be 'coached' on to short enemy transmissions. This latter involved a telephone or radio network, and unless this could be provided it was of little use forming such a control group.

Where control groups could be formed rapid communication between control and plotting centre was also needed, and usually available either by telephone or fixed W/T service (since 'Y' centres had to be in quick touch with Admiralty or their C.-in-C. for their other work). In the case of isolated D/F stations the problem of passing bearings quickly to a plot was often difficult, and usually meant providing special communications to the nearest cable point or naval W/T station.

It was found necessary to provide signal-to-line facilities between the 'Y' stations and D/F stations so that a signal received by the 'Y' station could be transmitted over the telephone system and compared by the D/F operator with the signal that the latter was receiving. This made the recognition of signals much quicker and easier. Such a system became virtually a necessity in the H/F D/F organization for speed: it also helped to reduce the number of bearings taken on incorrect signals, in error.

Communications were far too slow in the early days of the war. Often a few bearings would arrive quickly from local stations, but there would then be a wait of hours while the more distant stations reported. In a big centre like the Admiralty there were apt to be internal delays owing to the mass of general traffic being handled. These difficulties were steadily overcome by improving coding systems, making the form of D/F reports distinctive so as to expedite handling, improving actual communications and by internal organization (for instance in the Admiralty a Tactical Urgency section was formed in the War Registry to handle operational signals including D/F bearings). In the Atlantic a further improvement was made after the U.S.A. came into the war by forming the D/F stations into three groups, reporting respectively to London, Washington and Ottawa, these centres being in constant direct inter-communication.

Plotting and Evaluation of D/F Ashore

5. Plotting in the Admiralty was carried out by officers (all except one of them ex-civilians), with no special qualifications or training for this work. It was soon found that the task of estimating the Most Probable Point of a transmitter, from a 'cocked-hat' resulting from many bearings of differing class and reliability, called for a more scientific approach. There was, for example, an early tendency to regard

a series of positions resulting from the intersection of as few as two bearings as capable of providing precise information on the course and speed of an enemy unit.

The formation of the statistical and scientific section in 1942 marked the first important advance in plotting technique. It now became possible for the plotters, in assessing the Most Probable Point, to give greater weight to bearings from stations of known reliability. This work led the statistical and scientific section to investigate the possibilities of devising a plotting system which would be entirely objective, and independent of the experience and skill of the plotters.

Finally, in 1944, a mathematical method of D/F plotting was evolved, which enabled two unskilled persons of school certificate standard, after five weeks' training, to give the Most Probable Point and the lengths of the major and minor axes of the ellipse of 80 per cent probability, with the true bearing of the major axis

Comparative trials with the Admiralty plotters, in 1945, showed that the Admiralty Mathematical Method, in unskilled hands, gave rather better results than the Admiralty plotters could achieve, after several years' experience, with their ordinary methods.

The war ended before this method could be adopted operationally. In its original form it was rather cumbersome and slow, though readily capable of refinement.

The main lessons learnt during the war in the field of D/F plotting may be summarized as:—

(a) The necessity for scientific analysis of D/F results for plotting of any accuracy.

(b) The supreme importance of an objective method of D/F plotting which is independent of the skill and experience of the plotters. It should be noted that the skill which the Admiralty plotters had undoubtedly obtained by the end of the war was acquired at heavy expense.

(c) The value of the American system of border co-ordinates on D/F plotting charts, which enables bearings from any station to be plotted on any charts. This system also avoids the necessity for reprinting charts whenever a new D/F station is opened or an existing station moved.

(d) The importance of segregating D/F plotters from all other sources of intelligence, such as sighting reports. This is particularly necessary, when an objective plotting method is not used, to avoid 'wishful' plotting.

Enemy Counter-Measures to H/F D/F

6. The enemy did eventually realize that we were making valuable use of his H/F transmissions, but he never really appreciated how accurate our system became since he lacked large-scale experience of taking and plotting H/F D/F bearings. Enemy operational methods and the W/T equipment fitted in U-boats prevented him shifting his W/T organization, but he did attempt to make our D/F task very difficult by constant frequency shifts and by manual and automatic means of shortening transmissions.

By this time cathode ray presentation had so advanced the technique of D/Fing brief signals, and the 'Y' organization was so quick in following frequency shifts, that the counter-measures proved of little more than nuisance value.

In 1944 the Germans were developing a system of automatic transmission from U-boats which would cut the length of signals to about half a second; by a very fine intelligence effort we intercepted the sea trials of this apparatus and designed D/F equipment to keep pace with it. In fact this new gear was only just going to sea in May, 1945, but we were confident that, provided frequency was known from 'Y' or other sources, we should still be able to intercept a fair proportion of U-boat signals.

Operational Results of D/F Ashore

7. The Submarine Tracking Room in the Admiralty, which kept a very detailed plot of the movements of all U-boats in the Atlantic, depended to a great extent on the H/F D/F organization for its data. As the diversion of convoys and independently routed merchant ships to clear concentrations of U-boats, and the routeing of aircraft and surface hunting groups, was largely determined from this plot, the value of H/F D/F is clear.

H/F D/F also gave the clue many times to the position of enemy surface raiders and enabled our cruisers to be sent to good positions to intercept them. H/F D/F again played a big part in keeping track of major enemy units on their rare break-outs, and assisted in bringing our surface and air forces into contact.

Naturally the accuracy of fixes depended on the strength of the D/F organization in the area concerned. In the North Atlantic at the close of the European War the degree of accuracy achieved in fixing a U-boat making a brief transmission was of the order of four-to-one 'on' her position being within a specified area of about one hundred miles square — accuracy improving with longer transmissions.

H/F D/F Afloat

8. In 1940 it was appreciated that H/F transmissions had become an indispensable feature of U-boat operations, especially in connection with pack tactics. Although we had tried H/F D/F in ships pre-war without much success, it was determined to make another effort with improved sets carefully fitted in two destroyers to see whether they could, with specially trained operators, get bearings on the ground wave of nearby U-boat transmissions. Successful results were obtained during a heavy attack on a convoy in mid-1941, and fitting was quickly extended to other vessels.

It was found that H/F D/F afloat could be made to give satisfactory results if the aerials were given the masthead position (at the expense of radar), ships were carefully calibrated, and officers and operators carefully trained in using and maintaining the sets. At the end of 1941 a new set, incorporating visual presentation of bearings, still further improved results, and skilled operators were even able to make some estimate of range.

H/F D/F rapidly became a potent anti-U-boat weapon, locating victims beyond the range of radar and often leading the hunters into a range at which radar and asdics could complete the kill.

From 1942 onwards a number of merchant ships were also fitted; particularly those ships which normally made the Atlantic run. The radio officers of these ships received the same training as the naval D/F operators. By the end of the war it was usual for every North Atlantic convoy to include at least three H/F D/F ships, some being in the convoy itself and others in the escort.

Frequencies used by U-boats were well known and H/F D/F watch could be organized on a guard system. Each ship had an extra receiver in its D/F office so that operators could watch two waves with split earphones. Special inter-communication was arranged between D/F offices of ships so that any operator picking up a signal could shift all H/F D/F guards to the frequency and so get cross bearings.

It is strange that the enemy never really appreciated the tactical value we were getting from H/F D/F, even after 'Y' watch in one of his U-boats had revealed our methods. Probably his lack of experience led his staff to discount the actual value we were getting.

H/F D/F played little part in the Japanese war, as the Japanese submarines normally maintained W/T silence.

Whether H/F D/F afloat will play much part in any future war depends on the communication tactics adopted by the enemy. To keep the art alive and to be ready for any future emergency, destroyers and other A/S escort vessels will still be fitted with H/F D/F.

V H/F and U H/F D/F

9. Following the development of the V H/F R/T interception service, ashore and afloat, in connection with anti-E-boat operations, there was a call for V H/F D/F equipment to fix the enemy's position. Early sets were extemporized from existing components and gave an accuracy of a few degrees up to a range of about seven miles; such results proved of value and numerous sets were fitted ashore and afloat. Later in the war a more sensitive and more accurate set was produced.

A few V H/F D/F sets were produced for special ships, such as H.Q. ships and F.D. Tenders, for use on enemy aircraft communication frequencies.

Apart from these there was no call to D/F radio communications on V H/F, since the enemy made little other use of the band.

As we were generally superior to the enemy in radar little need was found for D/F equipment to locate his sets, but a few special instruments were produced when required, *e.g.*, for locating coastal radar sites prior to a landing. The enemy with his inferior radar, developed many ingenious instruments for this purpose, and has definitely pointed the way to future development. At the end of the war we had two high grade equipments under development for general — as opposed to specialized — use in the Pacific theatre.

CHAPTER V

'Y' AND D/F—SCIENTIFIC AND TECHNICAL RESEARCH AND DEVELOPMENT

Communications Interception Receivers

NO H/F receivers were specifically designed for 'Y' work, but by using several different types of high grade commercial receivers it was possible to cover technical requirements. Lack of standardization did not much matter where shore stations were concerned, but when 'Y' receivers were required for ship fitting later in the war standardization for this purpose was obviously necessary. Ship requirements could however be met adequately by the B28, then in good supply.

For V H/F R/T interception the American S27 series proved very satisfactory.

Noise Investigation Receivers

2. When noise investigation started towards the end of 1940, only one British V H/F receiver (P15) was available, and this was used for the detection of the enemy coastal radar chain, operating on 350-400 mc/s. There were, however, also available two American V H/F and U H/F commercial receivers (S27D and S27C). By the end of 1942, sufficient models of suitable receivers had been developed which, with the American receivers, provided complete coverage of the frequency spectrum from 30 mc/s to 3000 mc/s. In view of the very limited resources available, both experimental and productive, all effort was concentrated on those receivers which it was thought would *most likely* be required in any numbers.

Many difficulties were encountered in working in these comparatively unknown frequency bands, and it took a long time to overcome them, particularly as the frequencies used rose ever higher. The chief difficulties were in the design of suitable valves and tuning circuits, and in the provision of accurate laboratory measuring equipment.

We had, however, one great advantage in that samples of all types of enemy radar transmissions could usually be intercepted on the South Coast of England, and therefore practical scientific tests were easy.

Development of receivers proceeded along two main lines — General Search Receivers for intercepting, measuring and analysing transmissions, and Monitor Receivers for use in conjunction with jammers.

A third type, mainly used by the scientists, was the Initial Intercept Receiver; this consisted of an untuned device, covering a particular frequency band, and was used for seeking evidence of any fresh enemy radar band. These receivers were practically all laboratory models, and only used at special stations.

General Search Receivers

3. Appendix A shows that a good many receivers were designed during the war, an inescapable feature where a new art is concerned. It will be seen that the 300-600 mc/s band, in which most enemy types of radar were found, was fairly well covered, but we had to rely on American Lease-Lend sets chiefly for the 30-200 mc/s band, and the 200-300 mc/s band was never really properly catered for.

Fortunately sufficient suitable receivers were available by about 1943 to cover all important enemy naval radar bands, but we were always anxious about developments towards the 3000 mc/s band. To this end two laboratory types of superhet search receiver were developed to enable periodic checks of this frequency band to be made. It was only right at the end of the war that we were in a position to supply general search receivers covering the 3000 mc/s band — a definite requirement for the Japanese War, as it was suspected that the Japanese were using radar of this frequency.

Main developments of receiver technique were:—

(i) Simplification of controls, especially the introduction of single knob tuning. It was found essential to give the operator an easy set to handle, even if some sensitivity had to be sacrificed.

(ii) Reduction of intermittent contact noises by the development of alternative types of non-contact tuning circuits and thus eliminating the offending sliding contacts which were a feature of all the early U H/F circuitry.

(iii) Provision of aural output to headphones at the final stage of the receiver, plus a video frequency output, through a video frequency amplifier, to an oscilloscope. Some of the later sets had provision for video examination of the waveforms at intermediate stages of the receiver.

(iv) Circuit improvements. Superhets proved the best receivers for this purpose. They were improved by providing balanced input circuits, wide band I.F. circuits to give distortionless amplification of pulses, and co-relation of R.F. and I.F. circuits to give good image signal rejection.

(v) Development of pulse lengthening and trigger output systems to facilitate detection of short pulse signals and to enable pulse rate to be counted.

Monitor Receivers

4. At first search receivers were perforce used for monitoring jammers, but improvements were needed to:—

(i) give accuracy of frequency measurement;

(ii) secure complete elimination of image signal;

(iii) enable incoming signal and jammer frequency to be accurately aligned.

The first true monitor receiver was the P39 — a development from P33 — with image rejection secured by having a very high I.F. mid-band frequency. The output of this was lined up with a marker oscillator and the frequency of the latter and of the associated jammer were displayed on a panoramic display unit, thus facilitating accurate alignment. The system permitted enemy frequency changes to be followed in a matter of seconds. A modified P39 was subsequently produced for use afloat.

Special Receivers

5. Apart from production models many special receivers were made for particular work, and as a rule these were handled by selected operators. An example of this kind of work was the fitting out of an M.T.B. for noise investigation duties off the coast of France prior to the Normandy Invasion, so that detailed intelligence of enemy coastal radar could be obtained. Another example is the production of a few initial intercept receivers mentioned in para. 5.2 and the production of laboratory types of superhet general search receiver mentioned in para. 5.3.

Automatic and Panoramic Reception

6. For ship use the sole development of automatic reception (*i.e.*, low speed frequency sweep) was the adaptation of certain receivers, notably the P29, to auto

tuning. This was done for the benefit of operators in small ships, where fatigue was great. Auto tuning did not give such satisfactory results as manual tuning owing to the greater flexibility of the latter.

Panoramic reception (*i.e.*, high speed frequency sweep in conjunction with a calibrated visual presentation of intercepted signals) is designed to show all signals intercepted in a particular frequency band. Its use in conjunction with monitor receivers has already been described. It was tried out for general noise investigation, but was not very suited to it; it is essentially a sampling process in that any one frequency is covered for a time dependent on the ratio of the I.F. band width to the band covered, and also on the rate of sweep. If the transmitted energy be periodic (*e.g.*, morse or pulse) no energy may be emitted during the period in which the receiver is tuned to the nominal frequency of the signal; the situation may be further complicated if the transmitter employs a scanning aerial system. The general result is that violent amplitude changes occur in the visual presentation of the signal. Other troubles encountered were eye strain, image jitter and the impracticability of examining the characteristics of a transmission without stopping the panoramic sweep.

Panoramic reception was, however, found useful for the interception of missile signals — rapid switch from panoramic display to aural reception being provided.

For H/F reception panoramic display was generally unsuitable owing to the confusion that resulted when many signals were present, but it was found to have an application in the interception of 'Kurier' signals.

Aircraft Receivers

7. Until the formation of the British Pacific Fleet we had little need for noise receivers in naval aircraft. The R.A.F. developed these receivers very fast for their purposes, and the U.S. Navy in the Pacific also made great progress since they needed such equipment in that area.

At the end of the war we were equipping our aircraft-carriers with American sets for fitting as needed in aircraft.

Aircraft receivers are naturally compact, and usually designed for quick installation or removal. Considerable use was made of auto tuned receivers with associated recorders, so that an aircraft on a mission could make a record of all intercepted transmissions on a particular wave band without the necessity of carrying a special operator.

Photographic Recording Equipment

8. The oscilloscope was in common use before the war, and about 1938 the first photographic recording equipment was produced for R.F.P. work (*see* Chapter V, para. 10). This outfit was known as REB, and an improved model — REB2 — was evolved in 1940. Both these equipments used a film to record what was shown on the oscilloscope.

Towards the end of 1940 Admiralty Signal Establishment were engaged in conjunction with the R.A.F. in trying to determine the various non-communication uses to which the Germans were putting radio. In these investigations REB was found of much assistance, and it was not long before REB3 was designed primarily for noise investigation. The main advance in REB3 was its ability to use many different types of receiver; it also had variable film speed — the earlier models had a fixed film speed suitable for morse recording. Towards the end of the war REB4 was produced for use afloat; it was an improved version of REB3.

An ancillary equipment for use with the REB series was the G206 oscillator and the double beam (Cossor) oscilloscope, which provided a quick method of analysing simple modulation tones and of fixing pulse repetition rates. An improved version in the form of a wave analyser capable of analysing some complicated modulation tones was under development at the end of the war.

Sound Recording Equipment

9. Soon after the tactical communications interception and noise investigation organizations were established in the U.K. a need was found for some simple sound recording equipment to enable R/T transmissions to be analysed subsequently, or new noises to be recorded so that other stations could be instructed in a practical manner as to what to look out for.

Various commercial outfits were used at first, standardization being eventually achieved on disc recorders REC1 (battery operated) and REC2 (mains operated), which could be connected to the output of any receiver. These were used ashore only.

Later an American Wire Recorder (Model 50) was standardized for use ashore and afloat.

Apart from the uses outlined above, sound recorders were useful in training new operators.

Identification of Transmissions — R.F.P and TINA

10. One of the main problems of the 'Y' service was the positive identification of transmitting stations, in particular to enable movements of enemy ships to be followed. Considerable scientific effort was devoted to this problem, the particular lines followed being the identification of a transmitter by the particular characteristics of its wave form, and the identification of individual operators by their idiosyncracies.

It was well known before the war that individual transmitters, though they might be of standard manufacture, had each their own particular characteristics. In 1938 a start was made in filming and analysing wave forms of a number of foreign transmitters, and by degrees a catalogue of characteristics was built up. This art was known as Radio Finger Printing (R.F.P.).

R.F.P. was confined almost entirely to the analysis of amplitude variations although experimental work on the analysis of frequency variation was highly developed by the end of the war. At first we had very little knowledge of the effects on our picture of propagation conditions, radio-frequency variations, and the inherent variability of several characteristics such as degree of smoothing, relay effects, etc.

By degrees, however, the scientists learned to distinguish between the permanent characteristics of a transmitter and transient variations; and by the end of the war a suitable basic classification system had been evolved which enabled the transmissions of most enemy surface units to be identified. No great success was achieved with U-boat transmissions since mass production of their sets tended to reduce individual characteristics.

R.F.P. was found very useful in checking our own transmitters when used for deception purposes, to ensure that they really did correspond to the transmitters which they were impersonating.

TINA — the art of identifying individual operators — was never developed beyond the experimental stage in the Navy as it was found that mass training of U-boat operators so standardized their style that sufficiently detailed analysis was impracticable. Used in conjunction with R.F.P., however, TINA proved of some value for U-boat and surface ship identification, and a further use was found in the checking of our own operators who were engaged in deception work.

Initially TINA was confined to measuring the lengths of dots and dashes made by individuals, and comparing two messages letter by letter. In 1944 a better method of analysis was evolved as it was found that each individual tended to have his own particular method of making a certain sequence of dots and dashes — *e.g.*, the initial dot-dash of J,L.P.R. and W — and also to make his own peculiar pause in making a long letter.

Analysis of Noises

11. Certain standard means of identifying enemy radar transmissions, which could be applied by noise investigation operators, were evolved. These consisted of frequency measurement, determination of pulse repetition rate, and type of sweep. From these the probable use of the particular radar could be deduced.

If further analysis was required to obtain more detailed information it became a matter for scientists, who had to be supplied with really good film records. It became the practice for noise investigation stations intercepting an unusual signal to take records and forward them for scientific examination. Operators were briefed as to records needed to give the scientist a chance to identify the signal, and the latter could call for more records as necessary to follow up a particular point. Similar detailed procedure was followed with all types of signal in the H/F and V H/F bands.

It was proved essential for scientists engaged on this work to keep in close touch with those dealing with similar transmissions for our own purposes, since otherwise they could not tell what features were most likely to appear in particular forms of radar, etc.

H/F D/F Ashore

12. In 1939 there were two types of shore H/F D/F equipment in use, the Naval AH1 and the Marconi DFG12. The former was the more accurate, but was difficult to handle; the controls of the latter were simpler.

Both sets used the Adcock aerial system, and this proved so satisfactory that it was used throughout the war, though there were modifications to provide sense-finding, and to eliminate unwanted horizontal pick-up by the use of special earthing systems.

Up to 1942 the main effort was to produce sufficient AH1s and DFG12s to equip the many new stations, but during this time the tuning controls of the AH1 were much simplified.

The success of FH4 afloat led to its adaptation for shore use, where, used with an Adcock aerial system, it became known as AH6. This set was good, and a Signal Injection Unit was evolved with which the operator could quickly test his set for instrumental accuracy, and so provide means in the set to eliminate errors thus detected.

Marconi's had also been developing the DFG24, but this still relied on aural presentation. This set was quite good and was later improved by the addition of a special earthing system — such outfits being known as DFG24/5.

The final advance in technique, still under development in 1945, was the AH4 with a spinning goniometer and visual presentation.

Close liaison was maintained with the U.S. Navy, but they were rather behind us in technique and we did not use any of their equipment.

The main difficulty in obtaining accurate H/F bearings lay in ionospheric rather than in instrumental errors. We found, after the war, that the Germans had some experimental sets which were in advance of our technique instrumentally, but in operation these sets gave no better results than ours. An interesting attempt to reduce ionospheric errors was made by Marconi's with their 'Dot-Lock' system, by which a bearing was taken on the leading edge only of each incoming morse symbol — the theory being that this leading edge had presumably come by the most direct path and was therefore likely to give the most accurate bearing. In practice the scheme only worked on strong signals, which were the least likely to contain ionospheric errors.

A more serious attempt to reduce ionospheric errors was made towards the end of the war by grouping H/F D/F stations in lots of five, the stations of a group being spaced at least half a mile apart. In theory this diversity effect should have given a 50 per cent reduction in error, but experimental work only yielded a 30 per cent improvement, which was reduced to 10 per cent in actual operation. The grouping did, however, greatly increase the chances of picking up a short transmission, and proved worthwhile for this alone.

A final problem presented to the H/F D/F experts in 1944 was the practical D/Fing of German Kurier signals. To achieve this AH6 was modified by the provision of A.V.C., a persistent screen, and the necessary equipment to detect the Kurier signals and to put the set into operation only when these were being transmitted. Although the Germans never used Kurier operationally, tests after the war showed that the signals could have been D/Fd provided frequency was known within 10 kc/s.

Siting of stations was always a problem. It was known in 1939 that sites must be carefully chosen, but the exact requirements were largely a matter of personal opinion. There was also a tendency to subordinate technical requirements to administrative convenience. Later in the war, with increased experience a standard set of siting requirements was laid down, and their observance insisted on. The various factors involved are still, however, imperfectly known, and can only be really solved by long and costly experiment.

Range Estimation Equipment (R.E.A.)

13. This was developed during the war as an ancillary to H/F D/F fixing. It consisted of taking measurements of the path differences between various incoming rays appertaining to the same signal, and, by co-relating these differences with current ionospheric data, estimating the distance of the transmitter.

In 1944, after a great deal of experimental work, a method of analysing results was evolved which enabled some 80 per cent of experimental intercepts to be assessed for range with a 10 per cent accuracy. The scheme never became a practical success as it was complicated and suffered from many difficulties.

H/F D/F Afloat

14. Before the war considerable experimental work had been carried out with H/F D/F equipment in ships, many of which had been fitted. Results proved disappointing and, as aerials occupied the valuable masthead position, most sets were removed early in the war to make room for radar.

For the reasons given in paragraph 4.7 further experimental work was carried out in 1941 with improved equipment manned by specially trained operators. The success of this work led to the introduction of FH3 as a standard outfit in many escort vessels, which covered 1-20 mc/s, had good sense finding and aural presentation. Whenever, possible aerials were sited at the higher masthead, though reasonable results were also obtained with aerials at the lower masthead.

FH3 was later superseded by FH4 which had C.R.T. presentation; this enabled operators to obtain snap bearings more easily and also to determine with confidence whether transmissions were near (ground wave) or far (sky wave).

As a result of trials with a captured U-boat a guide to the strength of signals from a U-boat transmitter working on full power was prepared for various ranges, and with the help of this a skilled operator could often give some estimation of the range of nearby transmissions.

The key to H/F D/F afloat, given good equipment, lay in skilled operation, careful maintenance and a knowledge of the tactical implications.

V H/F and U H/F D/F

15. Tactical interception of enemy V H/F R/T naturally led to a demand for D/F outfits to fix enemy positions. The first set (FV3) designed in 1942 was an extemporized affair using a slightly modified H/F D/F frame coil and a V H F receiver. Although it was comparatively insensitive and errors were large, the set gave a fair indication of direction; it was used in coastal escort vessels right up to the end of the war.

A much better set (FV7) was not designed till 1944, and there was only time to fit it in a few special ships. This set covered 30-100 mc/s using fixed Adcock aerials and was to be used for anti-E-boat and anti-air operations; accuracy of three degrees was expected.

Concurrently with FV7 a new outfit for coastal escort vessels was being produced; this was RV2 with a rotating Adcock aerial system and covering 30-50 mc/s. It was not quite ready at the end of the war.

The problem of D/Fing noises not only involved the application of D/F to a new band of frequencies, but also meant the development of fresh aerial systems which would pick up both vertically and horizontally polarized waves. The receivers used were those already developed for noise reception.

The first attempt was made quite early in the war with an unsatisfactory set — FV1. It was not till 1944 that a useful set was evolved, when the Noise investigation M.T.B. used for obtaining radar intelligence of the French Coast was fitted with a special set covering 70-600 mc/s and using a rotating Adcock aerial system.

At much the same time the carrier homing set — FV4 — was adapted for use at certain shore noises stations with a continuous tuning receiver and two aerials. A few other experimental sets were also fitted in shore stations.

Early in 1945 a few A/S vessels were fitted with an S-band D/F set to check intelligence reports that enemy U-boats were being fitted with S-band radar.

It will seen from the above that noise D/F during the war remained on an experimental basis, but in 1945 there were under development for use afloat four standard models which between them would cover the whole known noise band. These were the RU series, and the most advanced was RU4 (2000-6000 mc/s) using a dipole inclined at 45 degrees (to pick up waves of both types of polarization) backed by a reflector. The aerial was power rotated at speeds variable up to 120 r.p.m. visual presentation was used and sense-finding was automatic. Trials had shown an overall accuracy of two degrees at surface ranges up to two or three times' optical range, and up to about twice optical range for aircraft radar.

CHAPTER VI

RADIO COUNTER MEASURES

Introductory

THE term 'Radio Counter Measures' (or R.C.M.) has been defined as that field of radio involving action to reduce the effectiveness of enemy use of radio waves; it does not include traffic manipulation or communications security, but it does cover jamming, radar deception, 'noise' investigation and the obtaining of intelligence concerning enemy use of radio.

Noise investigation and the obtaining of intelligence have been dealt with under 'Y', and a separate chapter is devoted to the countering of radio-guided missiles. This chapter deals with the other aspects of R.C.M.

In the British and American Navies R.C.M. was mainly concerned with countering enemy radar activities; communications jamming was little practiced for reasons given in para. 6.2.

Jamming of Radio Communications

2. The jamming of radio communications has always been considered the weapon of a weak naval power. Such jamming usually interferes seriously with the complicated W/T network of the Fleet and, owing to the long range of many frequencies used for communications, is liable to have serious repercussions on our own W/T organization in areas far removed from the scene of jamming. It is also liable to provoke enemy jamming reprisals which would be hard to counter.

For these reasons it was the Admiralty policy during the war to limit such jamming to the following occasions:—

(i) the jamming of enemy shadowing aircraft believed to be attempting to home an enemy air striking force;

(ii) the jamming of enemy fighter control signals;

(iii) the jamming of raider distress signals when brought to bay.

The reason for (i) is obvious since the force concerned has much to gain and little to lose. Somewhat similar arguments apply to (ii); as regards (iii) it was particularly important to deny the enemy High Command information that one of his raiders had been sunk, and the risk on these rare occasions of interference to our own communications in other areas was accepted.

The R.A.F. on the other hand, engaged in a large-scale communications jamming programme when operating over enemy territory in order to disrupt the enemy defences. This was a case where the attackers could afford to dispense largely with their own communications if by so doing they could handicap the enemy. In order that naval aircraft could jam communications under similar conditions they were fitted towards the end of the war with a jamming attachment to their normal communications transmitter.

In general the Americans pursued a similar policy.

General Development of R.C.M. in the Navy

3. Apart from communications jamming and the countering of radio-guided missiles, we may divide R.C.M. into four broad categories:—

(i) electronic jamming, in which some form of radio transmission is used to produce confusion in the enemy radar receiver, and make it difficult for him to detect a target echo;

(ii) non-electronic jamming, in which a large number of reflecting devices (usually consisting of strips of metal foil known as 'Window') are projected into the air around the target (either being sown by aircraft, or by bursting window filled shells or rockets in the desired area) so as to present the enemy with a mass of echoes in which he cannot distinguish the true target echo;

(iii) radar deception, in which the enemy's attention is deliberately drawn to a particular area either by sowing window, by planting decoys giving an echo similar to a ship, by fitting special reflectors to a small vessel to magnify its echo, or by using a special radar transmitter in a small vessel which, when energized by an enemy radar beam, returns a series of 'echoes' giving the enemy the impression that there are a number of ships in company;

(iv) radar camouflage, in which certain absorbent materials are used to reduce the echo returned by a target. Developed by the Germans to some extent, though not very effectively, the Allies experimented with it but never used it in service.

Electronic jamming was born in the Navy in early 1941 when it became essential to reduce the effectiveness of enemy radar in the Straits of Dover if our convoys were to continue to pass through without crippling losses from enemy long-range shelling. R.C.M. in the Navy made no further advance until large-scale amphibious operations in the Mediterranean showed its necessity for reducing the effectiveness of enemy coastal radar both to prevent him learning the details of assault convoys and also to stop him bringing accurate radar controlled fire to bear on them. Meanwhile the R.A.F. had developed the use of window, and German submarines had shown us the possibilities of radar deception.

In later amphibious operations all forms of R.C.M. were used to upset enemy coastal radar and to support feint operations.

In the Pacific, where naval aircraft often operated against shore targets, the Americans found R.C.M. in their aircraft of great benefit in reducing the accuracy of enemy A.A. fire and searchlight control. They also found that ship-borne R.C.M. was of value in preventing Japanese aircraft using their radar effectively at night to locate the fleet.

For all these reasons R.C.M. afloat and in naval aircraft grew from being a matter of extemporization for particular operations to being a standard fitting, which could be used not only for amphibious, air and anti-air operations, but also for countering enemy radar in surface action — though the ineffectiveness of enemy surface forces in the closing stages of the war gave no opportunity for R.C.M. to prove its real value in the latter respect.

R.C.M. in the Straits of Dover

4. It is strange that R.C.M. was first used navally to protect convoys passing through a narrow strait — a specialized function which may well never be required again.

Soon after the Fall of France the enemy established a number of search and gun control radars in the Pas de Calais and our convoys began to suffer from his accurate shelling. In March, 1941, it was decided that jamming of this radar was essential and, following a careful intercept watch to determine enemy sites and frequencies, a number of multiple jamming stations were set up near Dover. General control of these stations was exercised from Dover H.Q., jamming being laid on whenever shipping movements were taking place and at other odd times so that the incidence of jamming did not necessarily indicate an approaching convoy.

Each jamming station had an associated monitor station; when jamming action was ordered by Dover the monitor stations picked up the German transmissions (there were always a few stations searching) and guided the jammers on. The Germans used two frequency bands and until 1944 we deliberately confined our jamming to his search radars, while at the same time installing jammers ready to counter his gun control radar (which had such a narrow beam that it was of little use without a search radar to put it approximately on to the target). This policy was pursued lest complete jamming might encourage the Germans to instal new types of radar which we might be unable to jam at the critical time of the Normandy Invasion. Just before this invasion we began to jam his gun control radar, and found to our relief that he had not in fact any new types in reserve in the area.

The effectiveness of the Dover counter-measures may be judged by the fact that, of some 2000 ships which passed through the Straits after jamming started, only six were actually hit by shells.

The German anti-jamming measures were singularly ineffective and were limited to slight shifts of frequency (quickly observed and countered by the monitor stations), and the use of two radars on adjacent frequencies in the hope that we should not realize this and only jam one of them.

R.C.M. in the Invasion of Sicily and Italy

5. Operation 'Husky' (the Invasion of Sicily) was the first occasion on which R.C.M. was used in an amphibious operation. There were known to be only a few coastal radars in the assault area, and by later standards the jamming would have been simple. However, very few jammers were available at the time and these were fitted in selected ships with the general object of confusing enemy radar — an object which seems to have been achieved.

Encouraged by the successful experiment in 'Husky' many more jammers were obtained for 'Avalanche' (the landings at Salerno), and sufficient ships were fitted to provide a barrage of jamming over the known enemy coastal radar band. A number of sets were also kept in reserve to cover any gaps or to deal with radar found in unexpected bands. The jammers were switched on just before the assault convoys were likely to be detected by radar. Once again enemy radars seemed to be thoroughly confused, and the assault convoys appeared to be adequately screened. In this operation R.C.M. was also used for the first time in a feint operation.

R.C.M. in the Normandy Invasion

6. Profiting by our experience in the Mediterranean R.C.M. was called in to perform three tasks:—

(i) to assist in obtaining tactical surprise by preventing the enemy coastal radar from determining the actual composition and direction of approach and thus the probable landing point;

(ii) to prevent enemy coastal batteries being controlled accurately by radar;

(iii) to assist in making feint attacks realistic and thus tie down enemy forces in the wrong areas.

The task was a formidable one since enemy radar was known to be thickly sited and well organized. Also the R.C.M. plan had to be closely co-ordinated between British and American sea and air forces. A further problem was to prevent the R.C.M. effort interfering with our own very important radar and communications organization in a small and congested area.

Naturally the physical destruction of enemy radar by air attack was given high priority before D-Day, but it was never anticipated that this would completely remove enemy radar; in fact it was about 50 per cent effective when the actual assault commenced.

As against the above difficulties we had a very exact knowledge of the sites and characteristics of enemy radar, and R.C.M. equipment, though still in short supply, was far more readily available than it had been in the previous year's operations.

The general plan included the following:—

(*a*) Pre-set jammers (set to cover known enemy frequencies, and requiring no attention beyond switching on) in destroyers, minesweepers and small craft. This was partly for self-protection and partly to help form a solid jamming screen in the van of the assault.

(*b*) Powerful monitorable jammers in cruisers and battleships mainly for self-protection against enemy gun control radar.

(*c*) Automatic sweeping jammers, in conjunction with an intercept receiver covering a pre-set band. On receipt of a signal, the frequency sweep stopped, and the jammer automatically locked on to the signal for a given time.

(*d*) Radar decoy balloons moored in bombardment areas to multiply the targets seen by enemy radar, and so reduce the chances of real targets being picked out.

(*e*) A.R. shells and rockets for bombarding ships, so that they could make their own window screen when necessary.

(*f*) R.C.M. diversionary forces on the flanks of the assault so as to extend the area in which activity would be apparent to enemy radar.

(*g*) Feint forces with R.C.M. deception equipment to make the enemy think large forces were approaching in the wrong areas. Apart from special R.C.M. equipment carried by the small craft in these forces, aircraft laid a continuous curtain of window overhead — the intention being that the enemy radar should 'see' a massive force slowly approaching and rather poorly screened by jammers (the jammers concealing any defects in the window curtain which might cast doubt on its reality.

The prevention of D/F bearings of the jamming transmissions and thus the direction of approach of the assault forces was accomplished by ensuring that the intensity of the jamming signals on both flanks of the bridgehead increased at the same rate as on the bridgehead itself. The Germans were thus not able to use their radar receivers as efficient intercept and D/F receivers and thus plot the progress of the assault forces.

Although subsequent analysis revealed that the scale of R.C.M. effort was still theoretically below that needed for complete screening, it is clear that the measures taken paralysed the enemy radar in Normandy and so contributed largely to the success of the operation in its initial stages. Enemy reactions at the time showed that the diversionary and feint attacks were also successful, and some of the credit for this is due to the R.C.M. measures taken.

In this operation — the first in which R.C.M. had been used on a really large scale — the necessity for close co-ordination between all Services concerned, and the need for scientific preparation of R.C.M. plans, was very evident. Not only were scientists called in to advise on the best methods of using the available R.C.M. equipment, but careful tests had to be made beforehand to determine the actual effect of this equipment against enemy radar (using captured sets as targets) and also its probable interfering effect on friendly radar and communications.

R.C.M. in Subsequent European Operations

7. R.C.M. played an important part in the invasion of the South of France, being used to screen the assault convoys and (with the assistance of window laying aircraft) in feint operations.

R.C.M. was also employed in the various ancillary naval operations involved in the liberation of Northern France and the Low Countries, especially in protecting bombarding ships from radar controlled coastal batteries.

R.C.M. in the Pacific

8. Here development was entirely an American affair. The U.S. Navy had become interested in the subject just before Pearl Harbour, and after their entry into the war they devoted considerable research, manufacturing effort and training to the subject.

R.C.M. was used to shield amphibious assaults in much the same way as in the European theatre, but, in view of the paucity of Japanese coastal radar, it was never necessary to plan on the scale of the Normandy Invasion.

A particular development in this theatre was the fitting of R.C.M. in aircraft to upset enemy radar associated with A.A. and searchlight control both ashore and afloat. This equipment took the form of jammers (usually pre-set) and window; pilots soon reported a very definite falling off in the accuracy of A.A. fire when R.C.M. tactics were started.

Another development was the use of ship-borne R.C.M. to blind search radar in enemy aircraft at night; the Japanese had developed rather successful night air tactics, but as soon as R.C.M. was used against them they completely failed to find their targets and flew aimlessly around, thus presenting American fighters with sitting targets.

Co-ordination and Control of R.C.M.

9. As soon as R.C.M. had emerged from the experimental stage to become of practical value in operations the necessity for strict control of its use, and for co-ordination between the various users, was realized.

R.C.M. is a two-edged weapon; without careful control it may cause serious interference to our own radio (both radar and communications), and its use must also be considered from the security aspect since enemy interception of jamming transmissions may reveal the presence of units prematurely. As the fitting of R.C.M. equipment became general in the Fleet, standard policies for its use were laid down in the same way as for radar; for special operations detailed R.C.M. plans were usually prepared.

For general Anglo-U.S. and inter-service co-ordination the R.C.M. Board was formed in Washington, with a British Board in London acting as a local co-ordinating agency.

For large-scale amphibious operations special inter-service planning and control boards were usually formed. The method used in planning and executing R.C.M. in the invasion of Normandy is of special interest, as it has probably set the pattern for the future. In this case planning was closely co-ordinated between all the Services (British and American), scientific advice was called on at all stages and several trials carried out to determine likely interference from R.C.M. to our own radio in the beach-head. As a result of these trials various restrictions were imposed on the use of R.C.M. (and also as a matter of interest on the siting of radar and W/T stations) and the whole radio frequency allocation plan worked out to cause the least possible mutual interference. General control of all R.C.M. was vested in the Allied Naval Commander during the approach, and thereafter in the

Allied Air Commander. The Naval R.C.M. plan was prepared in great detail and each ship fitted had definite instructions as to the frequency for its jammers and the occasions for their use; only ships with skilled personnel were permitted to vary jamming frequency. Local control of naval R.C.M. was delegated to Assault Force commanders, who were provided with necessary monitoring facilities. As a final safeguard an inter-service Board was established on a watchkeeping basis at Supreme H.Q. during the critical early days of the operation, with powers to take immediate action to clear any mutual radio interference reported.

Summary of Lessons Learned

10. Extensive use of R.C.M. developed so late in the war that policies for its use were still in a tentative state when the war ended. It was clear that more experience was needed. We may, nevertheless, draw certain broad lessons as follows:—

(i) R.C.M. equipment (jammers, means of sowing window, etc.) is now an essential feature of the radio equipment of ships and aircraft. In the case of aircraft it must normally be capable of quick fitting and removal depending on the actual mission.

(ii) The jamming of enemy radar would appear to be an essential feature of future naval actions, whether amphibious, air, anti-air or surface; its value has already been proved in the first three cases. Against this, however, the recent development of centimetric radar has greatly increased jamming difficulties, and we must be cautious in assuming that jamming will always be a feasible proposition in the future.

(iii) As a corollary to (ii) jamming should be included in peace exercises both to gain experience in its use and to train radar operators in anti-jamming techniques. To this end a proportion of jammers, capable of working against our own radar, is needed in the Fleet's peace-time radio equipment. Large-scale fitting of jammers is not justified since the actual types required for any future emergency cannot be determined until we know our enemy and have intelligence of his radar equipment.

(iv) Strict control of the use of R.C.M. is essential, and good inter-service co-ordination of general policies is needed.

CHAPTER VII

R.C.M. EQUIPMENT

Electronic Jammers

MANY different jammers were used during the war; a list, giving the principal features of each jammer, is given in Appendix C.

The first purely naval jammer — Type 91 — was designed for use in the Dover R.C.M. barrage, where it proved very successful; it was subsequently used equally successfully in large ships, until improved British and American types were evolved.

In general jammers fell into two main classes:—

(i) Monitorable jammers of high or medium power for fitting in large ships, where the necessary skilled handling was available. These jammers were tunable over a wide frequency range, and concentrated their output at any particular setting over a very narrow band width. They were known as 'spot' jammers, and could be most effective.

(ii) Pre-set automatic jammers, usually of low power, for use in small ships, aircraft, landing craft, etc., where skilled handling was not available. These were usually compact, pre-set to a particular frequency by experts beforehand, and merely needed switching on when required. The output was normally designed to jam over a fairly wide band width, and the jammers were known as 'barrage' jammers. In view of their low power and the wide band over which the jamming effect was spread, they were naturally far less effective than 'spot' jammers; but against this the craft in which they were carried were often able to get far closer to the enemy transmission which it was desired to jam, and thus increase the effectiveness of the jamming.

Towards the end of the war an improved type of automatic sweeping and locking jammer was designed for use where skilled handling was not available. This jammer, with an associated intercept receiver, could be set to sweep continuously over a particular band of frequencies, until a transmission was picked up, when the jammer automatically 'locked' on to it.

As a rule aircraft carried automatic jammers so as to avoid the necessity of an R.C.M. operator. Towards the end of the war the Americans in the Pacific were beginning to find it desirable to include a small proportion of R.C.M. aircraft, with tunable jammers and the necessary operators, in air strikes.

Electronic Jammers — Power and Modulation

2. As experience was gained, and the enemy developed anti-jamming techniques it was found necessary to use considerable power, and in some cases to use directional aerials. In this respect it must be remembered that the power of the radar being masked is concentrated in short pulses, whilst the jammer power is constant.

It was found particularly difficult to design jammers for the higher radar frequencies — a jammer to cover 'S' band (9-11 cm.) was still in the experimental stage at the end of the war; the siting of jammer aerials at the higher frequencies also presented special problems, owing to the characteristics of radar propagation.

Many types of modulation were tried in jammers to determine which gave the best masking effect; nearly all were successful at first owing to the novelty of jamming and the consequent confusion of inexperienced radar operators. As enemy anti-jamming technique improved and his operators gained experience, it was found that only 'random noise' modulation was really effective.

This type of modulation effectively increases the noise level in the radar receiver, thus reducing the signal to noise ratio of the echo signal and consequently the chances of detection of the target.

Use of American and R.A.F. Jammers

3. The R.A.F. were the first to develop R.C.M. on a vast scale, mainly in connection with the Bomber offensive over Germany. In consequence much use was made of R.A.F. equipment in early amphibious operations.

Later in the war full advantage was taken of the greater facilities available in America for research and production, and most of the jammers fitted from 1943 onwards were of American design.

British Naval scientists were, however, well to the fore in the development of future jammers when the war ended.

Anti-Jamming Devices

4. Although the enemy developed little R.C.M. effort at sea, the possibilities of jamming were clearly demonstrated by our own success. As a consequence radar sets were developed to be as immune as possible from any jamming, and the devices included for this purpose also proved beneficial to the actual performance of the radar sets.

Towards the end of the war much attention was also paid to training radar operators in operating through jamming.

Non-Electronic Jammers

5. The possibility had been realized early in the war of flooding an area with small metallic reflectors, each of which would return an echo to enemy radar and so produce a hopelessly confused pattern in his receiver display and thus mask the actual target echo. It was decided not to employ this counter-measure until our own radar (particularly in connection with the air defence of Britain) had developed sufficiently to obviate enemy reprisals having too serious an effect on it.

It was not till July, 1943, that the R.A.F. first used this counter-measure (known as 'Window') during a raid on Hamburg, and its success was astonishing. After this, window was employed by both ourselves and the Americans in naval aircraft. The small carrying capacity of naval aircraft usually limited its use to the last moments of the approach and to the get-away; it was found to cause grave confusion to enemy radar controlled A.A. fire and searchlights. Window was usually launched by hand through the flare chutes, but an automatic launcher was just becoming available at the end of the war.

Window had a great advantage over electronic jammers in that it was effective over a comparatively wide frequency band, though it was naturally most effective against radar of the frequency to which the metallic strips had been cut.

Various types of window were supplied to aircraft carriers for use against radar of different frequency bands; window for the higher bands could be cut to the required length on board. Window for the lowest radar frequencies was known as 'Rope'; to make this type fall slowly it usually had a paper parachute or air brake attached.

A.R. Shells and Rockets

6. Although window was first developed in the Navy for the defence of aircraft, it was clear that, owing to the poor vertical discrimination of most radar sets, ships

could also be screened if a window cloud could be formed over them. To this end shells filled with window were produced for firing from A.A. guns (on the same principle as star shells); for small craft rockets filled with window were designed, and could be used to screen ships and craft from enemy radar, particularly gun control radar.

Radar Decoys and Deception Devices

7. The types developed during the war were:—

(i) Balloon decoys, either 'Filberts' which were Mark VI (ship type) balloons with corner reflectors, or 'Peardrops' which were meteorological balloons with covers of radar reflecting fabric. These balloons could be towed by a small ship so as to give a big echo and deceive the enemy radar as to the size of the ship or else they could be moored among bombarding ships so as to present the enemy with an apparent multiplicity of targets.

(ii) Corner reflectors mounted in small craft during feint operations, the enlarged echo which resulted giving the appearance of a large ship.

(iii) The enemy tried balloon decoys attached to a float and set free from a submarine with the idea of misleading the radar operators of hunting craft. He also tried floating spar decoys fitted with radar reflectors. Neither achieved much success.

'Moonshine'

8. This was an R.A.F. device which, on receipt of an enemy radar signal, transmitted a number of pulses producing a series of echoes on the enemy radar display, and so giving the appearance of a number of targets. This device was used afloat in feint forces to ensure that enemy A.S.V. aircraft got the impression of a number of ships — whether this type of deception achieved any success is not known.

Radar Camouflage

9. Towards the end of the war the Germans were putting great effort into the development of materials which would absorb radar energy and so prevent any echo being returned. They were certainly successful in reducing the echo returned from small objects, such as the Schnorkel, and so reducing detection range, but the problem proved to be one of great difficulty and neither the Germans nor the Allies had made much progress with it on a large scale.

Experimental work was also in hand at the end of the war in an attempt to deflect incident radar beams upwards, by means of special reflectors, and so prevent the echo returning to the enemy radar.

The last experiments, carried out by the Germans before the collapse, appeared however to hold considerable promise, where small objects such as Schnorkel head were concerned.

Production, Fitting and Maintenance of R.C.M. Equipment

10. Production was always a difficult matter since the science of R.C.M. advanced so rapidly. As has already been remarked in paragraph 3 much use was made of American and R.A.F. types. It was particularly difficult to secure production capacity in U.K. as suitable firms were already engaged to capacity on other radio work.

The natural desire to make use of the latest progress in this new science inevitably led to much last minute fitting of new sets for operations. This often resulted in breakdowns owing to too rapid fitting and lack of experience of operators. Nor were ships' officers always adequately briefed as to the best use of the equipment.

Maintenance presented many difficulties owing to the novelty of the equipment: many sets went to sea while they were really still only in the experimental stage, and before serious defects had been eliminated; in particular valves burnt out very frequently.

It is easy to say that we should have known more about this new science before we tried to employ it operationally; but in fact, with all the defects enumerated above, it did pay handsome dividends. In any future emergency we may expect that most of these troubles will have been overcome and R.C.M. properly established as a branch of radio.

The production of R.C.M. equipment will inevitably have to be rushed as its final development must always take place after the enemy has brought his radio weapon into use.

CHAPTER VIII

RADIO CONTROLLED MISSILES

Pre-War Radio Control

W/T had been used for many years for the distant control of crewless vessels and aircraft. The Germans developed a rather crude form of W/T control for guiding explosive motor-boats against Allied bombarding ships off the Belgian Coast during the 1914-18 War, and the system was much developed both by us and by other nations between the wars, chiefly for the control of target vessels and aircraft.

Two old battleships, first AGAMEMNON and later CENTURION, were fitted with wireless control for target use, as were also a number of small high speed craft. The control system depended on a number of electric relays in the target craft, operated over a W/T link from the controlling vessel; the system was analagous to an automatic telephone but with a W/T link between the instrument and the exchange.

A somewhat similar system was developed by the Navy and R.A.F. for the control of pilotless target aircraft, first used successfully by the Fleet in 1931, and subsequently used on a considerable scale both by the Fleet and by shore A.A. batteries.

Although CENTURION was put to other uses during the war, crewless high speed craft and aircraft continued to be of much value for gunnery training. The control system was also adapted for the distant control of light buoys in the Thames, so that these could be switched on and off from shore H.Qs.

From the above it can be seen that we were fully aware of the practical possibilities of radio control of weapons, though we had not actually developed any ourselves.

The Advent of Enemy Radio Controlled Missiles

2. The first warning that the enemy had developed a radio controlled missile for use against warships came when H.M.S. UGANDA was attacked and hit off Salerno in September 1943. An intensive effort was at once made to discover details of the enemy control system, so that counter-measures could be instituted. 'Y' watch provided some clues but opportunities were short and fleeting; much valuable knowledge was gained by expert examination of fragments of missiles recovered from damaged ships. Finally we were fortunate enough to capture a detailed document.

The Germans developed two main types of anti-ship aerial missile (Types HS293 and FX1400), and a wireless controlled explosive motor boat. They also had under development several novel control systems for non-naval weapons.

Types HS293 and FX1400

3. HS293 was a wireless controlled, jet propelled glider bomb with a speed of 325 knots; the control aircraft could carry two of these to the launching point.

FX1400 was an armour-piercing bomb, without any propellant, but fitted with small wings and a tail for controlling its flight path. Its charge/weight ratio was small, and it was only of value against armoured ships; height of release normally exceeded 20,000 feet to enable it to gather sufficient speed.

The control systems were almost identical; the control aircraft transmitted a continuous carrier wave, modulated at will by one of four tones, depending on whether the missile was to be given right or left rudder, or up or down ailerons. The aimer had a form of 'joystick' whose movements controlled the modulation of the transmitter; the missile receiver interpreted the tones and transformed them into movements of the control surfaces *via* a servo mechanism. There was no control over the HS293's propellant.

Counter-Measures

4. Once the control system had been determined and the carrier frequency identified, the problem was to introduce into the missile receiver a jamming signal which would override the control and keep one of the missile control surfaces hard over, so as to deflect it from the target.

The first jammer produced was Type 650. At the time complete information about the enemy system was lacking, so the jammer had a wide frequency range (10-60 mc/s) with adjustable audio and frequency modulation. Theoretically it was a good jammer, capable of overriding the missile control for the last 40 per cent of its flight. The trouble, however, was the short time available for the operator to find the control frequency and monitor on the jammer. The jamming task would in fact have been impossible if we had not, by the time Type 650 was at sea, determined within narrow limits the characteristics of the enemy system. Even so, with special monitoring equipment incorporating a panoramic frequency display a capable operator was needed to use this jammer effectively.

Following the receipt of full details of the enemy control system, including the fact that he had a choice of 18 carrier channels in the 47-50 mc/s band (to any one of which the missile receiver could be pre-set), Type 651 was designed. Type 651 employed two transmitters which between them could jam the missile receiver system whichever carrier channel was in use; although means were provided for varying the frequency and modulation of the set, it was normally left set to a mean value which would give effective jamming over the whole range, and merely switched on from the bridge when the presence of radio controlled missiles was suspected. As the jamming power was effectively dissipated over a fairly wide band of frequencies, the power actually introduced into the missile receiver was comparatively small and only overrode the missile control for about the last 10 per cent of its flight — this was, however, sufficient to deflect it from the target.

A special advantage of Type 651 over 650 was that it overcame any enemy attempt to mislead the jammer operator by transmitting several dummy control frequencies besides the real one.

These jammers were fitted in most important warships by the end of the war; Type 651 was preferred, but could only be fitted in larger ships owing to its weight and size.

'Linse' — German Wireless Controlled Explosive Motor Boat

5. This type of weapon was used to a small extent off the coast of Normandy and in the South of France.

A 'Linse' unit comprised a control and two weapon boats. The weapon boats were filled with explosive and piloted manually to within a short distance of their target; the pilot then abandoned it and subsequently control was by a conventional W/T system from the control boat.

Type 650 could easily have been altered by ships' staffs to counteract this menace, but such little success was achieved by the enemy that it was never found necessary to institute counter-measures.

German Radio Controlled Missiles of a Non-Naval Nature

6. The Germans developed two anti-aircraft missiles, HS298 launched from aircraft, and HS117 launched from the ground, for use against bomber formations.

Both missiles were somewhat similar to HS293 and had exactly the same form of control.

Another form of control system for a ground-to-air missile employed two radar sets to keep track of target and missile respectively, with an instrument to present the relative picture to the operator. The path of the missile was controlled by W/T in a similar manner to HS293.

The V2 rockets were guided on the first stage of their flight by means of a radar beam, a receiver in the rocket detecting any variation from the true path and operating the control surfaces to rectify it; in effect the radar beam acted as a 'gun barrel' for the initial part of the flight.

Final Developments in German Radio Controlled Missiles

7. The Germans had two important developments in hand at the end of the war to improve the performance of their anti-ship missiles. The HS293 was being fitted with a television transmitter in the nose so that the aimer could have a continuous picture of what the nose of the missile actually 'saw'; this would obviously improve the accuracy of control during the last part of the missile's flight and would also enable the control aircraft to seek safety in clouds, etc., after launching the missile.

A decimetric control system for HS293 was also being produced which was reckoned to make jamming practically impossible.

Proximity fuses and means of homing the missile visually on to the target (after control had brought it fairly close) were also being developed for all types of controlled missiles.

Development of Radio Controlled Missiles by other Nations

8. Neither the Italians nor the Japanese developed any form of radio controlled missile.

Following the recovery of German missiles the Americans carried out intensive experiments and produced several improved versions for use against the Japanese, but as far as is known they were not ready in time to be used operationally.

V.T. Fuses

9. A variable time (V.T.) fuse is one which causes an H.E. shell to detonate on approach to a target; it consists of a complete radar set in the nose, transmitting a continuous signal, which, on reflection from the target, produces a beat in the set which eventually reaches sufficient strength to trigger a detonator.

The principle was developed by an Anglo-U.S. effort, but care was taken not to use the shells where duds might be recovered by the enemy and so expose the system. They were first used against German pilotless aircraft (VIs), and subsequently afloat. They increased the lethal effect of A.A. fire enormously, since it was only necessary to cause the shell to pass fairly close to an aircraft instead of actually hitting it.

With the introduction of this weapon considerable research was devoted to producing an effective jammer in case the enemy turned the weapon on us, but not much progress had been made by the end of the war.

CHAPTER IX

PERSONNEL AND TRAINING

Pre-War State

PRIOR to the war 'Y' and D/F duties ashore had been carried out by a part of the Shore Wireless Service (ex-R.N. W/T ratings who manned all Admiralty W/T stations and some 'Y' stations at Home), and by the Admiralty Civilian Shore Wireless Service specially recruited for 'Y' and D/F duties ashore at home and abroad.

Afloat D/F was regarded as a normal part of ships' W/T work, and they were responsible for training their own ratings in it. 'Y' afloat was not regarded very seriously, though ships were expected to keep 'Y' watch when other duties permitted. Sufficient information was provided to the main Fleets to enable 'Y' watch to be organized, and returns were sent in to the Admiralty; this was regarded more as a means of training potential 'Y' operators for war than as a normal source of intelligence.

General Lines of Expansion of 'Y' Personnel during the War

2. Recruiting for the Admiralty Civilian Shore Wireless Service was stepped up, but it was soon clear that fresh sources would have to be tapped to meet the rapid expansion of the 'Y' service.

The means adopted were broadly as follows:—

(i) In early 1940 training of WRNS started. At first these were employed only in the U.K., but from the autumn of 1941 onwards they were also drafted to all well established bases abroad.

(ii) In mid 1941 the Telegraphist (SO) or 'Special Operator' branch was formed in which H.O. entries were trained for shore 'Y' and D/F duties.

(iii) In mid 1941 a number of Telegraphists were specially trained for H/F D/F operation in ships fitted. This was a necessary measure if the best was to be got out of the new H/F D/F sets afloat since normal W/T staffs could not deal with their complexity in addition to normal communication duties.

(iv) In 1943 the training of Telegraphists (SO) was extended to cover H/F D/F afloat. Telegraphists already trained in H/F D/F were given the option of turning over or reverting to general duty. This new branch was known as Telegraphists (S).

(v) In 1944 the need to produce noise investigators and R.C.M. operators led to Tels (S) being given additional training in these matters and becoming Tels (SN). The final rating was therefore a 'Jack-of-all-trades' available for 'Y', D/F or R.C.M. duties ashore or afloat.

The Telegraphist (SO) Branch

3. This branch was established in June, 1941, and recruited from new entry H.O. ratings.

After five weeks general disciplinary training ratings were sent to civilian wireless schools for three months to learn morse. Results were not very satisfactory and in early 1942 morse training was moved to a new R.N. establishment at Brighton. On completion of morse training ratings went to Soberton Towers for one month to learn foreign W/T procedure, and then to either Southmeads (Wimbledon) or to

H.M. Signal School for D/F training. Final training in practical 'Y' and D/F was carried out at Scarborough. From June, 1942, St. Bede's (Eastbourne) took over all 'Y' training.

In June, 1942, training of a proportion of ratings in Japanese morse commenced at Southmeads.

H/F D/F Training of Telegraphists

4. In 1941 it became clear that H/F D/F afloat could only be exploited successfully if ratings were specially trained in its operation and maintenance. In August, 1941, the first class of general service telegraphists commenced D/F training at Scarborough, and those qualifying were given the notation 'D/F Tr:' and drafted additional to complement in H/F D/F ships. Training included the operation and maintenance of modern ship sets, and also German U-boat W/T procedure. Training was later shifted to St. Bede's (Eastbourne).

When the Tel (S) branch took over H/F D/F afloat the general service ratings were given the option of transfer to the new branch or reversion to normal communications duty.

The Telegraphist (S) Branch

5. This branch was established in 1943 to absorb the Tels (SO) who were now being trained additionally in H/F D/F afloat. The new technique involved training also in British W/T operation and procedure since operators had to be able to use the inter-communication facilities provided between H/F D/F ships, and to 'home' ships and aircraft in connection with U-boat hunts.

By May, 1944, the (S) branch had taken over all H/F D/F afloat, and the expansion had proceeded far enough to enable further recruiting to be suspended in November, 1944.

The Telegraphist (SN) Branch

6. In early 1944 a new requirement arose for ratings who could investigate and interpret non-morse signals ('Noises') and operate R.C.M. equipment. It was decided that this should be undertaken both ashore and afloat by Tels (S), who, after conversion, would be known as Tels (SN).

In February, 1944 a school for 'Noises' and R.C.M. was added to the Soberton Towers establishment, and later transferred to Funtington Hall. Courses lasted eight weeks — six weeks 'Noises', and two weeks R.C.M. Altogether some 300 ratings qualified.

The Writer (Sp) Branch

7. The free use by the enemy, especially the Germans, of P/L on their short range intercommunication circuits (*see* chapter III) led to a requirement for linguists who could intercept R/T, afloat and ashore, and immediately interpret the messages to enable Commanding officers (or shore staffs) to seize a quick tactical advantage.

For this purpose men with a working knowledge of German, Italian or Japanese were recruited from all branches of the Navy (and later outside sources), given brief instruction in the handling of R/T receivers, and drafted as Writers (Sp); the greatest number were employed in coastal escort vessels. Japanese interpreters were promoted to the rank of Sub Lieut (Sp), and about a third of the other interpreters were also made officers.

Training of WRNS

8. WRNS were eventually employed in all branches of 'Y', D/F, R.C.M. and R/T intercept work ashore, at home and in established bases abroad.

Initial entries were for 'Y' duty; training was started at King's College (London) in January, 1940, and first parties were drafted to home 'Y' stations in March. The first foreign draft was to Singapore in March, 1941 — these WRNS having been trained in Japanese morse as well. Training was shifted to R.N.C. Greenwich in June, 1940, and to Soberton Towers in March, 1941.

At first all 'Y' WRNS were rated C.P.O., but this caused many administrative difficulties and proved quite unnecessary; advantage was taken of a short break in recruiting in early 1942 to drop this special advancement.

After March, 1942, entries were trained on the same lines as Tels (SO), with two weeks' disciplinary training, three months initial W/T training at New College (Hampstead) and later at Scarborough, and thirteen weeks final 'Y' training at Soberton Towers. A proportion also received training in Japanese morse.

Linguists were trained in receiver operation and in morse at Southmeads, Wimbledon.

Shore D/F training was added in 1944, and later in that year some WRNS were also trained in 'Noises'.

Recruiting stopped in December, 1944, as by that time sufficient had been trained to meet all commitments.

Operators for 'Y', D/F and R.C.M. Afloat

9. We have seen that 'Y' afloat ceased at the beginning of the war, and for a period there seemed to be no particular requirement for it; but it was not long before a demand arose for special ratings to deal with the new aspects of radio being used in the Fleet.

First came the call for linguists in coastal escorts (Chapter III and Chapter IX, para. 7 above) and then for specially trained H/F D/F operators — the latter mainly for ships employed in the Battle of the Atlantic.

The success of the linguists in intercepting enemy surface R/T, and R.A.F. progress in intercepting and interpreting aircraft R/T and W/T signals ashore, led to a demand for linguists and 'Y' parties in Fleet units engaged in inshore operations or likely to be subject to heavy air attack. This demand was met; at first R.A.F. parties were often used for the 'Y' aspect, but later they were replaced by Tels (S).

Finally, the value of R.C.M. afloat was appreciated and once again requirements had to be met by drafting quite large numbers of Tels (SN), after initial requirements had been dealt with on an extempore basis by hurried training of ships' W/T ratings.

The constantly increasing requirements, both in numbers and capabilities, led to administrative difficulties which were solved by evolving a 'Jack-of-all-trades' — the Telegraphist (SN) — theoretically capable of dealing with any 'Y', D/F or R.C.M. need. Reviewing the situation at the end of the war it was clear that this attempt to produce an all-round rating had outstripped the capabilities of the average man available for training, and future policy is likely to aim at producing a 'Radio Analyst' for duty afloat capable of limited 'Y' interpretation so as to give tactical warning and able to control and use R.C.M.

Lessons Learned in Training

10. Five main difficulties were encountered:—

(i) Lack of instructors, especially officers, with experience — due to the novelty of the art.

(ii) Shortage of training equipment — this was equally applicable to all forms of radio training.

(iii) Constantly changing syllabus—due to introduction of Japanese, R.C.M., etc.

(iv) The need to employ several small establishments for different aspects of training — forced on us owing to difficulties of accommodation, but clearly it would be better to try and have a central training establishment on any future occasion.

(v) Unsatisfactory results of initial morse training at civilian centres. We had to use these civilian schools to some extent owing to lack of instructors, but it should be avoided if possible; the main reason for poor results was probably due to lack of service discipline.

CHAPTER X

ENEMY 'Y' D/F AND R.C.M.

Introductory

WHILST this chapter is intended to cover all our enemies it is largely confined to German activities, since these were of much greater significance than those of either the Italians or Japanese. The Italian contribution was negligible. The Japanese, did, however, succeed in developing equipment for 'Y' D/F and R.C.M., even if of a somewhat crude nature.

Since the Germans did not whole-heartedly trust the Japanese, little direct assistance in the form of advanced equipment for 'Y' and R.C.M. was made available to the latter. In return, of course, the Japanese had little to offer the Germans since their techniques and equipments were of a fairly elementary standard.

Germany's Inferior Position in the Radio War

2. It is surprising that the Germans fell so far behind in the Radio War, especially as German scientists have always been in the van of scientific progress.

This was probably due mainly to the following causes:—

(i) A belief that Germany would win the war quickly, and that therefore long term research was unprofitable. This belief also led to many young scientists and technicians being called up for active service, so weakening research.

(ii) Failure of the German Admiralty to appreciate the need for research, excessive optimism in regard to production time factors, and a general lack of co-ordination between the Naval Staff and industry.

(iii) Neglect of research as regards valves for the higher frequencies.

(iv) The effects of bombing in the later stages of the war.

In 1943 it was realized that the German U-boat campaign had failed, at least for the time being, and it was also appreciated that the war would last a long time. The Naval C.-in-C. then took the drastic step of appointing a professor as a sort of super-Director of Scientific Research, with almost dictatorial powers. This professor collected a really good team of scientists and technicians from all sources, and set about organizing research on proper lines. From this moment the Germans began to pick up lost ground, and it is clear that had the war lasted a few months longer we should have been in for some unpleasant radio surprises. As it turned out this team had insufficient time to advance many of their projects to the operational stage.

Communications Interception

3. All the German Armed Forces paid close attention to normal 'Y' work; they were probably as well organized in this respect as we were, and clearly they obtained a lot of information.

The German Navy concentrated their 'Y' effort on the Battle of the Atlantic, and a particular point of attack was on the Convoy R/T Wave, from which they were able to keep quite good track of our convoys at times.

'Y' parties were sometimes embarked in U-boats, and it was from this source that the Germans first learned the tactical use we were making of H/F D/F bearings.

The Germans made no significant technical advances in communications interception.

M/F and H/F D/F

4. The Germans had a good U-boat M/F D/F set in 1939, and their results soon compelled us to take stringent precautions against receiver re-radiation. The constant use of the Convoy R/T wave led the Germans to try and extend the range of their D/F sets to cover this band, but they never got good results from this project.

The Germans always discounted the practicability of satisfactory ship-borne H/F D/F, and never developed any ship sets. Even after warning from their 'Y' of the success we were achieving against U-boats they still did not really believe that we had solved the problem.

Ashore the Germans were prepared to credit the advantage of an H/F D/F organization, and this led them to develop the Kurier (high speed) transmission system from U-boats in an attempt to make our D/F useless. They also produced some very ingenious shore H/F D/F equipments, notably one capable of taking accurate bearings on Convoy R/T wave at very long ranges. The Germans suffered, however, from lack of practical experience in the art, and they also lacked a really good 'base-line' for the erection of stations. As a result their H/F D/F organization was never so elaborate nor anything like so successful as ours.

The Japanese had a fairly comprehensive shore-based H/F D/F organization covering a wide area in captured and home territories. The installations employed elevated H-type Adcock aerial systems and the superhet receiver covered a frequency of 2.5 to 20 mc/s. The performance accuracy and reliability of the equipment was comparable to similar Allied Naval Equipment of 1941.

Noise Investigation

5. German inferiority in radar led them to devote much effort to counter-measures, notably in the production of warning receivers for U-boats to enable them to dive before a radar fitted hunter could approach them.

U-boats were equipped with warning receivers at a fairly early date, but fortunately they remained unaware for a long time of the development and use of our 10 cm. ASV.

At the end of the war a U-boat receiver, capable of being fitted as part of the Schnorkel, covering 2-4 and 8-12cm., and giving warning as well as some indication of bearing, was nearly operational.

The Japanese developed a V H/F intercept receiver capable of providing a rough bearing indication for surface vessels and submarines to intercept Allied ASV. They also developed a S-Band warning receiver of the untuned type for a similar purpose. Both these equipments were crude in design and were of limited tactical value to the Japanese.

R.C.M.

6. The Germans began using window soon after we did. As regards electronic jamming they were always in two minds as to its desirability, but in fact they never advanced any jammers to the ship-fitting stage largely owing to acute shortages of suitable valves.

Our jamming worried the Germans and drove them to adopt many anti-jamming measures and devices. They stated that our R.C.M. effort in Normandy was very good, but did not completely obliterate their radar; they were of the opinion that a combination of window and electronic jamming was the best form of R.C.M.

It is of interest that the Germans always believed we would retaliate with radio guided missiles, and they devoted a lot of effort to preparing counter-measures.

The Japanese placed most effort in radar deception and made liberal use of window and various forms of decoy. Neither of these were very effective.

Radar Decoys

7. The Germans were firm believers in these and used them extensively, released from U-boats, to distract radar operators in hunting vessels.

Radar Camouflage

8. An intensive effort was made in 1944-45 to prevent Schnorkels being detected by our radar. The radio scientists called in chemists to help, and a form of covering which would largely absorb radar waves and so reduce range of detection was evolved; early forms of this material were in use at the end of the war, and good progress on better materials was being made. This project received top priority in radio research at the time.

Methods of deflecting radar rays by careful shaping of surfaces were also being explored.

APPENDIX A

'Y' EQUIPMENT IN USE DURING THE WAR

Note.—Very many experimental outfits were used, mostly in small numbers, but only equipment in fairly general use is recorded here.

Type	*Date of design*	*Frequency (mc/s)*	*Remarks*
(a) SEARCH RECEIVERS			
P15	1940	30-600	A rush production job to meet early needs. Transportable, battery operated. Had several R.F. heads to cover band.
AB2 (R.A.F.)	1940	500-3000	Much used operationally, but ineffective above 1000 mc/s. High sensitivity, but complicated control. Video and aural output. 'Tuned lines' tuning.
RL75, RL85	1941	30-80	'Stop-gap' sets.
P19	1941	240-640	Transportable, battery. Video and aural output. 'Tuned lines' tuning.
P22	1941/2	30-300	Multi-purpose for communications or noises. A good design, but owing to manufacturing difficulties it did not become operational till after war.
P29	1942	240-640	Improved, mains version of P19.
P33	1942	150-550	Small and compact. Designed as an insurance against new enemy bands. Pre-set to tune over any given 40 mc/s. Low I.F. which caused signal and image to coincide.
P55 or ABR6	1942/3	1000-2000	Similar to AB2. Proved noisy and little used.
P56	1943	300-600	A rush production job, developed from a U.S. set. Non-contact tuning.
P58	1943	300-600	Non-contact tuning. Wide band I.F. Good image rejection. P.R.R. indicator. Widely used in R.N. and R.A.F. since 1944.
ABR3	1941	130-550	A good R.A.F. set which needed skilled operation.

P102	1943	120-300	The latest range of sets under development at the end of the war.
P62	1944	600-1200	
P63	1944	3000-6000	
P64	1944	2400-3750	
(b) Monitor Receivers			
P33	1942	150-550	A search receiver (see above) also used for monitoring.
P39	1943	300-550	Pre-set for accuracy of frequency measurement over any particular 80 mc/s band. Used in Dover R.C.M. scheme.
P60			P39 modified for use afloat.
(c) U.S. Equipment			
AN/APR1		40-3400	Airborne search receiver employs interchangeable R/F units. The performance as a search receiver is degraded by very spurious responses at the higher frequencies.
AN/APR2		90-1000	Airborne search receiver with auto tuning.
AN/APR5-AY		1000-6000	Employs sliding contacts and very soon becomes noisy in operation.
AN/APA6			Pulse analyser for use with search receivers.
AN/APA10			Panoramic adaptor and oscilloscope for use with search receivers.
AN/APA17		200-3000	Airborne D/F employing scanning aerials and C.R.T. presentation.
AN/APA23			Motor operated tape recorder for use with search receivers.
RDO		40-3400	Search, D/F and monitor receiver.
RDP			Panoramic adaptor for RDO. Swept ± 5 mc/s about input frequency.
AN/SPR2		1000-12,000	Ship-borne search receiver.

(d) Recording Equipments

REB1, REB2, REB3, REB4	All fundamentally consisted of an oscilloscope with a film camera. REB1 and 2 developed for R.F.P. and had fixed film speed. REB3 and 4 were primarily for noise investigation, and had variable film speed. REB4 was for use ashore or afloat, the remainder for use ashore only.
REC1, REC2	Sound recording equipments for use ashore.
Model 50	An American wire type sound recording equipment, used ashore and afloat.

APPENDIX B

D/F EQUIPMENT USED DURING THE WAR

Note.—Experimental types, of which perhaps only a few were used, are not included.

Type	*Frequency*	*Remarks*
(a) SHIP-BORNE H/F D/F		
FH3	1-20 mc/s	Fixed frame coil and gonio. Aural presentation.
FH4	1-25 mc/s	An improved version of FH3 with C.R.T. presentation.
(b) SHORE H/F D/F		
AH1	677-20,000 kc/s	Adcock aerials. Aural presentation.
DFG12	1-20 mc/s	ditto.
AH6	1-24 mc/s	Adcock aerials. Special earth system. C.R.T. presentation.
DFG24	1.5-20 mc/s	Adcock aerials. Aural presentation. When modified with special earth system was known as DFG24/5.
AH4	1.5-21 mc/s	Adcock aerials. Spinning gonio. Special earth system. C.R.T. or Aural presentation.
(c) V H/F AND U H/F D/F		
FV1	250-600 mc/s	An early experimental set.
FV3	41-46 mc/s	A rush job for tactical interception in coastal escort vessels. Used an H/F D/F frame modified. Vertical polarization only.
FV4	70-200 mc/s	An aircraft carrier homing set, modified for 'Y' purposes to give continuous tuning. Adcock aerials — vertical polarization only.
FV7	30-100 mc/s	Replacement for FV3. Only fitted in a few special ships at end of war. Adcock aerials — vertical polarization only.
RV2	V H/F	Rotating Adcock aerial system. Developed for special work in connection with Normandy Invasion.
RU1	100-500 mc/s	These sets were under development at end of war for noise investigation. RU4 was the most advanced and had given encouraging results in sea trials.
RU2	500-1000 mc/s	
RU3	1000-3000 mc/s	
RU4	2000-6000 mc/s	

APPENDIX C

ELECTRONIC JAMMERS USED DURING THE WAR

Type 91	Shore and ship jammer. Spot jammer. Tunable and monitorable. Frequency 200-600 mc/s. Sine wave modulation (1 mc/s). Power output 8-22 watts, depending on frequency. Developed for use in the Straits of Dover.
Type 91M	Shore and ship jammer. Spot jammer. Tunable and monitorable. Frequency 90-600 mc/s. Noise modulation. Power output 8-22 watts, depending on frequency. The standard jammer for large ships until the production of TDY and CXFR (see below).
TDY (American)	Ship jammer. Tunable and monitorable. Frequency 90-770 mc/s. Noise modulation. Power output approximately 100 watts.
CXFR (American)	Ship jammer. Tunable and monitorable. Frequency 350-750 mc/s. Noise modulation. Power output approximately 100 watts.
Type 653/1 *and* 2 (Naval Carpet II)	Ship jammer. Frequency 300-600 mc/s. Noise modulation. Automatic sweeping and locking jammer. Can be set to sweep any 50 mc/s of range.
Type 654 (American Carpet I)	Spot or barrage jammer. Frequency 480-700 mc/s. Noise modulation. Power output 5 watts.
Type 656 (American Rug)	A pre-set spot or barrage jammer. Frequency 200-550 mc/s. Noise modulation. Power output 5-20 watts.
Type 659 (American Mandrel)	Aircraft jammer. Pre-set for spot or barrage jamming. Frequency 75-145 mc/s. Noise modulation. Power output 10 watts.
Type 663 (American Carpet IV)	Pre-set for spot or barrage jamming. Frequency 350-1400 mc/s. Noise modulation. Power output 5-40 watts depending on frequency.
AN/APT-1 (American)	Aircraft jammer. Spot or barrage jammer. Frequency 90-220 mc/s. Noise modulation. Power output 8-15 watts (with amplifier up to 140 watts).

APPENDIX D

RATINGS TRAINED IN RADIO WARFARE

P.O. Tels (SO) (S) and (SN)		96
Ldg Tels	ditto	840
Tels	ditto	2295
P.O. Writers (Sp)		73
Ldg Writers (Sp)		63
Writers (Sp)		17
C.P.O. WRNS (SO) (S) and (SN)		254
P.O. WRNS	ditto	56
Ldg WRNS	ditto	218
WRNS	ditto	418
	Total	4330

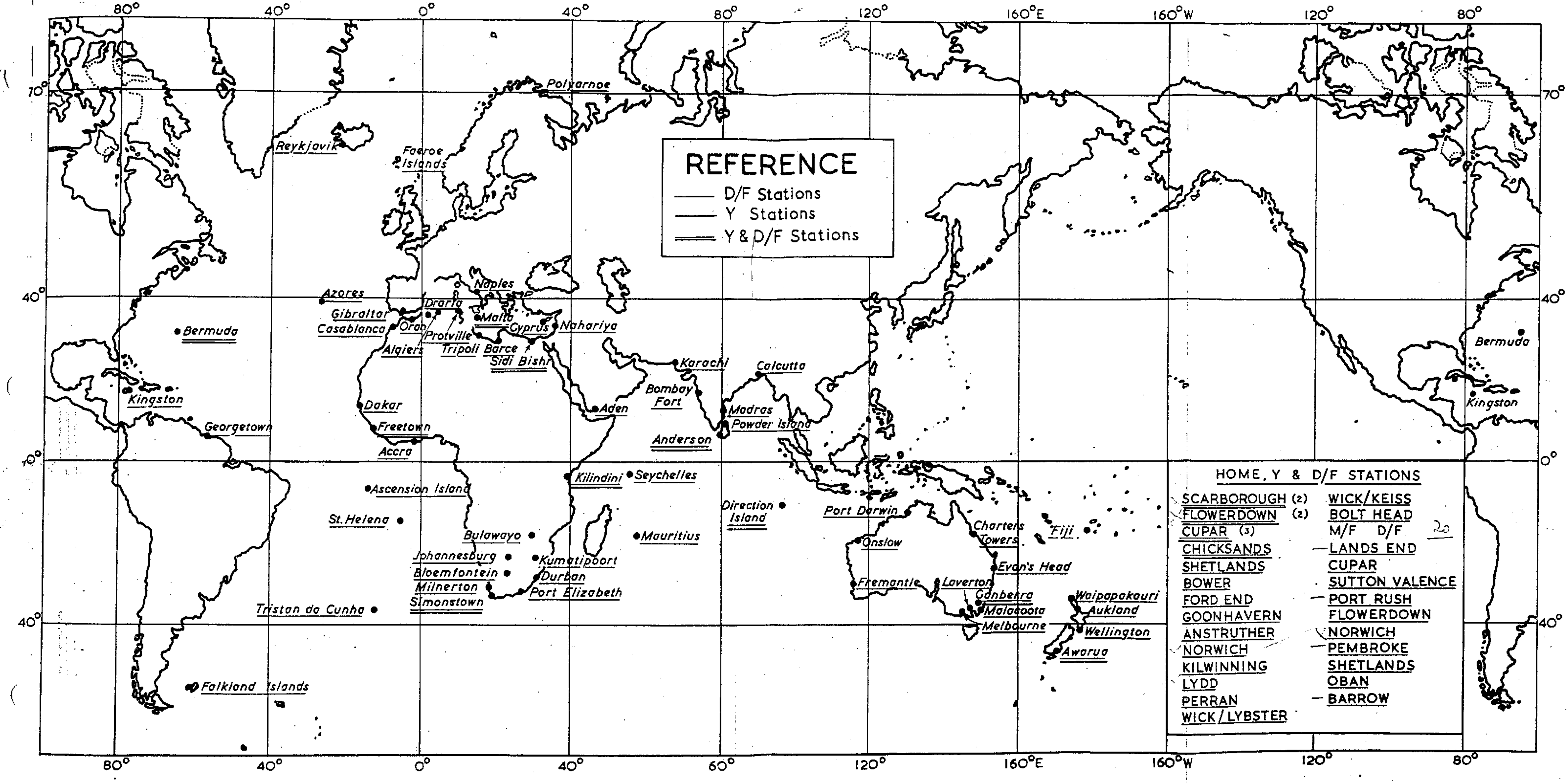
Also—Tels (D/F Tr.) . . . . about 600

Adty Civ: S.W.S. . . . . . from 160 in 1939 to 450 in 1945

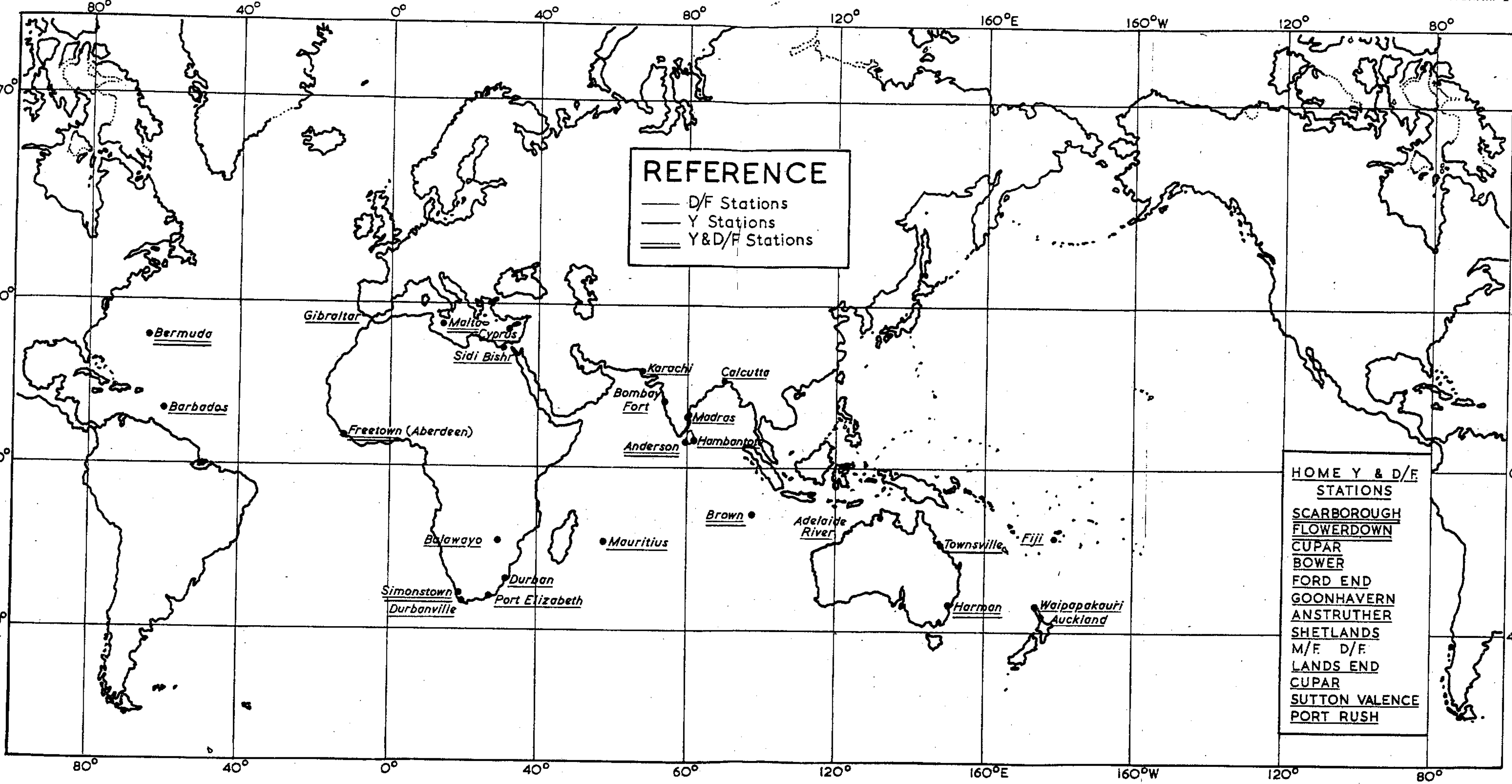
TRAINING ESTABLISHMENTS

Various Civilian Wireless Schools	Initial W/T training
King's College, London New College, Hampstead	ditto (WRNS)
R.N.C. Greenwich	WRNS 'Y'
Soberton Towers (near Portsmouth)	'Y' Japanese Morse R.C.M. and Noises
Southmeads, Wimbledon	R/T and D/F Japanese Morse
Brighton	Initial W/T training
St. Bede's, Eastbourne	'Y' and D/F
H.M. Signal School	D/F
Scarborough D/F stations	Operational training
Funtington Hall (near Portsmouth)	R.C.M. and Noises

DIAGRAM 1

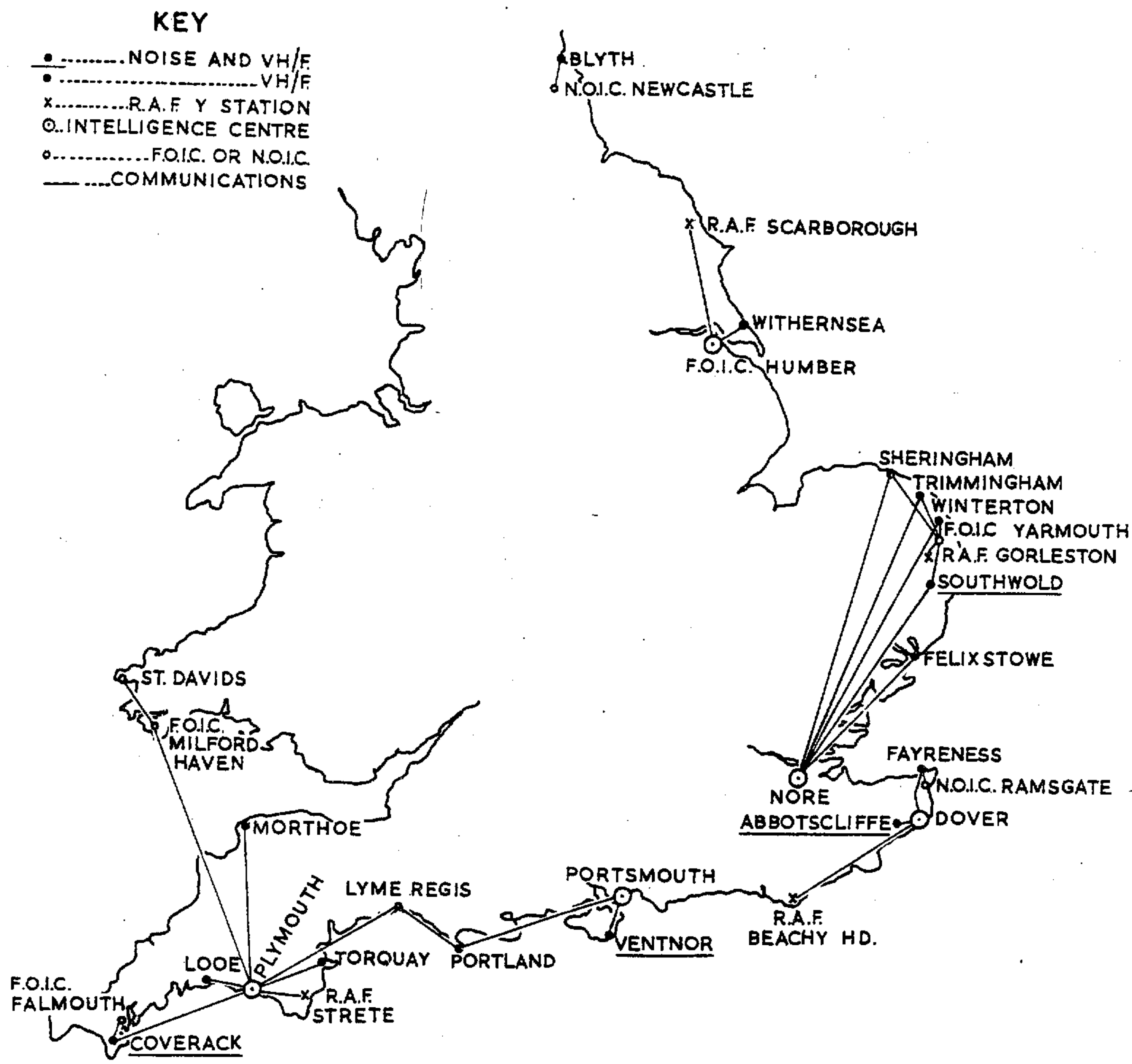


Y AND D/F STATIONS ESTABLISHED FOR GERMAN - JAPANESE WAR



Y AND D/F STATIONS REMAINING FOR JAPANESE POST WAR (JUNE 1945)

SHORE TACTICAL INTERCEPTION AND NOISES ORGANISATION



Repayment X BLUE	**Repayment Expenditure** Repayment Supplies to : Other Navy Votes. Other Departments of Home Government. Allied and Dominion Governments. (*See* Art. 50, paras. 1(*b*) and (*c*)).

54. VOUCHER IDENTITY CODE

To enable the section of the office responsible for vouchers to be known and to facilitate distribution of office copies of packing notes, each issue voucher is to have a letter code in front of registered number, as follows :

Supply Service Group		*Letter code for vouchers raised at*								
Group	*Ships, etc.*	HASLEMERE	GLOSSOP	OLDHAM	SOWERBY BRIDGE	STOCKPORT	ROCHDALE P.	ROCHDALE U.	DELPH	PROCKTER'S VALE MILL
W/T	Cruisers and larger vessels, M.A.C. ships, small craft (T.W. 12 sets)	A	GA	OA	BA	SA	PA	RA	DA	VA
W/T	Flotilla Leaders, Destroyers, Corvettes, Frigates, Sloops, etc., Submarines, all depot ships, A.M.Cs	B	GB	OB	BB	SB	PB	RB	DB	VB
W/T	Naval, Air and W/T Stations, Training and Experimental Estbs., Repayment Services, Dominion, Foreign and Colonial Governments, other depts., etc.	W	GW	OW	BW	SW	PW	RW	DW	VW
Radar	All Ships and Establishments and Repayment Services ..	F	GF	OF	BF	SF	PF	RF	DF	VF
V/S etc.	All Ships and Establishments and Repayment Services ..	L	GL	OL	BL	SL	PL	RL	DL	VL
All	Initial stock supplies and deciencies for Yards, Depots and Bases	D	GD	OD	BD	SD	PD	RD	DD	VD
All	Replenishment stocks for Yards, Depots and Bases	E	GE	OE	BE	SE	PE	RE	DE	VE
All	Repairs, etc., F.I.A.	C	GC	CC	BC	SC	PC	RC	DC	VC
All	Repairs, etc., other subheads	J	GJ	OJ	BJ	SJ	PJ	RJ	DJ	VJ
All	Free issues	H	GH	OH	BH	SH	PH	RH	DH	VH
All	Pool issues	P	GP	OP	BP	SP	PP	RP	DP	VP
All	A.S.E. requirements	Y	GY	OY	BY	SY	PY	RY	DY	VY
All	Miscellaneous (D.184) ..	M	GM	OM	BM	SM	PM	RM	DM	VM